The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis

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This paper measures the direct and indirect incidence of a carbon tax using current income and two measures of lifetime income to rank households. Our results suggest that carbon taxes are more regressive when annual income is used as a measure of economic welfare than when lifetime income measures are used. Further, the direct component of the tax, in any given year, is significantly more regressive than the indirect component. We observe a modest shift over time with the direct component of carbon taxes becoming less regressive and the indirect component becoming more regressive. These effects mostly offset each other and the distribution of the total tax burden has not changed much over time. In addition we find that regional variation has fluctuated over the years of our analysis. By 2003 there is little systematic variation in carbon tax burdens across regions of the country.

1. INTRODUCTION

Economists have long argued that market based instruments are more efficient than regulations as a means of addressing the social damages arising from polluting activities. By market-based instruments we mean policies that force firms to "internalize" the cost of polluting activities. In the context of climate change arising from greenhouse gas (GHG) emissions, the polluting activity is the release of carbon dioxide and other greenhouse gases.[1] Carbon taxes and cap

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1. The major greenhouse gases include carbon dioxide, methane, nitrous oxide, and various fluorocarbons and other gases.

and trade systems are two examples of market based instruments that create a cost to emissions. A carbon tax does this directly by taxing the carbon content of fuels while a cap and trade system imposes a cost by requiring the surrender of valuable permits in proportion to the carbon content of fossil fuels.[2]

U.S. greenhouse gas emissions equaled 7,147 million metric tons of CO_2 equivalent ($MMCO_2e$) in 2005, an increase of 17 percent over 1990 levels. Carbon dioxide emissions account for the vast bulk of emissions and equaled 6008.6 $MMCO_2$ in that year. A consensus is emerging in the United States that climate change is a critical issue requiring a reduction in GHG emissions. Several bills have been proposed in the current Congressional legislative session (110th Congress, 2007 – 2008) to control greenhouse gas emissions.[3] And May 2007, President Bush called for the United States along with other major greenhouse gas emitting countries to "set a long-term goal for reducing greenhouse gases" (Stolberg (2007)). The recent releases of reports by Intergovernmental Panel on Climate Change Fourth Assessment Report's Working Groups provide additional evidence to support the role of anthropogenic warming.

A major concern with either a carbon tax or a cap and trade program to reduce emissions is that the burden of the costs arising from the policy will fall disproportionately on poorer households – or in the terminology of incidence analysis, the policies will be regressive.[4] Metcalf (1999, 2007) argues that even if a carbon tax is regressive, a carbon tax reform (combining a carbon tax with a revenue neutral reduction in some other tax) can be distributionally neutral or even progressive if desired.

In this paper, we focus on a related but different point. We measure to what extent a carbon tax is regressive in a lifetime income framework.[5] We also decompose the burden of the tax into direct and indirect components. The direct component measures household burdens from their direct consumption of fuels (gasoline, home heating, and electricity) while the indirect component measures the increase in the cost of other goods resulting from the higher fuel costs used in their production. We look at three different years, 1987, 1997, and 2003 to see how the incidence pattern would change had a carbon tax been in effect in these three time periods.

Our results suggest that in general, carbon taxes appear more regressive when income is used as a measure of economic welfare than when consumption (current or lifetime) is used to measure incidence. Measures based on current

2. While this analysis focuses on energy-related carbon emissions only, a carbon tax or cap and trade system can incorporate all greenhouse gases, typically by using the 100 year global warming potential coefficient for the various gases to convert to a CO_2 equivalent.

3. Paltsev et al. (2007) describe and conduct an economic analysis of climate mitigation scenarios based on these proposals.

4. The costs of a regressive policy as a share of income fall as income rises. The opposite holds for a progressive policy. We are focusing only on the higher costs of fossil fuels arising from the policies. We do not focus on the use of the funds from a carbon tax or from auctioning permits in this paper.

5. Without loss of generality we will frame the policy as a carbon tax. The analysis is identical for a cap and trade program where the permits are auctioned.

energy consumption can be misleading as retired persons have relatively low incomes and high energy consumption shares. Further, the direct component of the tax, in any given year, is more regressive than the indirect component. In fact, for 1987, the indirect component of the tax is actually mildly progressive as the higher income groups tend to pay a larger fraction of their income in carbon taxes. This is consistent with the observation that many luxury goods such as air travel are energy intensive while, in contrast, direct energy consumption is a necessity.

