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ABSTRACT

We use the 2003 Consumer Expenditure Survey and emissions estimates from an input-output model to estimate the incidence of a price on carbon induced by a cap-and-trade program or carbon tax in the US context. We present results on how much difference income deciles pay for a carbon tax as well as which industries see the largest increase in costs due to a carbon tax. We illustrate the main determinant of the regressivity: consumption patterns for energy-intensive goods. We find that a policy targeting CO2 from energy consumption is more regressive than a price on all emissions. Furthermore, on a per-capita basis a carbon price is much more regressive than calculations at the household level. We discuss policy options to offset the adverse distributional effects of a carbon emissions policy.

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I. Background

There are currently several proposals being considered in the U.S. Congress for a national greenhouse gas policy in the United States, and a policy is likely to emerge under the Obama Administration. Although there are proposals for a national tax on carbon, most proposed policies rely on a national cap and trade program for limiting and reducing carbon emissions. Like a carbon tax, a cap and trade program for greenhouse gas emissions has the effect of inducing a price on carbon; this means that for the first time in the U.S. a price will be placed on each ton of CO_2 emitted. That price per unit of carbon emitted will ultimately be paid by consumers, shareholders, and workers. How these costs are distributed among these groups and among income classes is a great concern to policymakers and the general public.[2]

Companies facing regulations on greenhouse gas emissions take costly steps to reduce their emissions levels, but the burden is ultimately borne by consumers, workers, or shareholders in the firm.[3] The costs of compliance are passed on through changes in consumer prices, stock returns, wages, and other returns to factors of production. While an emissions reduction can be achieved in many ways, each method has different costs and consequences. In the case of an emissions tax, there is an additional cost associated with the payment of the tax. Of course, this is not a net cost to society since the cost of a tax payment is exactly equal to the gain to the government. If a permit is initially

[2] In addition to the distribution across income groups, there may be variation in the spatial distribution of costs and benefits (Burtraw, Sweeney, and Walls, 2008).
[3] This is true regardless of statutory incidence; that is, the costs of reducing emissions are ultimately passed on, regardless of the point of compliance.

auctioned by the government, the same transfer occurs.[4] There may, in addition, be additional costs or inefficiencies generated by the interaction of the tax or permit payment with other taxes, such as an income tax (Goulder, Parry, and Burtraw, 1997).

In this paper we use 2003 consumption data, emissions factors and 1997 data on the structure of the US economy to calculate how a price on carbon is ultimately distributed across income groups. Our estimates are admittedly first order; we assume all costs are passed on to consumers, and workers and capital owners bear none of the costs. Furthermore, we only calculate the direct burden of the price on carbon, not taking into account consumer and firm response to a higher carbon price in terms of reductions in carbon emissions. Finally, we do not examine the incidence of the benefit of a price on carbon, in terms of the benefits of a marginal reduction in climate change.

Our aim is to obtain a first-order estimate of the extent to which a price on carbon is progressive or regressive by examining consumption patterns and associated emissions for different parts of the income distribution. In what follows, we focus on a carbon tax, noting that a fully-auctioned emissions trading program (with a correctly chosen quota) would generate the same results, albeit through a different mechanism.

Without loss of generality, we analyze the effect of a carbon tax; the consequences of a carbon price induced by a fully-auctioned cap and trade system should be identical. Our results suggest that the burden as a percent of annual income is much higher among lower income groups than higher income groups. This policy is less regressive when considering the burden as a percentage of lifetime income, proxied by current expenditures (Poterba, 1989). However, when accounting for systematic

[4] In the case of a grandfathered cap-and-trade program, scarcity rents are created, which can actually benefit shareholders. The distributional impact of a cap-and-trade program depends critically on the allocation method (i.e. auctioning vs. grandfathering). See Parry, 2004.

differences in household sizes across income groups using equivalence scales[5] (see, for example, Citro and Michael, 1995), we find that a price on carbon is even more regressive. We then suggest ways in which the regressive nature of a carbon tax may be ameliorated by pairing it with a reduction in other taxes.

We are not the first to study the incidence of a price on carbon, and previous studies have generally found that carbon taxes and tradable emissions permits are regressive. Metcalf (1999) studies the incidence of green tax reforms, including a carbon tax. Using household-level Consumer Expenditure Survey data and input-output accounts, he finds that a carbon tax is regressive, but targeted tax cuts can make the policy distributionally neutral. Parry (2004) uses an analytical model to show that a cap-and-trade program for carbon emissions is regressive. Furthermore, he argues that even if the poor do not have large budget shares for carbon-intensive goods a cap-and-trade program with grandfathered permits can be quite regressive. In a recent paper, Hassett, Mathur, and Metcalf (2009) show that it is fuel and electricity use that drives the regressivity of a carbon tax.

Our study differs from previous literature in several ways. First, we illustrate how consumption differences across income groups is the main driver behind the regressivity of the policy. Second, in addition to providing household-level consumption and incidence estimates, we show that using equivalence scales and per-capita emissions leads to higher calculated levels of regressivity. Finally, we show how the degree of regressivity varies with the breadth of the tax as well as the measure of income used in

[5] Because there are economies of scale in household consumption, household-level analysis may understate the regressivity because wealthier households are larger, on average, than poorer ones. For example, a household with three people does not need three times as much space and electricity as a household with one person. Equivalence scales attempt to account for the nonlinear relationship between household size and needs. This methodology is discussed in greater detail in section III.

the calculations (Hassett, Mathur, and Metcalf, 2009). We calculate the incidence of a broad CO_2 price, a price on CO_2 for direct energy consumption, and price on all greenhouse gas emissions (CO_2-equivalent).

