The Impact of a Carbon Tax on Inequality Supplemental Materials

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This document provides supplemental materials for our paper "The Impact of a Carbon Tax on Inequality". The first section describes our method for calculating the carbon footprints of U.S. households. The second section presents supplementary tables. Our data and code is available on our personal website.

1. Detailed Methods

1.1 *CO_2 intensities of 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 purchases between 71 industries, while the most recent decennial Detailed I-O tables describe the purchases 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. 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 our carbon intensities by BEA category, which are in producer prices, into carbon intensities by Consumer Expenditure Survey category, 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 (DR) matrix for 64 industries 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 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 we attribute 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:

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

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 0.04 kg of CO_2 per dollar of output, while the coal mining industry generates 64 kg of CO_2 per dollar in 2014. These 2012-2014 intensities provide the basis for our estimates of household carbon footprints.

1.2 *CO_2 intensities of 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 following 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. Like most other papers in the literature, we assume that the carbon intensity of imported goods is equal to that of domestically-produced goods.

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 A1, 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 (0.05 kg of CO_2 per dollar), while expenditures on gasoline generate the highest (3.22 kg of CO_2 per dollar).

Table A2 also compares our intensity estimates to the implied intensities in Metcalf (1999), Mathur and Morris (2014), Horowitz et al. (2017), as well as our alternative "utility method" intensities, which we describe in Section 5.1 of our paper. 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 partly account for the differences 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.

1.3 *CO_2 footprints of U.S. households*

We 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 85-95 percent of household expenditures (CEX 2014, 33). While this survey fails to capture household expenditures on some 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 perfectly 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 76,448 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 9,616 household-years. When we sort individuals into deciles below, we are left with 962 observations per decile. 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 *i*'s carbon footprint is simply the sum of the carbon embodied in each of these categories of goods:

$$\text{Carbon Footprint}_{\text{i}} = \sum_{j=1}^{27} \text{CEX intensity}_{\text{jt}} * \text{CEX expenditure}_{\text{ijt}} \qquad \text{(Equation 2)}$$

where *jt* specifies the category-year intensity.

Our sample suggests that U.S. household consumption in 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 note that our method does not capture CO_2 emissions generated by federal, state, and local governments, which our industry-level intensities suggest generate 24 percent of CO_2 emissions. Accounting for government emissions, our methodology attributes 82 percent of CO_2 production-based emissions to final users in the U.S.

References

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2. Supplementary Tables

Table A1: Carbon Intensity of Industries (in kgCO2/$)

	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 Intensity of Consumer Goods across Studies (in kgCO2/$)

Consumer Expenditure Survey Categories	Metcalf (1999) for year 1992	Mathur & Morris (2014) for year 2010	Horowitz et al. (2016) for year 2007	Fremstad and Paul (2019) for year 2013 using extraction method	Fremstad and Paul (2019) for year 2013 using utility method
Airfare	0.48	1.34	2.18	1.00	0.61
Alcohol	0.16	0.48	0.14	0.33	0.20
All Education	0.13	0.29	0.53	0.24	0.34
Auto Insurance	0.08	0.04	0.07	0.05	0.04
Autos	0.20	0.69	0.22	0.73	0.17
Books	0.18	0.23	0.17	0.22	0.14
Charity	0.13	0.17	0.20	0.19	0.16
Clothes	0.20	0.23	0.23	0.22	0.18
Electricity	3.00	3.47	3.60	2.24	7.40
Food at Home	0.23	0.55	0.58	0.39	0.24
Food at Restaurants	0.13	0.31	0.07	0.24	0.17
Furnishings	0.20	0.49	0.34	0.71	0.22
Gasoline	2.90	3.15	5.92	3.22	2.11
Health	0.13	0.21	0.22	0.22	0.16
Home Heating Fuel	3.03	4.07	5.80	2.75	1.80
Household Supplies	0.00	0.55	0.23	0.36	0.20
Life Insurance	0.08	0.04	0.07	0.05	0.04
Mass Transit	0.20	0.50	1.84	0.94	0.58
Natural Gas	4.90	12.61	5.93	1.82	6.90
Other Car Services	0.13			0.23	0.14
Other Dwelling Rentals	0.13	0.13	0.28	0.06	0.04
Other Recreation	0.13	0.21	0.46	0.25	0.15
Recreation and Sports	0.18	0.42	0.23	0.70	0.20
Telephone	0.15	0.18	0.17	0.18	0.10
Tenant-Occupied Dwellings	0.05	0.11	0.35	0.05	0.02
Tobacco	0.10	0.43	0.14	0.36	0.22
Water	0.15	0.31	0.98	0.38	0.24

Notes. Authors calculate implied intensities using published price increases in Table 3 in Metcalf (1999), Table A1 in Mathur and Morris (2014), and Table 2 in Horowitz et al. (2016).

Table A3: Distribution of Burden of $50/Ton Tax on CO2 across Expenditure Deciles, using Utility Method

Decile by Equivalent Household Expenditures	Equivalent Household Expenditures	Mean Benefit/Cost as Percent of Expenditures				Fraction of Individuals Better Off		
		No Revenue Recycling	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend
1	$10,524	-4.13	-2.80	-2.68	4.32	0.05	0.08	0.89
2	$15,469	-3.48	-1.69	-1.53	2.20	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	-2.94	-0.65	-0.48	0.81	0.33	0.39	0.69
5	$26,706	-2.64	-0.30	-0.13	0.51	0.41	0.45	0.62
6	$31,014	-2.53	-0.32	-0.15	0.19	0.42	0.47	0.52
7	$36,171	-2.47	0.32	0.44	0.23	0.54	0.58	0.46
8	$42,823	-2.12	0.21	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	0.21
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	0.53
Mean Poorest Half of Population	**$18,908**	**-3.11**	**-1.03**	**-0.87**	**1.49**	0.25	0.29	0.75

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.

Table A4: Distribution of Burden of $50/Ton Tax on CO2 across Income Deciles

Decile by Equivalent Household Income	Equivalent Household Income	Mean Benefit/Cost as Percent of Income				Fraction of Individuals Better Off		
		No Revenue Recycling	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend
1	$8,063	-4.65	-3.85	-3.78	5.11	0.01	0.01	0.88
2	$16,099	-2.79	-1.70	-1.60	2.08	0.06	0.09	0.81
3	$22,106	-2.60	-1.42	-1.32	1.05	0.12	0.16	0.75
4	$28,188	-2.14	-0.81	-0.69	0.65	0.23	0.29	0.68
5	$34,907	-1.88	-0.44	-0.31	0.39	0.36	0.43	0.63
6	$42,198	-1.75	-0.29	-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	0.49
8	$62,778	-1.43	0.12	0.24	-0.22	0.64	0.68	0.34
9	$80,320	-1.24	0.33	0.38	-0.30	0.73	0.75	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**	**0.44**	**0.56**
Mean Poorest 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.