Studying the intertemporal distribution, we find that between 1987 and 2003, direct taxes have become marginally less regressive while indirect taxes have become marginally more regressive. As a result the distribution of the total tax burden has not changed much over time.

Carbon taxes are also thought to have uneven regional effects. We report the average carbon tax paid per household across regions and find that the regional variation is at best modest. By 2003 variation across regions is sufficiently small that one could argue that a carbon tax is distributionally neutral across regions. Not surprisingly much of the variation that we do observe arises from the direct carbon tax rather than the indirect tax. In other words, differences in electricity generation, driving patterns and weather conditions lead to the variation rather than the choice of energy intensive commodities in different regions.

In the next section, we explore different methods used to measure incidence and motivate the lifetime measure of consumption employed in Bull et al.(1994). Section III details our data and methodology. Section IV presents results for the economic incidence of the tax. Section V explores the geographic incidence of the tax. Section VI concludes.

2. MEASUREMENT OF INCIDENCE

Tax incidence measures the ultimate impact of a tax on the welfare of members of society. The economic incidence of a tax may differ markedly from the statutory incidence due to price changes. For a carbon tax, the short run economic incidence is likely to differ markedly from the statutory incidence. While the statutory incidence of an upstream tax on gasoline may be on the refinery owner, the economic incidence is likely to be on final consumers as the tax is shifted forward to consumers in the form of higher prices. Measuring the incidence of a tax requires numerous assumptions and we begin the analysis by setting out our assumptions and methodology.

First, we must determine the appropriate unit of observation, which could be an individual or a household. For this study, we use the household as a unit. Second, we must choose the appropriate time frame of analysis. As we discussed in the introduction, the choice of the time frame for the analysis is extremely important. Early tax incidence analysis used current income as the base i.e. it compared the tax liability over a short period to income earned over that period. Following Friedman (1957) and the permanent income hypothesis, there was a realization that consumption decisions are made over a longer time horizon. Hence income should be measured as the present discounted value of lifetime earnings and inheritances. Failing to do so creates substantial measurement problems, particularly at the low end of the income distribution. For example, elderly people drawing down their savings in retirement will look poor when in fact, they may be comfortably well off in a lifetime context. In other words, many low-income people are not necessarily poor.[6] Caspersen and Metcalf (1993) report cross tabulations on income and consumption that show that a large fraction of households are in consumption deciles substantially above their income deciles.

Poterba (1989) follows the approach of using current consumption as a proxy for permanent income, since if consumer behavior is consistent with the permanent income hypothesis, then consumers would set current consumption proportional to permanent income. However, as we mentioned earlier, using data from the 1987 Consumer Expenditure Survey, Bull et al. (1994) show that consumption, instead of being smooth, closely tracks current income over the life-cycle. Moreover, energy consumption also shows a marked lifetime pattern.

This could be problematic for the incidence measurement. Suppose that as people grow old their energy consumption becomes a larger share of their total consumption, and suppose, as well, that over a lifetime the energy tax has a proportional incidence, then using current consumption to measure lifetime income, the energy tax would appear regressive.

As an alternative to current consumption, we use an adjusted lifetime measure for consumption that is intended to correct for long-run predictable swings in behavior. This measure was first employed in Bull et al. (1994). Ideally, a lifetime measure of incidence would be constructed by taking the ratio of lifetime energy taxes to lifetime earnings. Unfortunately, the lack of any sufficiently long longitudinal panel data set precludes such an approach.[7]

To proxy for lifetime consumption, we therefore use the age profile of people sampled in a particular year by the Consumer Expenditure Survey (a more detailed description of the calculation is presented in Bull et al. (1994)). In particular, we first classify people into different subsamples based on their educational level, since the pattern of income and consumption will be quite different for people with vastly different human capital stocks. For each sub sample, we then calculate a "typical" path of consumption through the averages for the age groups. For a given person in the sub sample we know the ratio of their current consumption to the average for their age group. We then compute their lifetime consumption by multiplying this ratio by the present value of the typical lifetime path.

For example, suppose an individual is a 35-year-old PhD whose energy

6. Pechman (1985) realized that income data for the low income groups suffered from substantial income mismeasurement. Since then, the approach adopted by him and several others, including in this paper, is to discard the bottom half of the lowest decile i.e. to only look at the bottom 5-10 percent in the bottom decile, rather than the entire 10 percent.

