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Abstract

This paper examines the distributional impacts of a $50 tax per ton of CO_2. Using Input-Output tables we calculate the carbon intensity of goods to estimate households' carbon footprints. Findings indicate the tax is regressive. Using the revenue to reduce taxes on labor leaves 60 percent of people worse off, while rebating the revenue in equal dividends increases welfare for 55 percent of individuals, including 84 percent in the bottom half of the distribution. Many economists have dismissed dividends on efficiency grounds, but we show that potential macroeconomic benefits of tax cuts are insufficient to protect the poor.

JEL Numbers: H22, H23, Q48, Q52, Q54, Q58

Keywords: Carbon Tax; Distribution; Tax; Environment; Climate Change; Global Warming; Fossil Fuels; Tax-and-Dividend

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1. Introduction

This paper examines the distributional impacts of placing an economy-wide tax on carbon dioxide (CO_2). Most economist supports a carbon tax as an efficient mechanism for reducing greenhouse gas emissions (IGM 2012), but the policy represents a substantial reorganization of property rights, thus how those rights are allocated is of great importance. We estimate that a $50 tax per ton of CO_2 would redistribute $138 billion across U.S. households per year. The paper compares the distributional implications of a tax-and-dividend policy to two other revenue-neutral policies that devote carbon tax revenues to a proportional labor tax cut or an Old-Age, Survivor, and Disability Insurance (OASDI) payroll tax cut. We analyze welfare effect across the income distribution and find that a tax-and-dividend policy is the only policy that would benefit most individuals, including the vast majority in the bottom half of the income distribution. The paper provides new findings that will better inform policymakers on the design of carbon taxes in the U.S. economy.[3]

Carbon dioxide is emitted primarily by burning fossil fuels,[4] which account for approximately 76 percent of U.S. greenhouse gas (GHG) emissions (Horowitz et al. 2017).[5] While CO_2 emissions have decreased 12 percent from their peak in the United States in 2007 (EIA 2015) they must be rapidly 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 (EIA 2013). While a carbon tax is but one policy option to reduce emissions[6], studies have found that placing a price on emissions would be more cost-effective than other policy options, such as increasing emissions standards, subsidizing renewable energy, or investing in research and development (Fisher and Newell 2008; Williams 2016). The U.S. does not currently

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[3] A recent report from the Climate Leadership Council, coauthored by prominent Republicans and economists, calls for a carbon tax in which the revenues are rebated in equal lump-sum dividends (Baker et al. 2017).

[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 GHG 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 $50/t$CO_2$.

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,[7] 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).

Our analysis is concerned with the distributional implications of taxing carbon and rebating the revenue under various scenarios. It uses Input-Output tables to estimate the carbon intensity of 64 industries and 33 expenditure categories in the U.S., under the assumption that the full burden of the carbon tax is passed on to consumers in the form of higher prices. Using the Consumer Expenditure Survey (CEX), we calculate the carbon footprints of a representative sample of U.S. households, which allows us to analyze the carbon tax burden across the income distribution. Like other researchers, we find that taxing CO_2 is regressive, but that most people receive more money back than they pay in under a tax-and-dividend scheme (Boyce and Riddle 2007; Boyce and Riddle 2010; Horowitz et al. 2017; Williams et al. 2014). Our results show that 61 percent of Americans receive positive net transfers when carbon tax revenues are devoted to equal dividends, and that 55 percent of people benefit from the policy when we account for abatement costs but *ignore* environmental and health benefits of emission reductions. Other research has traditionally focused on the net cost of a policy for the mean household in each income decile (Boyce and Riddle 2007; Boyce and Riddle 2011; Horowitz et al. 2017; Mathur and Morris 2014; Williams 2014), but we find that this approach can be misleading. For example, our results show that the mean person in the bottom seven deciles is better off under a tax-and-dividend scheme, but that only 41 percent of individuals in the seventh decile benefit from the policy. Our findings illustrate that a tax-and-dividend policy can maintains the purchasing power of most Americans, including the vast majority of people in the lower class, which has received little increase in income since 1980 (Piketty 2014).

[7] For example, the Regional Greenhouse Gas Initiative (RGGI) is a multi-state effort to collectively cap carbon emissions from power plants, covering seven states in the Northeast. This paper focuses on an economy wide tax on carbon. Previous work by Grainger and Kolstad (2009) has shown that a carbon tax that only applies to energy, such as RGGI, is more regressive than an economy wide carbon tax.

Table 1: E.P.A. 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.