II. Consumption and Emissions Data

The economic incidence of a tax refers to how the ultimate net costs are distributed in an economy, usually referring to how different income groups are impacted. The distribution of costs and benefits determines the winners and losers from environmental policy. A progressive policy places a larger burden, as a percentage of wealth or income, on richer households, while a regressive policy places larger percentage burdens on poorer groups. Fullerton (2009) discusses six ways environmental policies may have distributional impacts; forward cost-shifting is one of the major drivers of the incidence of environmental policy.

To completely capture the incidence of a price on carbon, we would want to take into account carbon-reducing abatement activities or behavioral changes in examining the extent to which consumers or factors of production bear the cost of the tax.[6] We would also want to estimate the incidence of those abatement activities and how the government uses or refunds the revenues from the taxes or permits. A general equilibrium analysis of the issue would also take into account the changes in relative prices in the economy induced by the tax or costly permits.

A much more modest approach would fix economic activities at their current level and apply a price of carbon, assuming that there is no behavioral or secondary price response in the economy—the carbon price is passed through in its entirety to consumers

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[6] Metcalf, et al (2008) use a calibrated model to estimate the incidence of alternative greenhouse gas policies under various assumptions about forward and backward shifting. Their results depend on various factors, including the breadth of the tax, whether other countries act, and short- vs. long-run effects.

and consumers do not adjust behavior. Such an analysis will overstate the burden on consumers since in actuality factors of production will bear some of the cost and, further, a higher price of carbon will induce actions to reduce carbon consumption and thus the household's burden. Our results would be most valid if commodity demands were inelastic, or if all industries use the same ratio of inputs, because this would not lead to changes in relative factor demands and prices.

In our analysis, we examine the effects of a price of $15 per ton of carbon dioxide, equivalent to approximately $55 per ton of carbon.[7] Although there is a great deal of uncertainty regarding what price of carbon may emerge from the current policy debate in the US, this figure is in the range of the current proposals before Congress (e.g. Paltsev et al, 2007). It should also be noted that, in our analysis, the relative burdens across income groups are independent of our choice of a price.

We begin with data from the 2003 Consumer Expenditure Survey (CES) from the Bureau of Labor Statistics. The CES provides annual consumption patterns for households in each income quintile in the U.S. for a variety of products and services. For each income group, we can then calculate the average household-level expenditure for shelter, electricity, gasoline, vehicles, food, clothing, insurance, and a host of other goods and services. A breakdown of the per-capita expenditures of some of the goods and services is shown in Table 1. For example, according to the CES, an average household in the lowest income quintile spent roughly $527 in 2003 on gasoline and motor oil, which was about 4.8% of their net annual income, whereas the corresponding percentage

[7] The conversion between CO_2-equivalent and Carbon-equivalent follows from the ratio of the atomic mass of a carbon dioxide molecule to the atomic mass of a carbon atom (44:12). Therefore, a $15 tax per ton of carbon dioxide is equivalent to a tax on carbon of $55 per ton.

for a household in the wealthiest quintile is only 1.7%.

Table 1: Selected Average Household Expenditures by Income Quintile (2003)

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Mean Household Income After Tax	$10,879	$19,982	$34,007	$54,546	$110,878
Gross Income Range	$7,500- $14,761	$14,762- $28,594	$28,595- $47,801	$47,802- $77,670	> $77,671
Mean Number Persons/Household	1.8	2.3	2.6	2.9	3.1
Mean Household Expenditures:					
Food & Alcohol	2,708	3,534	4,635	5,943	8,172
Shelter	4,613	8,570	14,049	17,800	35,486
Natural Gas	259	258	308	409	567
Electricity	620	761	912	1,031	1,306
Fuel Oil & Other Fuel	60	71	92	85	151
Telephone Services	506	635	833	1,020	1,342
Water & Other Public Services	177	223	295	362	495
Household Operations, Supplies, Furnishings, Equipment & Apparel	1,440	2,076	2,907	4,223	7,648
Transportation & Vehicle Exp.	1,823	3,306	5,020	7,874	10,955
Gasoline & Motor Oil	527	861	1,223	1,574	1,940
Healthcare	1,500	1,723	2,176	2,388	3,264
Other Expenditures	1,597	2,609	4,230	6,196	10,940
Total Household Expenditures	15,829	24,626	36,679	48,905	82,266

Source: Consumer Expenditure Survey (2003). The households with the lowest income levels (<$7,500) are dropped from the lowest quintile for reasons described in the text. Figures are annual household expenditures in 2003 dollars. The less emissions-intensive consumption categories were aggregated here for exposition only; all subcategories were used in the estimates produced in this paper.

Income measurement in the low end of the distribution is poor in the CES, as students, retirees, and transitionally unemployed people are included in this category. As a result, the households with the lowest income in the CES have, on average, an extremely high expenditure to income ratio. Therefore we do not include households with income less than $7,500 in our analysis.[8] Including these households leads to a more regressive calculation of the incidence of a price on carbon emissions.

[8] $7,500 corresponds to around the 5.8th percentile. To be consistent with other studies using these data, as well as studies of the incidence of other taxes, we do not alter our definitions of income quintiles to account for dropping these households.

To estimate the consumption consequences of a carbon price, we need to look at how that price would ripple through the economy, ultimately being borne by the consumer. For instance, food production requires fuel to run tractors (with associated carbon emissions), but it also requires fertilizer, for which carbon was emitted during its production. This suggests the use of an input-output approach.

The standard input-output tables for the US, produced by the US Bureau of Economic Analysis (BEA), divide the economy into a large number of industrial sectors. The IO table for a particular year indicates for each sector *j*, how much was purchased from each of the other sectors $i=1,2,\ldots,n$ to produce \$1 of output for sector *j*. It is thus a straightforward calculation to translate a vector of final demands in these industrial categories into total production in each of the categories, satisfying both final demand and intermediate demand. This same technique can be used to calculate how a tax on direct carbon emissions in each sector will ripple through the economy to increase the price of final consumption for the sector, assuming no steps are taken to substitute away from carbon intensive goods.

More formally, let *A* be a $n \times n$ input-output matrix, where the coefficients a_{ij} represent the inputs (in \$) from sector *j* necessary to produce \$1 worth of output for sector *i*. Let *c* be a vector of final demands for goods in each industry (in dollars), and let *x* be a vector of total output (in dollars) for the various sectors of the economy. Leontief (for example, 1986) formulated this input-output model such that

$$Ax + c = x \Leftrightarrow x = (I - A)^{-1} c \qquad (1)$$

where *I* is the identity matrix.[9]

[9] We assumethat (*I*-*A*) is regular so that it is invertible; in practice, this assumption generally holds true.

A straightforward extension of this traditional input output model is to calculate the emissions necessary for production of final consumption goods, accounting for emissions of all primary and intermediate processes necessary to produce final goods (Leontief, 1970; Hendrickson, et al, 2006). Let g be a vector with the j^{th} element equal to the greenhouse gas emissions (in CO_2-equivalent) per $1 of output for that sector. For a consumption vector c, the resulting total emissions e (a scalar) are then given by

$$e = g'x = g'(I - A)^{-1}c . \qquad (2)$$

This method essentially traces emissions through an economy and provides us with estimates of emissions attributable to the consumption of final goods. Now if a tax of τ dollars per ton emissions of CO_2-equivalent were levied, the total tax paid, associated with a consumption vector c, would be τe.

The input-output matrix for the US is regularly compiled and published by the BEA. The vector of emissions factors, g, is not as readily available, though can be estimated from available data. Researchers at Carnegie-Mellon University (Hendrickson et al., 2006) have estimated these emissions factors and developed an easily used version of the 1997 US input output tables to allow the tracing of greenhouse gas emissions throughout the economy.[10]

Using the Carnegie Mellon version of the US input-output model (the "CMU Model"), we obtain the amount of emissions (both CO_2 and all emissions in terms of CO_2-equivalent) associated with each of the 491 sectors of input-output accounts.[11]

[10] The CMU model (the Economic Input Output Life Cycle Assessment (EIO LCA) model) is available online at http://www.eiolca.net/about.html.
[11] Because consumption data were from (2003), we adjusted expenditures using the Consumer Price Index (CPI) to make prices compatible with 1997 conditions. Because energy prices have increased more than the average price levels, we apply specific deflators for consumption category. This was only to done to get emissions factors for consumption goods; all consumption figures are in 2003 dollars.

Table 2 shows the top 20 sectors in terms of CO_2 emissions. Assuming a $15 carbon price in 2009, the final column shows the percent cost increase for that sector implied by the model. For $1 million in purchases, the top emitting sector is lime manufacturing, which is responsible for 9,840 MT CO_2. The second-highest emitter is sector 221100, Power Generation and Supply, emitting 7,455 MT CO_2. Considering the large number of sectors in the economy, there are remarkably few sectors that see substantial cost increases (though what constitutes substantial is a subjective judgment). What is relevant to these specific industries is who ultimately bears the burden: consumers, workers or owners.

Then, using data from the BEA, we match sectors of the IO model to the Personal Consumption Expenditure (PCE) categories, which are then comparable to the categories in the CES version developed by the National Bureau of Economic Research (NBER) and which are used in the analysis.[12]

In practice, for any product category, the CMU model tells us how many tons of greenhouse gases are emitted to create $1 Million worth of output. Because the process is linear, we can then calculate the number of tons of CO_2 and total greenhouse gases (in terms of CO_2-equivalent) that were emitted so that an average consumer in each income quintile could purchase his or her bundle of goods and services.[13] It is then a

[12] The NBER CES extracts, available online, are condensed to 109 categories (including income sources) of the CES. This allows the categories to be more comparable to the PCE categories.

[13] Emissions resulting from combustion in motor vehicles and the use of natural gas are not included in the CMU Model, as the model only calculates the greenhouse gases associated with the production and distribution of these goods. We add the emissions from using gasoline and natural gas using the standard EPA estimates, imputed by using the average price for these fuels in 2006 to determine the amount purchased. There is evidence that poorer households drive older, less fuel-efficient cars, which would imply that emissions per gallon of gasoline for these income groups could actually be higher (West and Williams, 2004). We assume that each income quintile has similar driving habits and vehicles, though differences across income groups would lead to slightly different incidence estimates. In this case, it would

straightforward calculation to determine how much the average consumer in each income quintile would pay for a given price on carbon induced by a tax or permit price.