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 from the pollution can improve social welfare.[8] The United States Environmental Protection Agency (E.P.A.) and other federal agencies use the social cost of carbon to estimate the climate benefits of rulemaking. If the tax rate is set equal to marginal external damage, it ensures that the price of goods reflects their full marginal social cost and internalizes the externality. The E.P.A.'s estimates for the social cost of carbon are presented in Table 1. In this paper, we model a carbon tax of $50 per ton of CO_2, which is equal to the E.P.A.'s estimate of the social cost of carbon for 2020 using a 3 percent average discount rate in 2017 dollars,[9] and would increase gasoline prices by about $0.50 tax per gallon.[10]

[8] The case for carbon taxes are frequently made on the grounds of inter-generational equity. For example, Rezai, Foley, and Taylor (2012) show that diverting investments to climate change mitigation can generate a Pareto improvement for all generations. There are also immediate benefits to abatement. Boyce (2016) finds that substantial gains for present generations can be achieved through improvements in air quality.

[9] The choice of a discount rate is crucial to determining the social cost of carbon, yet there is a lack of consensus on the appropriate discount rate used in climate economics. The lower the discount rate, the more important the outcomes in later years are - thus a discount rate of 3 percent as opposed to 5 percent (the two put forth by the E.P.A.) estimates a higher social cost of carbon. The EPA uses a 3 percent as the benchmark for policy.

[10] 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.

This study makes several improvements on the literature on the distributional implications of a carbon tax. First, since there is still no common method for analyzing the distribution of the tax burden, we work to build consensus by providing a detailed description of our methods, publishing intermediate tables, and comparing our carbon intensities to those in other papers. To our knowledge, this is the first analysis of a carbon tax to fully account for renters' CO_2 emissions when their utilities are included in their rent, which has been shown to matter in other contexts (Glaeser and Kahn 2010; Levinson and Niemann 2004). Second, we analyze the impact of revenue-neutral carbon tax schemes across the income distribution as well as across race and ethnic groups, age brackets, and urban and rural households, which illustrates stark differences across policy options. Third, 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 behavioral responses to vary across the income distribution. Fourth, we show that a double dividend from devoting carbon tax revenues to tax cuts is too small to protect the purchasing power of most Americans, and that a tax-and-dividend policy results in the least horizontal redistribution of income across individuals of similar means. The following section reviews existing literature on the distributional impacts of carbon taxes. Section 2 describes the data and methods utilized in this paper and presents carbon intensities (in $kgCO_2/\$$) for 64 industries and 33 categories of consumer goods. Section 3 presents the key distributional impact of competing carbon tax policies. Section 4 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 5 discusses our results in the context of the equity-efficiency tradeoff and in terms of vertical and horizontal equity. Section 6 concludes.

2. Background

The vast majority of studies find that the incidence of a carbon tax is regressive (Boyce and Riddle 2007; Dinan 2012; Hassett, Mathur, and Metcalf 2009; Jorgenson et al. 2015; Mathur and Morris 2014; Williams et al. 2014), although two recent studies find that the burden of a carbon tax is fairly constant across the income distribution (Cronin et al. 2017; Horowitz et al. 2017).[11] Although it is unclear *how* regressive the tax is, studies agree that the full distributional impact of a carbon tax depends crucially on what policymakers do with the carbon tax revenue. Researchers have provided a range of recommendations on how to best use the revenue. A review of the literature reveals a convergence toward devoting carbon tax revenue to three schemes: cutting taxes on capital income, cutting taxes on labor income, and rebating revenues in equal per-capita carbon dividends. Most papers find that paying everyone an equal per capita dividend is the most equitable option, but some studies argue for devoting revenue to reducing distortionary taxes on efficiency grounds (Dinan 2000; Mathur and Morris 2014). The exact arguments depend largely on the models employed in the analyses. While a range of models have been employed in the literature, the two most common are computable general equilibrium (CGE) models and Input-Output models, such as the one presented in this paper.

There are two main reasons that studies using CGE models tend to support devoting carbon tax revenues to reducing taxes on capital or labor. First, these studies analyze the distributional impact of a carbon tax over the very long run. Part of the reason for this is that CGE models allow for firms and households to change their behavior over time in response to a carbon tax. Researchers using CGE models also tend to examine the impact of policies on lifetime earnings instead of the immediate impact on household budgets (Jorgenson et al. 2015; Williams et al. 2014), which effectively assumes away a key component of intergenerational equity. A carbon tax will increase prices for everyone, so Americans who are in or near retirement would receive little benefit from tax cuts. Long run models also provide little practical guidance to voters, who are less concerned with how a carbon tax scheme may affect their lifetime earnings and more interested in how such a policy will affects their purchasing power over the next few years. Moreover, revenue recycling mechanisms are meant to provide temporary assistance as the economy transitions to a low-carbon economy, when there will be little carbon tax revenue to recycle.

The second reason that researchers using CGE models tend to support devoting carbon tax revenues to tax cuts is that they focus on the macroeconomic effects rather than the distributional

[11] See Table 5 column 6 in Cronin et al. (2017) and Horowitz et al. (2017) Table 6.

impacts of tax changes. CGE models suggest that there is a macroeconomic cost to devoting carbon tax revenues to lump-sum payments instead of reducing taxes. Compared to cutting taxes on capital, Jorgenson et al. (2015) estimate 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. As a result, research using CGE models find that the mean household is better off in the long run when carbon tax revenues are devoted to cutting distortionary taxes instead of paying for a carbon dividend (Jorgenson et al. 2015; Williams et al. 2014).