Table 2: Sector-Level Emissions

	Sector	Sector Description	CO2 Emissions (MT)	CO2e Emissions (MT)	Cost Increase
1	327410	Lime manufacturing	9,840	10,064	14.8%
2	221100	Power generation and supply	7,455	7,827	11.2%
3	327310	Cement manufacturing	5,554	5,680	8.3%
4	325311	Nitrogenous fertilizer manufacturing	4,435	9,393	6.7%
5	325312	Phosphatic fertilizer manufacturing	3,660	4,197	5.5%
6	S00202	State and local government electric utilities	3,191	3,429	4.8%
7	324191	Petroleum lubricating oil and grease manufacturing	2,751	2,982	4.1%
8	325120	Industrial gas manufacturing	2,676	7,134	4.0%
9	331312	Primary aluminum production	2,639	4,249	4.0%
10	325221	Cellulosic organic fiber manufacturing	2,460	2,579	3.7%
11	331311	Alumina refining	2,385	2,587	3.6%
12	331112	Ferroalloy and related product manufacturing	2,296	2,475	3.4%
13	325130	Synthetic dye and pigment manufacturing	2,154	2,266	3.2%
14	212210	Iron ore mining	2,050	2,199	3.1%
15	212390	Other nonmetallic mineral mining	1,901	2,013	2.9%
16	331111	Iron and steel mills	1,811	2,050	2.7%
17	311221	Wet corn milling	1,774	3,362	2.7%
18	486000	Pipeline transportation	1,565	2,989	2.3%
19	484000	Truck transportation	1,498	1,580	2.2%
20	325314	Fertilizer, mixing only, manufacturing	1,498	2,348	2.2%

Note: Emissions estimates from Carnegie Mellon University Green Design Institute's EIO-LCA model. Emissions include direct and indirect emissions attributable to $1 Million in sales (2009 dollars) from that sector. The cost increase is computed assuming a $15 price on CO_2 emissions.

increase the regressivity, though accounting for behavioral responses by income group would lead to a greater decrease in quantity demanded for low-income groups, which would have an offsetting effect.

Using this method implies an aggregate level of US greenhouse gas emissions in 2003 to be about 5,298 Tg CO_2, compared to the EPA's greenhouse gas inventory estimate of 5,953 Tg CO_2 (US EPA, 2007).[14] Similarly, we calculate the total greenhouse gas emissions for 2003 to be 6,582 Tg CO_2-equivalent, compared to 7,104 Tg CO_2-equivalent from the EPA. Considering that the CMU model is calibrated to the 1997 economy, our implied emissions calculation for 2003 is remarkably close to observed data. On a per-capita basis, this implies an 'average' consumer's emissions of about 18.2 metric tons of CO_2,[15] compared to estimates of 20.5 by the EPA.

Table 3: Estimated Annual CO_2 Emissions by Income Quintile

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Household Income Range (after taxes)	$7,500-$14,761	$14,762-$28,594	$28,595-$47,801	$47,802-$77,670	> $77,671
Mean (After Tax) Income	$10,879	$19,982	$34,007	$54,546	$110,878
Mean Household Size	1.8	2.3	2.6	2.9	3.1
Mean Household Emissions					
Food & Alcohol	2.19	2.83	3.69	4.67	6.28
Shelter	1.87	3.68	6.04	7.32	14.74
Natural Gas	1.99	1.97	2.35	3.13	4.34
Electricity	7.26	8.91	10.68	12.08	15.30
Fuel Oil & Other Fuel	0.68	0.81	1.05	0.96	1.71
Telephone Services	0.06	0.07	0.09	0.11	0.15
Water & Other Public Services	0.17	0.21	0.28	0.34	0.47
Household Operations, Supplies, Furnishings, Equipment & Apparel	0.61	0.90	1.31	1.87	3.40
Transportation & Vehicle Expense	0.44	0.96	1.58	2.53	3.39
Gasoline & Motor Oil	4.99	8.15	11.59	14.92	18.38
Healthcare	0.29	0.33	0.42	0.42	0.62
Other Expenditures	1.16	1.66	2.38	3.65	7.21
Total Emissions	21.70	30.49	41.45	51.98	75.99

Source: Authors' calculations using Consumer Expenditure Survey (2003) data and the CMU model described above. Figures are in metric tons of CO_2.

[14] Tg stands for teragram and is equal to 10^{12} grams which is a million metric tons.
[15] This is based on a July, 2003 U.S. Census population estimate.

The total household emissions were calculated for each household's consumption bundle by simply adding the emissions for each product in the bundle for that year. Annual average emissions estimates are shown for households in each income quintile in Table 3. As shown in the table, the households from the poorest income quintile consumed goods and services associated with 21.7 metric tons of CO_2 in 2003, while the average household in the top quintile was responsible for about emissions of 76 tons of CO_2. Similarly, Table 4 shows the breakdown of CO_2-equivalent emissions by income group.

Table 4: Estimated Household Annual CO_2-Equiv. Emissions by Income Quintile

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Household Income Range (after taxes)	$7,500 to $14,761	$14,762 to $28,594	$28,595 to $47,801	$47,802 to $77,670	> $77,671
Mean Per-Capita (After Tax) Income	$10,879	$19,982	$34,007	$54,546	$110,878
Mean Household Size	1.8	2.3	2.6	2.9	3.1
Mean Household Emissions					
Food & Alcohol	4.64	5.92	7.67	9.55	12.56
Shelter	2.22	4.37	7.17	8.68	17.46
Natural Gas	2.43	2.42	2.88	3.83	5.32
Electricity	7.62	9.36	11.22	12.69	16.06
Fuel Oil & Other Fuel	0.75	0.90	1.17	1.07	1.91
Telephone Services	0.06	0.08	0.11	0.13	0.17
Water & Other Public Services	1.16	1.45	1.92	2.36	3.23
Household Operations, Supplies, Furnishings, Equipment & Apparel	0.76	0.93	1.37	1.84	3.29
Transportation & Vehicle Expense	0.53	1.13	1.86	2.99	4.01
Gasoline & Motor Oil	5.73	9.36	13.30	17.12	21.11
Healthcare	0.36	0.41	0.52	0.52	0.77
Other Expenditures	1.21	1.93	2.74	4.17	8.09
Total Emissions	27.47	38.26	51.92	64.95	93.96

Source: Authors' calculations using Consumer Expenditure Survey (2003) data and the CMU model described above. Figures are in metric tons of CO_2-equivalent.