Recent research challenges some of the assumptions underlying these models, including the idea that lowering taxes on capital will spur economic growth (Gutierrez and Philippon 2016). However, even if cuts to distortionary taxes would increase economic growth, those gains would not be equally distributed. The optimal tax rate literature argues that the burden of the corporate income tax is shared between labor and capital (Piketty and Saez 2012), but recent empirical work suggests the tax falls mostly on capital. Horowitz et al. (2017) demonstrate that most of the benefits of a corporate tax cut are captured by the top 5 percent of the income distribution, and that most those gains accrue to the top 0.1 percent of income earners in the U.S.

DeCanio (2007) argues that the distributional burden of a carbon tax outweighs any macroeconomic effect. Even though their models produce a significant double dividend and analyze the distributional impacts over lifetime earnings, Williams et al. (2014) find that the median household loses when carbon tax revenues are devoted to tax reductions on labor or capital. Nevertheless, they suggest that labor tax cuts are a reasonable intermediate option between capital tax cuts and equal dividends for policymakers concerned with balancing the trade-off between efficiency and equity.

Instead of building CGE models, much of the research on the distributional impact of a carbon tax relies on simpler Input-Output models to calculate the carbon intensities of goods. These intensities are then combined with expenditure data from the CEX to estimate the carbon footprints of a representative sample of U.S. households. There are limitations to these I-O models. Unlike the CGE models, Input-Output models do not allow for industries or households to change their behavior in response to increases in the price of carbon intensive commodities. As a result, these models highlight the short run distributional outcomes rather than the dynamic effects of a carbon tax on production techniques and consumption bundles (Mathur and Morris 2014). While other I-O models have been developed to analyze the supplier response to a carbon tax (Stern 2006; Adkins et al. 2010), these are not well suited to assessing the distributional implications. Input-Output models generally assume full pass-through of price increases from producers onto consumers, which is consistent with some CGE models (see Metcalf et al. 2008) and expected under perfect competition. In a empirical study of carbon taxes, Fabra and Reguant (2014) find evidence for full pass-through to consumers in the form of higher prices. Boyce and Riddle (2007) show that relaxing this assumption and allowing some of the cost to fall on producers and, ultimately, shareholders, makes a carbon tax less regressive. Despite the limitations of the Input-Output analyses, this method provides in-depth, household-level analysis of the impact across the income distribution.

Research using I-O models to assess the distributional incidence of carbon taxes have arrived at different conclusions on how to best utilize carbon tax revenue. Some I-O papers find that a carbon tax is not regressive in the short run (Cronin et al. 2017, Horowitz et al. 2017) or that it is not regressive in the long run (Hassett et al. 2007). Other papers simply accept that there is a trade-off between equity and efficiency and ignore the distributional implications of carbon dividends (Metcalf 1999; Mathur and Morris 2014). Mathur and Morris (2014) argue that using the revenue to pursue reductions in distortionary taxes provides the greatest economic benefit. An important exception is Boyce and Riddle (2007, 2011), which find that a carbon tax is regressive and that carbon dividends increase the purchasing power of the median household in the bottom six deciles.

3. Data and Methods

An analysis of the distributional consequences of a carbon tax requires detailed data on households' carbon footprints in the U.S. We estimate carbon footprints using information about household expenditures on 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 American households from 2012 to 2014 in three steps. First, we calculate CO_2 intensities for 64 industries using the EIA's CO_2 emissions data and the BEA's Input-Output (I-O) tables. Second, we use these industry-level CO_2 intensities to estimate the CO_2 intensity of 33 categories of commodities defined by the BLS. Third, we calculate the carbon footprints of a nationally-representative sample of U.S. households using spending data in the Consumer Expenditure Survey. 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.

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.[12] 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 CBO estimates that there would be about 2,000 collection points in the United States, (CBO, 2001), and Metcalf and Weisbach (2009) estimate the number could be as low as 1,150.[13] 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.

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 (Boyce and Riddle 2007; Mathur and Morris 2014; Metcalf 1999; Perese 2010), our I-O model does not allow firms to change their technologies or mix of inputs. 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.

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[12] 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.

[13] 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.

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 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 33 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 33 CEX categories onto one or more NIPA categories using definitions used by 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 2 lists carbon intensities by CEX category. The first column presents our main estimates, described in the text above. There is slightly less variation in the intensities listed in Table 3 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), and Horowitz et al. (2016). A direct comparison is difficult, because papers calculate CO_2 intensities for different years and somewhat different categories of consumer expenditures. Across these 33 categories, the unweighted correlation between our intensities and those of the other three studies is 0.85, 0.64, and 0.92, respectively. It is unclear why studies arrive at such different intensities using the same I-O tables, and these differences in intensities may account for some of the variation in the distributional results across papers. Our baseline method generates lower carbon intensities for both electricity and natural gas expenditures than other studies. However, Section 5.2 shows that our key results also hold when we use an alternative method, which generates higher intensities for these categories.

Table 2: 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
Airfare	1.00	0.48	1.34	2.18
Alcohol	0.33	0.16	0.48	0.14
All Education	0.24	0.13	0.29	0.53
Auto Insurance	0.05	0.08	0.04	0.07
Autos	0.73	0.20	0.69	0.22
Books	0.22	0.18	0.23	0.17
Business Services	0.11	0.08	0.16	0.21
Charity	0.19	0.13	0.17	0.20
Clothes	0.22	0.20	0.23	0.23
Electricity	2.24	3.00	3.47	3.60
Food at Home	0.39	0.23	0.55	0.58
Food at Restaurants	0.24	0.13	0.31	0.07
Food at Work	0.50	0.25	0.70	0.58
Furnishings	0.71	0.20	0.49	0.34
Gasoline	3.22	2.90	3.15	5.92
Health	0.22	0.13	0.21	0.22
Health & Beauty	0.52	0.13	0.37	0.29
Home Heating Fuel	2.75	3.03	4.07	5.80
Household Supplies	0.36	0.00	0.55	0.23
Life Insurance	0.05	0.08	0.04	0.07
Mass Transit	0.94	0.20	0.23	1.84
Natural Gas	1.82	4.90	12.61	5.93
Other Car Services	0.23	0.13	0.25	-
Other Dwelling Rentals	0.06	0.13	0.13	0.28
Other Recreation	0.25	0.13	0.21	0.46
Other Transit	1.00	0.48	1.03	0.29
Recreation and Sports	0.70	0.18	0.42	0.23
Tailors	0.21	0.13	0.15	0.40
Telephone	0.18	0.15	0.31	0.17
Tenant-Occupied Dwellings	0.05	0.05	0.11	0.35
Tobacco	0.36	0.10	0.43	0.14
Toiletry	0.38	0.20	0.26	-
Water	0.38	0.15	0.31	0.98

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).

3.3. Calculating CO_2 footprints of U.S. households

We are now able to estimate the CO_2 footprints of U.S. households by combining our estimates of carbon intensities from Table 3 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 some 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. We address this problem by imputing electricity and natural gas expenditures for households that report that their landlords pay for electricity, gas, or heat using data from renters who directly pay for all their 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.

Each household's carbon footprint is simply the sum of the carbon embodied in each of these categories of goods:

$$\text{Carbon Footprint}_{\text{it}} = \sum_{i=1}^{33} \text{CEX intensities}_{\text{it}} * \text{CEX expenditures}_{\text{it}} \qquad \text{(Equation 2)}$$

where *it* specifies the category-year intensity. 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.

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 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. First, 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.[14]

Second, this study uses the individual rather than the household as the unit of analysis to account for variation in household size. This sets our work apart from Boyce and Riddle (2007), Mathur and Morris (2014), and Horowitz et al. (2017), but is consistent with Cronin et al. (2017). Table 3 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

[14] Section 4.2 shows that our key results are similar when we use income rather than consumption to sort households.

observe that household size, annual household CO_2 emissions, and annual per capita CO_2 emissions rise consistently with total expenditures, but average household size of the "richest" households is also over twice that of the "poorest" households. When we use 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).