As shown in Tables 3 and 4, the most carbon-relevant sectors are fossil-fuel intensive; gasoline, electricity, natural gas and food are the goods purchased by consumers with the highest associated emissions. In the next section we use these figures to calculate the incidence of a price on carbon.

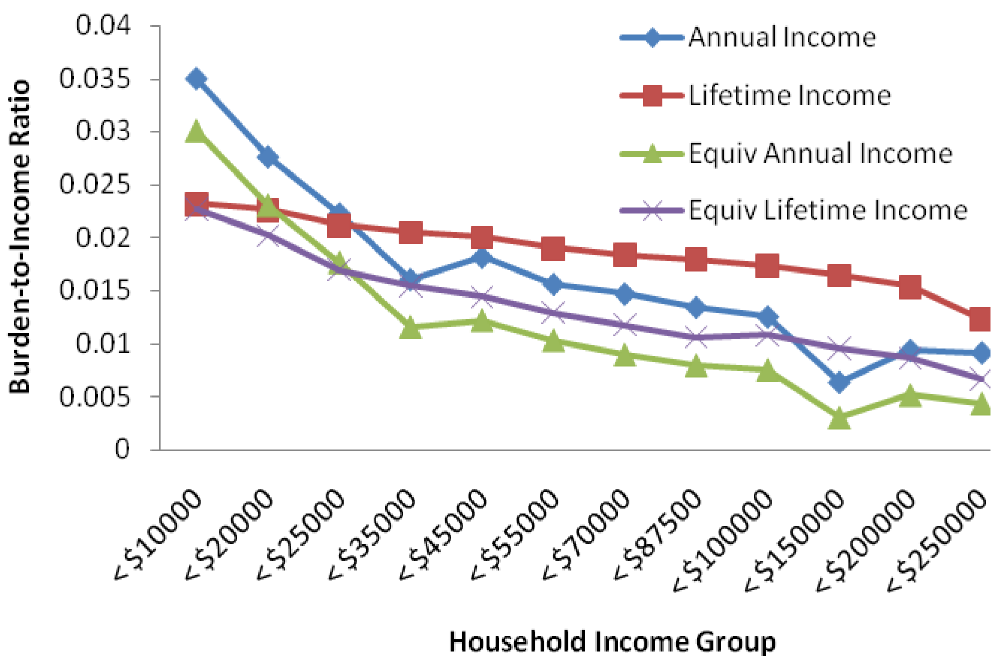
III. The Incidence of a Price on Carbon

Using emissions calculations from the previous section, we calculate the burden of a price on carbon emissions for each household in the CES. For a tax of $15 per ton CO_2 (based on the emissions estimates in Table 3), an average household in the lowest income quintile would pay around $325 per year, while an average household in the wealthiest quintile would pay $1,140 annually. Although wealthier households would pay more in absolute terms, as a percentage of annual income, lower income groups bear a disproportionate share of the burden. The poorest quintile's burden (as a share of annual income) is 3.2 times that of the wealthiest quintile's. The burden as a share of annual income for the lowest income group ($7,500-9,999) is almost four times higher than the burden-to-income ratio for the highest income group in the data ($200,000-250,000). This is seen graphically in Figure 1, where the percentage of household expenditures on a price on carbon is plotted against income groups.

There is a debate among economists as to whether current income or lifetime income should be used in the calculation of the incidence of a policy. Because annual income is volatile, and because it tends to increase and then decrease with age, a person's annual income may not be a good proxy for their relative income over their lifetime.

However, lifetime income is far more difficult to measure.[16] Current expenditures can be used as a proxy for lifetime income if consumption is relatively smooth over a person's lifespan (Poterba, 1989; Metcalf, 1999).[17] In this case, calculating the burden as a percent of lifetime income rather than current income results in a less regressive policy, though some authors find that using current expenditures as a proxy for lifetime income exaggerates the decrease in regressivity (Caspersen and Metcalf, 1994). When comparing the burden as a percentage of annual expenditures, a person's burden in the lowest income quintile is about 1.4 times that of the highest quintile.

Figure 1. Broad CO_2 Tax Burden by Household Income Group



[16] The data used here make measuring lifetime income impossible, so a proxy is used. Fullerton and Rogers (1993) measure lifetime income and classify households accordingly. They find that the bias in regressivity based on annual income is not as severe as suggested by previous researchers.

[17] According to the lifetime income hypothesis, consumption is relatively smooth across time because people make contemporaneous consumption decisions based on their lifetime (and not current) income. For example, students may take out loans to support themselves during college because they anticipate earning income after graduating, and workers forgo consumption and save so that they have money for retirement.

CO_2 price ($15/ton) as a percent of annual net income and current expenditures. Equivalent income measures are described in the text. Authors' calculations using consumption data from the Consumer Expenditure Survey and associated emissions from the Economic Input Output model from Carnegie Mellon University.