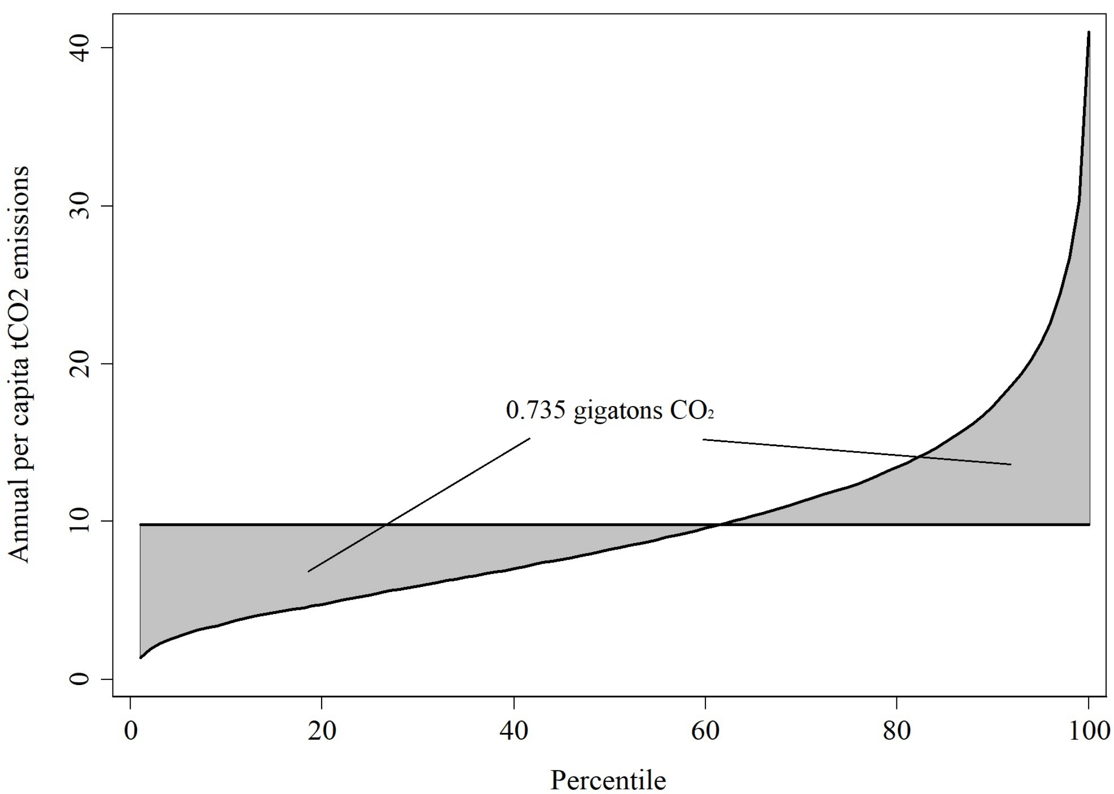
We bypass these complications by analyzing the distribution of emissions across individuals rather than households. The right-hand panel in Table 4 sorts individuals into deciles by equivalent household expenditures, so that each decile has the same number of people. We use the common square root scale 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 across deciles: the bottom row of Table 4 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.

Table 3: 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 households as the unit of analysis and using individuals as the unit of analysis. 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 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 per capita emissions 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 0.74 gigatons less and individuals with above-average emissions emit 0.74 gigatons of CO_2 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.

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

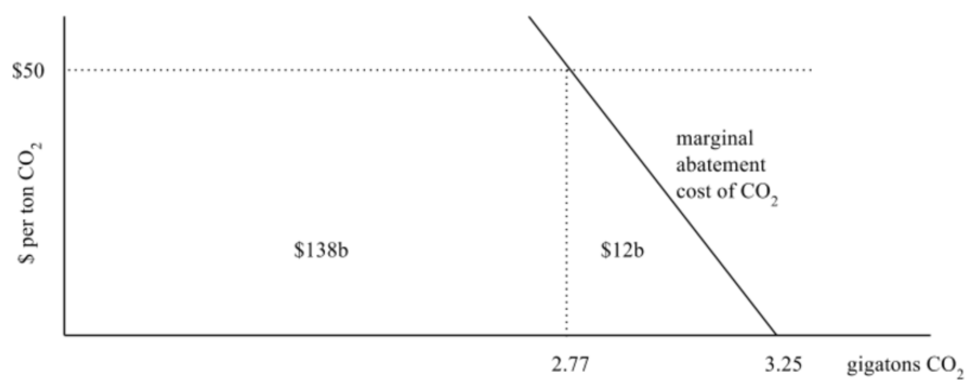


3.5. Behavioral response

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. 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, 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 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 (EIA 2014, Jorgenson et al 2015, Yuan et al 2017). The central analysis 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 be responsible for 3.25 gigatons of CO_2 and that a tax of $50 per ton CO_2 would decrease emissions to 2.77 gigatons in the short-run. The carbon tax would 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

Figure 2: Behavioral Response to Tax of $50/$tCO_2e$



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

billion annually from households in carbon tax revenues, which are devoted to either labor tax cuts or carbon dividends. Under each revenue-neutral policy, we 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 potential 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. Future work should attempt to incorporate these effects into welfare analysis of carbon taxation.

4. Distributional Results

Table 4 presents 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. Prior to the redistribution of revenue, we observe that price increases and abatement costs will reduce welfare of people in the bottom decile by 2.8 percent, while it will reduce the welfare of people in the top decile by 1.8 percent.[15] Like Mathur and Morris (2014) we find that the poorest decile pays about 50 percent more than the richest decile as a fraction of consumption. These results are at odds with recent findings reported by Horowitz et al. (2017) and Cronin et al. (2017) that the carbon tax is flat or even progressive, but they are consistent with the bulk of the literature (Boyce and Riddle 2007; Dinan 2012; Williams et al. 2014).

Next, we present three revenue-neutral policies to recycle carbon tax revenues. First, we model the two tax swap scenarios, where the revenue is allocated to reduce current taxes: a proportional decrease in the effective tax rate on labor income, and an Old-Age, Survivors, and

[15] 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.