There is a systematic difference in average household size across income groups, which can be seen in the CES summary statistics in Table 1. Households in the lowest income quintile have an average of 1.8 persons, whereas households in the top quintile have, on average, 3.1 persons. Since wealthy households are larger, on average, this inflates the relative income of the poorer households (Cutler and Katz, 1992). Thus, using household level data for emissions and income may lead to a lower estimate of regressivity than if one accounts for these differences. Therefore, in addition to household income (annual and lifetime), we use equivalence scales to calculate the incidence of a carbon price. Equivalence scales have been used widely (e.g. Cutler and Katz, 1992; Fernández-Villaverde and Krueger, 2007), and are meant to account for economies of scale in household consumption. We parameterize equivalent persons, *E*, as $E = (A + .4K)^{.5}$, where *A* is the number of adults, and *K* is the number of children. For households with at least two people, we assume that the first two people are adults and the others are children. However, if the number of income-earners in the household exceeds two, we set *A* equal to the number of income earners.[18] For each household, we then calculate the per-capita burden of a price on carbon as a percent of household income scaled by *E*.

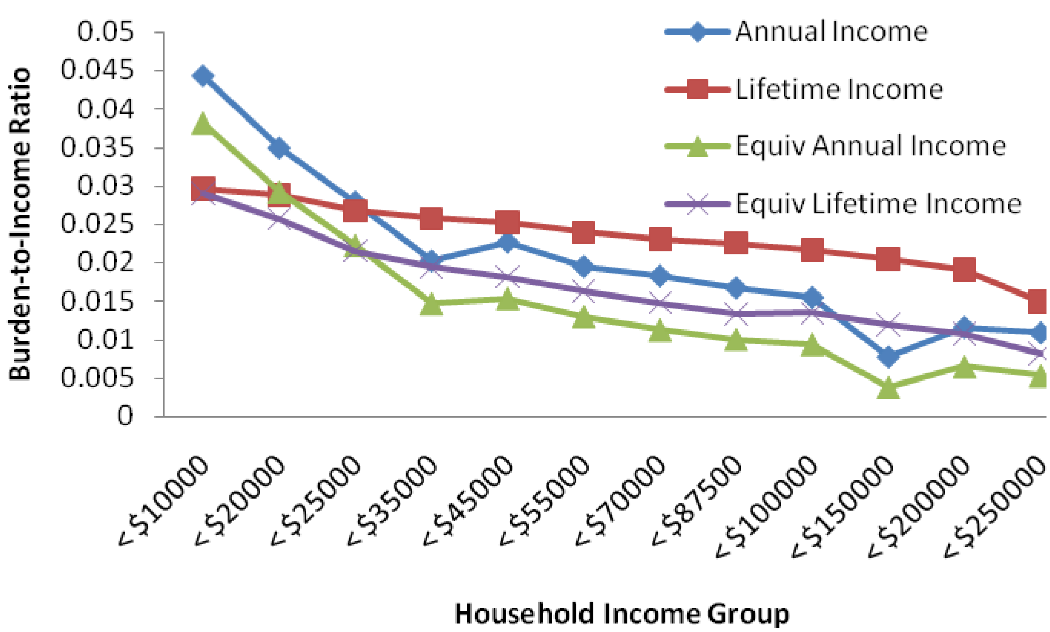
For a price on all CO_2 emissions, the use of equivalent annual income leads to a more regressive calculation than household-level annual income. The per-capita burden-

[18] We also used alternative methods to proxy for the number of adults in a household, as well as other equivalence scales. The incidence calculations vary slightly with the choice of equivalence scales, but the results with alternative equivalence scales are much more regressive than household-level analysis.

to-equivalent-income ratio for the lowest income group (between $7,500 and $9,999) is nearly 7 times greater than for the highest income group (between $200,000 and $250,000). On an equivalent lifetime income basis, the ratio is about 3.5 times higher for the lowest income group.

We then considered a price on all greenhouse gas emissions (in terms of CO_2-equivalent. Figure 2 shows the calculations by income group using the four measures of income. Again, the policy is regressive using all measures. Using annual income, the ratio for the lowest income group is over four times higher than the highest income group, but on a lifetime basis it is only twice as high. Using equivalent income, the per-capita burdens are about 7.25 times higher on an annual basis for the lowest income group than the highest. And on an equivalent lifetime income basis (i.e. equivalent expenditures), the ratio is about 3.6 times higher.