Disability (OASDI) payroll tax cut. Our model indicates that this labor tax swap would increase everyone's after-tax wages by 1.8 percent. A labor tax swap would redistribute 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; the distribution within deciles matters too. On the right side of Table 5 we show the fraction of individuals better off within each decile under the three policies. While the bottom decile received a mean net loss, 9 percent of individuals in this decile will still experience an increase in welfare. For deciles in the middle of the distribution, a labor tax cut has different impacts within groups with similar means. For example, while the mean person in the seventh decile benefits from the policy, 49 percent of individuals in this decile are made worse off under a labor tax cut, because income sources, energy needs, and consumption patterns vary substantially within deciles. Table 4 shows that only 40 percent of all individuals and just 30 percent of people in the bottom half of the distribution would see an increase in welfare under a proportional labor tax cut.

A policy to reduce taxes on labor income without redistributing a large share to top income earners is to reduce the OASDI payroll tax. OASDI payroll taxes are capped for high-income earners, with the 2013 law exempting income more than $113,700, so cutting this rate does not disproportionately benefit the wealthy. We assume all benefits from this tax cut accrue to employees in the form of higher wages. The carbon tax revenue would be sufficient to reduce the payroll tax rate by 2.2 percentage points. Results in Table 4 indicate that this tax swap would also be regressive. The bottom decile would have its welfare reduced by 1.45 percent. Although the majority of individuals in the top half of the distribution will be better off, only 34 percent of individuals in the bottom half of the distribution would benefit. For the middle of the distribution, we see that the payroll tax cut better maintains the purchasing power of households and that the mean welfare increase is modestly higher than under the proportional labor tax cut. This payroll tax cut is not as regressive as the proportional labor tax cut since it does not cut the marginal tax rate on high incomes. The policy benefits more people in the seventh, eighth, and ninth deciles than it does in the top decile. Nevertheless, under an OASDI payroll tax cut people at the bottom of the distribution continue to bear the burden of the carbon tax.

Table 4: 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.

Next, we analyze welfare impacts when carbon tax revenues are rebated in equal per capita dividends. We find that a \$50 tax per ton of CO_2 would fund a lump-sum payment of \$413 per person. Under this scenario, the mean individual in the bottom decile would receive 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. Further, we observe that 98 percent of those in the bottom decile and 84 percent of those in the bottom half of the distribution would be better off under a tax-and-dividend policy. For people in the middle of the distribution, we also see that a dividend provides larger net transfers and maintains the purchasing power a greater share of the middle class. A carbon dividend increases the welfare of twice as many people in the bottom half of the distribution as either tax cut, and it is the only policy to maintain the purchasing power of a majority of people overall.

While most analyses of the distributional impact of carbon taxes focus on the impact across incomes, our detailed data also allows us to investigate variation in impact across other group identities, including: race and ethnicity, age, and metropolitan status. An analysis of the impact of these three revenue recycling scenarios provides new insight into the political economy of carbon taxation.

Table 5 presents distributional findings across demographic groups. The first panel assesses the impact across race and ethnicity. We find that the incidence of the carbon tax falls disproportionately on blacks and Hispanics, while Asians experience the smallest welfare loss. Which groups benefit and which groups lose depends on how revenue is recycled. For whites, the three scenarios all lead to small net losses in welfare, and the fraction of individuals better off varies little. In other words, as a group the stakes are modest for whites. For blacks and Hispanics, the story is quite different. 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 the vast majority of blacks (73 percent) and Hispanics (91 percent). For Asians, we find that all three policies would benefit most individuals, with 63 to 66 percent of individuals made better off. However, there is important variation in welfare gains, and a proportional labor tax cut leads to mean welfare gains nearly twice the size as those obtained under the dividend scenario.

Since two of the three revenue recycling scenarios analyzed in this paper are labor tax cuts, the distributional impact varies substantially over the life cycle. While the initial incidence of the carbon tax is distributed relatively evenly across age groups, we do find that it falls modestly harder on young (20-29) individuals, who also have the lowest expenditures. After redistribution, 40-44 percent of individuals in the youngest group benefit from tax cuts, compared to 70 percent under a dividend. Many individuals in this group are not yet in the labor force or earn less than older workers, so cutting labor taxes has a smaller impact on them. Roughly half of individuals in the next three age brackets (30-39, 40-49, and 50-59) would be better off under either labor tax cut, but a larger fraction benefits from the dividend for every age group except 50-59 year-olds. We find the starkest divide in outcomes across policies for those 70 and over. While all revenue recycling scenarios lead to a mean welfare loss, a dividend will protect nearly half of these individuals while a labor tax cut will benefit only 6 or 7 percent of the elderly.

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.

Finally, we investigate how policies will affect individuals based on whether they reside in rural or urban areas. Policymakers may be concerned that carbon taxes fall disproportionately on rural households with higher energy needs. The findings indicate that a carbon tax does indeed disproportionately burden people in rural areas, and that the revenue recycling options have substantial effects on these groups. While a modestly higher percentage of urban individuals are better off under a dividend, we find that a dividend would benefit twice as many rural people as either labor tax cut.

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 using income rather than consumption to sort individuals, and (3) consider the results under different assumptions about individuals' behavioral response. We find that alternative carbon intensities do not significantly change our results (Table 6). Likewise, our distributional results are similar when we use income as our measure of household welfare (Table 7) 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 rely on 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."

Specifically, our utility method assigns all the carbon emissions from coal and approximately 30 percent of emissions from natural gas to the electricity utilities,[16] the remaining 70 percent of emissions from natural gas to natural gas utilities (EIA 2016), and all emissions from oil to the petroleum and coal product industry.[17] Our estimates of CO_2 intensities for all 64 industries are presented in Table A.1 using both our original "extraction" method and this new

[16] 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.
[17] 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.

"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.

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.

To check the implications of these alternative carbon intensities on our distributional results, we replicate Table 4 using carbon intensities from the utility method in Table 6. These findings suggest that under alternative assumptions about carbon intensities, 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 income for the bottom half of the distribution, compared to 2.8 percent using our extraction method. Indeed, the utility method exacerbates both horizontal and vertical redistribution because the carbon tax is more regressive and differences in spending on electricity and natural gas generate variation in transfers within deciles. However, our core results hold using the utility method: a dividend would maintain or improve the welfare of 54 percent of individuals, while tax cuts leave most people worse off. More importantly, the proportional labor tax cut benefits just 25 percent of people in the bottom half of the distribution and the OASDI payroll tax benefits just 29 percent of those in the bottom half of the distribution, whereas the dividend protects the purchasing power of 76 percent of the lower class. Since an upstream carbon tax would be paid by fossil fuel producers and importers, our extraction method probably provides a better approximation of how the tax would be shared throughout the economy. Nevertheless, our key distributional results are robust to alternative carbon intensity estimates.

5.2. Sorting Individuals by Income Instead of Consumption

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). While many economists prefer to use consumption as a measure of income, we use income to test the robustness of our key distributional results.

Table 7 replicates Table 4 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 sorting individuals by income rather than consumption does not affect *who* wins or loses; it simply changes where they fall in the distribution. The table shows that income is much more unequally distributed than consumption. The table indicates that those at the bottom of the distribution smooth their income, perhaps through borrowing or drawing down on savings, while the top of the distribution have incomes that substantially exceed their expenditures. A carbon tax appears even more regressive when the burden is calculated as a percent of income rather than consumption. The welfare loss is equal to 4.6 percent of income for the poorest decile but just 0.9 percent of income for the richest decile. Table 7 suggests that using carbon tax revenue to fund labor tax cuts is also regressive, reducing welfare of individuals in the bottom decile by roughly 3.8 percent under a proportional labor tax or payroll tax cut. 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 equal 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 sort individuals by income or consumption, poor people are much better off receiving a carbon dividend than either labor tax cut.

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.

5.3. Allowing for Heterogeneous Behavioral Responses

In Section 2.5 we describe how we account for individuals' behavioral 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 assumed 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 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

Over the past two decades several studies have addressed the distributional implications of a carbon tax, and most find that the initial incidence of the tax is regressive. While low-income people spend a significantly larger portion of their income on carbon-intensive goods, they have a substantially smaller carbon footprint than high-income people. Our study presents new results on the distributional implications of a carbon tax under three revenue recycling schemes. We find that a per capita dividend is the only revenue recycling approach that would benefit most Americans, while benefits from labor tax cuts would primarily flow to workers in the top half of the income distribution.

However, it is important to recognize that tax cuts may deliver macroeconomic benefits. While this paper emphasizes the equity benefits of the tax-and-dividend approach, 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). A labor tax cut may increase the supply of labor, while a cut in the capital tax rate may generate increased investment. Like Mathur and Morris (2014) we ignore these possible effects in our central analysis, but here we evaluate how these macroeconomic effects fit with our distributional results.

Most papers find that reductions in taxes on capital and corporations generate the largest positive macroeconomic effects. Goulder and Hafstead (2013) and Jorgenson et al. (2015) find that devoting carbon tax revenues to capital tax cuts would increase total income by 0.3-0.5 percent over the next several decades relative to the dividend case. However, the benefits to capital tax cuts flow overwhelmingly to the wealthiest households (Clausing 2012; Horowitz et al. 2017). The CGE models find smaller macroeconomic benefits from labor tax cuts, suggesting that these would raise welfare by about 0.1 percent over the long run relative to lump-sum payments (Goulder and Hafstead 2013; Jorgenson et al. 2015). If these gains were to be shared equally across the income distribution, they would have very little impact on the distributional results we report in Table 4.