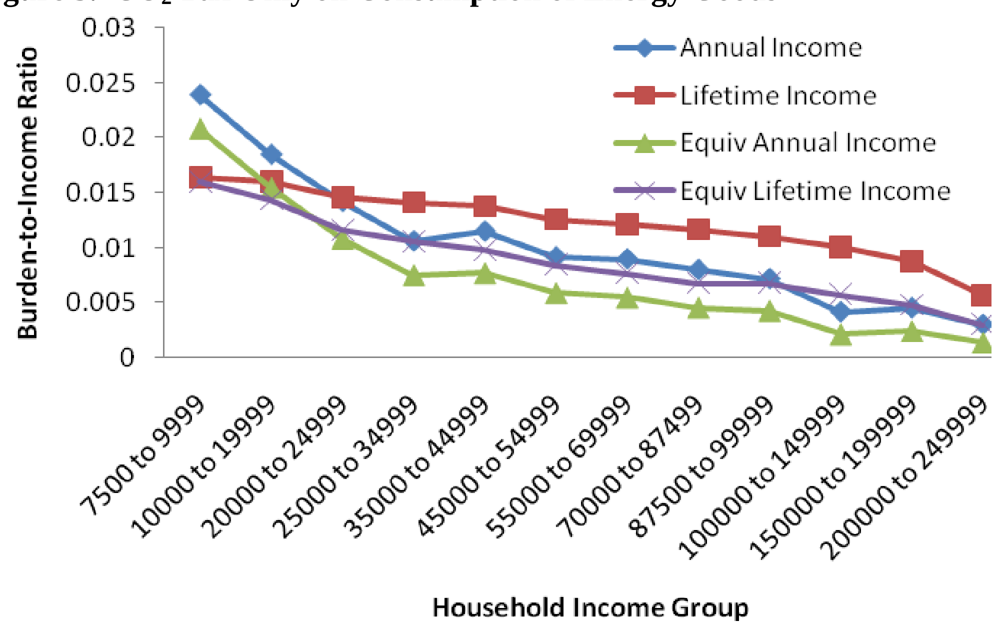
Figure 2. Broad CO_2-Equivalent Tax Burden by Income (%)



Tax on CO_2 ($15/ton) equivalent as a percent of annual net income and current expenditures. Equivalent income measures are described in the text. Authors' calculations using consumption data from the Consumer Expenditure Survey and associated emissions from the Economic Input Output model from Carnegie Mellon University.

Finally, we consider a price on CO_2 emissions only on consumption of energy goods. The distribution of the burden on consumers from a higher price on gasoline, electricity, natural gas and fuel oil is shown in Figure 3. Using household annual income, the ratio for the lowest income group is almost 8 times higher than the highest income group, and on a lifetime income basis (using expenditures) we calculate that the ratio is about 2.9 times higher. Using equivalent annual income, the per-capita burden is almost *fifteen* times higher, and using equivalent lifetime income the per-capita burden is over five times higher. Similar to the findings in Hassett, Mathur, and Metcalf (2009), it appears that the regressivity of the policy is driven largely by direct energy consumption.

Figure 3. CO_2 Tax Only on Consumption of Energy Goods



CO_2 price ($15/ton) as a percent of annual net income and current expenditures. Equivalent income measures are described in the text. Authors' calculations using consumption data from the Consumer Expenditure Survey and associated emissions from the Economic Input Output model from Carnegie Mellon University.

A price on carbon, given the assumptions above, would be regressive, but the degree of regressivity depends on the income measure used. On an annual basis, a carbon price is 2-3 times more regressive than on a lifetime basis (i.e. using annual expenditures). When examining the policy on a per-capita basis with equivalence scales, a carbon price is roughly twice as regressive than at the household level. In each case the regressivity is largely driven by direct energy consumption. This finding is consistent with other studies of the household incidence of carbon emission policies.[19] Furthermore, as discussed briefly in the next section, the overall regressivity of a policy depends critically on how the revenues are used.

IV. Policy Implications

The regressive nature of pollution control policies is often a concern of politicians, but these new revenues could be used to benefit those harmed disproportionately by the new policy. Because the price on carbon discussed here would generate substantial revenues for the government, it is important to consider how these revenues might be spent so that the burden does not fall disproportionately on lower income groups. As discussed elsewhere in the literature (e.g. Parry et al, 2005), a price on carbon could be made less regressive, or even progressive, by "recycling" the revenue

[19] Other economic studies of carbon taxes (e.g. Metcalf, 2008; Wier et al. 2005) generally find that they are regressive, but the degree varies based on the methodology, assumptions, and income basis (annual vs. lifetime). For example, Metcalf (2008) uses 2003 consumption data to estimate the partial equilibrium incidence of a carbon tax. For a $15 carbon tax, he finds that an average consumer in the lowest income decile would experience a decrease in disposable income of 3.4%, whereas the wealthiest income decile's disposable income would decrease by 0.8%. Wier et al (2005) find that the poorest decile spent 0.8% of disposable income on the Danish carbon tax, while the wealthiest spent about 0.3% of their disposable income. For a review of other policies, see Parry, et al. (2005).

into tax cuts elsewhere in an economy.[20] This could be achieved by targeting income tax cuts at lower income groups, reducing (or even eliminating) other federal taxes, or by increasing spending on government programs targeted at lower income groups. Here we briefly discuss these options; for a more thorough (partial equilibrium) discussion of a revenue-neutral carbon tax swap, see Metcalf (2008).

To make the carbon emissions policy discussed above distributionally neutral, lump-sum transfers, which are essentially cash payments that do not alter incentives or behavior, could be used. A more practical alternative would be in the form of reductions in the income tax burden for individuals based on their annual income. In practice, the price on carbon here could be made distributionally neutral by directing transfers (or income tax credits) in the amounts of $119, $112, $105, and $76 to individuals in the first four income quintiles, respectively. This would place a burden on each household of around 1% of net annual income (equal to the burden of the highest income group), offsetting the regressive effects of the price on carbon while leaving $49.6 Billion in government revenues.