Table 8: Vertical and Horizontal Redistribution

	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.

We find that devoting carbon tax revenues to labor tax cuts would reduce welfare of the poorest decile by 1.6 percent, which a 0.1 percent increase in income would do little to ameliorate.

In fact, this macroeconomic effect would do little to help anyone in the bottom half of the distribution, who are 0.6 percent worse off, on average, under the labor tax cut. Our results suggest that the distributional incidence of a carbon tax swamp the potential macroeconomic effects from reductions in distortionary taxes.

Although this paper focuses on the distributional impact of a carbon tax across the income distribution, it is also important to recognize differential impacts among households with similar means. While our central analysis focuses on vertical equity by examining the effects across deciles, we should also address the issue of horizontal equity by examining differences within deciles. Table 8 shows the standard deviation in welfare changes as a percent of expenditures within and between deciles under each policy. The variation in net transfers between deciles shows that the dividend is the most redistributive policy. Carbon dividends are also the only policy analyzed here that redistributes from the rich to the poor and mitigates vertical inequality. Recall from Table 4 that a tax-and-dividend policy would benefit the mean person in the bottom seven deciles, while a proportional labor tax cut and an OASDI payroll tax cut would primarily benefit the top four deciles. In a period of increasing economic inequality, we should be keenly aware of the distributional implications of major new tax schemes, including a carbon tax.

Table 8 also indicates that the proportional labor tax cut and the payroll tax cut primarily redistribute among households of similar means, while a dividend minimizes redistribution *within* groups of similar means. Table 8 illustrates that labor tax cuts generate greater level of horizontal redistribution. The standard deviation in net transfers within deciles is 1.53 under the proportional labor tax cut, 1.52 under the payroll tax cut, and just 1.17 under the dividend. This reflects the fact that everyone pays a carbon tax, but only some people earn labor income. Studies that analyze the impact of a carbon tax on the mean person -- even the mean person in each decile -- overlook the significant horizontal redistribution that occurs when carbon tax revenues are used to fund labor tax cuts. Devoting revenues to some combination of labor tax cuts and benefit increases may somewhat mitigate this horizontal redistribution, but Cronin et al. (2017) find that 27 percent of Americans would neither benefit from a payroll tax cut nor expanded social security benefits.

The central results in the paper describe the distributional effect of a modest carbon tax. We analyzed a tax of $50 per ton of CO_2 since that is the central estimate of the social cost of carbon published by the E.P.A., but this estimate 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/tCO_2. Further, a carbon price of the magnitude we evaluate above would only reduce emissions by an estimated 15 percent in the short run, and it would fail to bring about a full transition away from fossil fuels. If policymakers want to implement a carbon tax as a means of facilitating a transition to a low- or zero-carbon economy a substantially larger tax would be in order. To estimate the distributional impact of an aggressive carbon tax we apply our model to 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/tCO_2 leads to relatively small transfers between households, a tax of \$220/tCO_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 in the United States. We combine carbon emissions data from the Energy Information Agency and the economy-wide Input-Output tables from the Bureau of Economic Analysis to calculate the carbon intensity of 64 industries. Next, we generate carbon intensities for 33 categories of goods in the Consumer Expenditure Survey to estimate carbon footprints for a representative sample of U.S. households. We then analyze incidence of a carbon tax across the income distribution.

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, an OASDI payroll tax cut, and equal per capita dividends. While a carbon tax falls disproportionately on low-income individuals, we find that the policy can be made progressive if the revenue is rebated to the public though equal per capita dividends. Although devoting carbon tax revenues to cut labor taxes makes nearly everyone (91 percent) in the bottom decile worse off, devoting revenues to a dividend ensures that nearly everyone (98 percent) in the poorest decile is better off. While a dividend would maintain or increase the welfare of 55 percent of Americans, including 84 percent of those in the bottom half of the income distribution, neither of the tax cuts modeled here would preserve the purchasing power of most Americans. Moreover, both tax cuts would redistribute income from the poor to the rich. The paper also provides new findings on the distributional impacts when sorting the population by race and ethnicity, age, and urban status. Findings suggest that labor tax cuts bypass a sizable portion of vulnerable populations, including Hispanics, blacks, and the elderly.

We demonstrate that our key results are robust in three ways: our results are similar using alternative carbon intensities, our conclusion holds when we use income rather than expenditures to sort individuals, and results hold under different behavioral responses. We also show that accounting for a double dividend generated by tax cuts has little impact on our analysis. Moreover, while labor tax cuts redistribute income from the poor to the rich and have different effects on people of similar means, a carbon dividend promotes both vertical and horizontal equity. Since even a modest carbon tax represents a sizable reorganization of property rights, distributional concerns should be addressed. This paper demonstrates that careful policy design can protect the environment as well as the welfare of the most vulnerable populations.

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APPENDIX

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.