Alternatively, revenues from a price on carbon could be used to finance cuts in other taxes.[21] The study of the incidence of taxes is a major subfield of public finance, and many empirical (and theoretical) studies have focused on the distributional incidence of payroll taxes, value-added taxes[22], sales taxes, and excise taxes. The literature

[20] In a recent paper, Boyce and Riddle (2009) examine the state-by-state incidence of a $25 carbon tax/permit price, 80% of the revenues of which are rebated to consumers.
[21] To the extent that the pre-existing taxes are distortionary, under certain conditions this may even lead to an efficiency gain (Goulder, et al., 1997).
[22] The literature on the incidence of a value-added tax (VAT) generally finds that such a policy is regressive. Caspersen and Metcalf (1994) find that a value added tax on food, housing and healthcare is mildly regressive, with the ratio of the median tax liability to income for the lowest income decile equal to 2.3, and for the highest decile 1.1. When using proxies for lifetime income, the degree of regressivity

generally finds these taxes to be regressive, though the degree varies widely due to assumptions about income, the amount of pass-through, and other factors (Fullerton and Metcalf, 2002). For example, Poterba's (1989) study of the incidence of a gasoline tax finds that the bottom quintile's burden as a percent of current income is 5.3 times as high as that of the highest income quintile's. When calculating the burden as a share of current expenditures, he finds that it is less regressive—about 1.5 times as high.[23]

One candidate for revenue recycling would be to use revenues to finance cuts in the payroll tax.[24] The costs of a payroll tax are regressive, and although part of the burden is paid by the employer, most studies find that the burden falls almost entirely on workers through reductions in wages (Fullerton and Metcalf, 2002). The Federal Insurance Contributions Act (FICA) tax is regressive in its very nature because beyond the Wage Base limit (currently $102,000 per year), any additional earnings are untaxed. Therefore the tax, as a percentage of income, effectively declines as income increases beyond that level.[25] According to Chamberlain and Prante, the average effective tax rate for the payroll tax in 2004 was 2.75% for the lowest income quintile, 7.11% for the second, 9.05% for the third, 9.53% for the fourth, and 7.79% for the top quintile. Targeted revenue recycling from a carbon emissions policy could help create a more distributionally neutral payroll tax.

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declines. Because there is no federal VAT in the US, revenues from a carbon tax could not be used to finance reductions in the VAT.

[23] West and Williams (2004) also study the incidence of a gasoline tax, but they estimate the elasticity of demand for each income group and find that the tax is less regressive if one accounts for this behavioral response.

[24] In fact, Representative John B. Larson of Connecticut has introduced a bill (HR 3416) into the US Congress to tax carbon but to couple this with a revenue neutral reduction in the payroll tax. His proposal involves the carbon tax starting small and gradually increasing over time.

[25] However, a Congressional Budget Office study (CBO, 2006) argues that the overall social security system is progressive once benefits are factored in. On the other hand, Coronado, Fullerton, and Glass (2000) show that the progressivity of social security depends critically on the methodology of calculation. When incorporating mortality probabilities that differ by potential lifetime income, they find that social security, overall, is no longer progressive; for a discount rate of 4%, it is even regressive.

In order to fully analyze how to finance cuts in pre-existing taxes to create a distributionally neutral (or even progressive) bundle of taxes, we would need to analyze the general equilibrium effects of the overall tax system. However, a back-of-the-envelope estimate using the figures from the prior section suggests that the total annual revenues from a price on carbon of $15 per ton would equal approximately $79.2 Billion. Although this is most likely an upper bound on actual revenues, because of reasons discussed above, a price on carbon could yield substantial government revenues, and careful recycling of these revenues could offset the regressive nature of a national GHG emissions policy.

V. Conclusions

We use the Consumer Expenditure Survey and an augmented input-output model of the US economy to illustrate the regressive nature of a price on carbon in the United States. We show that the costs of a price on borne by consumers are regressive by nature because polluting goods are mostly energy-intensive and take up a large percentage of a low-income person's budget. The degree of regressivity varies with the breadth of the policy. The incidence of a carbon price applied only to final energy consumption is nearly twice as regressive as a price applied to all CO_2 emissions. Furthermore, taking into account differences in household size across income groups and equivalence scales, the per-capita incidence suggests a much more regressive policy than calculations at the household level.

We find that the costs of a greenhouse gas policy in the United States are regressive, but there are a few caveats that deserve some attention. The direct burden is only one channel through which a climate policy has distributional effects, and as discussed earlier, there are other factors that determine the overall incidence of a carbon tax or emissions trading system (Fullerton, 2009). For example, we do not consider the distribution of the benefits of a greenhouse gas policy. If low income groups have more to gain from a cap-and-trade program or a carbon tax, the 'net' incidence of the policy may actually be progressive; alternatively, if wealthier households have more to gain, the 'net' incidence may be even more regressive.

There are several other caveats from our analysis. First, producers were assumed not to change production choices, costs were assumed to be fully passed through to consumers, and consumers are assumed to be unresponsive to increased product prices. Other researchers have found that low-income consumers are more responsive to price increases of polluting goods such as gasoline (West and Williams, 2004). Depending on the price elasticity of demand for other energy-intensive products, this could reduce the regressivity of a price on carbon. Second, some of the costs may be borne by factors of production (Fullerton and Heutel, 2007). Environmental regulations may change real wages and returns to capital, which would change the optimal production inputs (and hence emissions) for various sectors, and the distribution of these costs across income groups affects the overall incidence of a price on carbon. Third, while we consider a broad price on carbon that takes into account all emissions, in practice a carbon tax or emissions trading system may have exemptions for emissions from some industries due to political considerations or high monitoring costs.

The regressive nature of the costs of a price on carbon could be alleviated (or eliminated) by carefully recycling revenues. This could be done by targeted transfers, financing cuts in regressive payroll or excise taxes, targeting income tax cuts at lower income groups, or by increasing spending on government programs targeted at lower income groups.

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