7. The Panel Study of Income Dynamics (PSID) has good data on income but lacks detailed data on consumption which we would require. Other authors have used it to study the lifetime incidence of alcohol and cigarette taxes (Lyon and Schwab, 1995) and gasoline taxes (Chernick and Reschovsky, 1992).

consumption is 80 percent of the average for her age and education group. Let's say the present discounted value of total lifetime energy consumption for a person with a PhD is $80,000. Then for this individual, the imputed lifetime energy consumption is $64,000.

This procedure allows the age profile of each variable to be different. This flexibility helps to control for any confounding effects on the incidence calculation that predictable lifetime patterns of consumption behavior introduce in the cross-section. For example, suppose an alternative lifetime correction method was used where the share of consumption received at age 35 was used as the correction method. If 5 percent of consumption occurs on average at age 35 for a person in a given educational class, then that person's imputed lifetime consumption is 20 times their current consumption. Suppose that the lifetime incidence correction did not renormalize for each variable studied, but rather used the same correction factor for energy consumption. Then one would multiply current energy consumption by 20 to impute lifetime energy consumption. But if in reality, ten percent of energy consumption is spent on average at age 35 for a person in a given educational class, then that person's imputed lifetime energy consumption should be ten times their current energy consumption. Failing to renormalize the incidence correction for each of the variables studied in this example would incorrectly double lifetime energy consumption, biasing incidence results.

Using consumption as the base for measuring income also addresses the problem of transitory income shocks. For instance, a transitory negative shock to income may push the recipient into a lower income decile, while leaving their energy consumption unchanged. In this case, the ratio of energy taxes to income would be higher than it would be under a correct lifetime measure. Similarly, an upward shock to income may push the recipient into a higher income decile, while leaving their energy consumption unchanged. Here, the ratio of energy taxes to income is lower than it would be under a correct lifetime measure. The combination of these effects would lead an income-based lifetime incidence correction to be biased toward regressivity. When lifetime incidence is measured against consumption, however, such transitory effects are less likely to lead to bias, since energy consumption and total consumption are likely to react together to income shocks, if they react at all.

The final issue in an incidence analysis is the allocation of the tax burden between consumers and producers. Taxes on energy can be passed forward into higher consumer prices or backward in the form of lower returns to factors of supply (capital, labor, and resource owners). Our approach implicitly assumes that consumers bear the burden of the tax.

Considerable theoretical work has been carried out on the incidence of energy taxes in general, and of carbon taxes, in particular. A number of large-scale general equilibrium models (CGE models) suggest that in the short to medium run, the burden of a carbon tax will be mostly passed forward into higher consumer prices (See, for example, Bovenberg and Goulder (2001) and Metcalf et al. (2008)).

This result falls out of the models because the demand for carbon intensive fossil fuels is relatively inelastic in the short run, while the supply, which is determined globally, is relatively elastic. In the longer run, as consumers find substitutes for fossil fuels, demand would likely be more elastic, and more of the burden would be shifted back to the producers. To the extent that owners of natural resources and capital have higher incomes, our results will then, tend to overstate the regressivity of a carbon tax.

While the identification of the full long run effects of a carbon tax requires a dynamic CGE model, our approach has certain advantages. Most CGE models rely on a number of assumptions relating to the functional form of the production and demand functions and the parameters defining the elasticity of substitution between factors of production as well as the relevant demand elasticities. Our approach, in contrast, is fairly transparent, and likely yields an accurate estimate of the short run impact of a tax, which, in itself, may be an upper bound on the regressivity of the tax.

Another advantage of our approach is that we are able to work with far more disaggregated data than the typical CGE model. In general, these models allow for a limited number of industrial sectors and consumption goods for ease of exposition and computability. However, we are able to work with more than 50 industry and commodity groups and more than 40 consumer goods. We can explore regional variation in the incidence of the tax as well.[8]

Our analytic approach assumes no consumer behavioral response. Consumer substitution away from more carbon-intensive products will contribute to an erosion of the carbon tax base. The burden for consumers, however, will not be reduced as much as tax collections will fall. Firms incur costs to shift away from carbon-intensive inputs, costs that will be passed forward to consumers. Consumers also will engage in welfare-reducing activities as they shift their consumption activities to avoid paying the full carbon tax. Although the burden impacts reported here do not take account of the range of economic responses to the tax, the impacts provide a reasonable first approximation of the welfare impacts of a carbon tax.

3. METHODOLOGY AND DATA

For purposes of our analysis, we consider the effect of a carbon tax set at a rate of $15 per metric ton of carbon dioxide assuming it were in effect in three different years: 1987, 1997, and 2003.[9] This allows us to see how changing consumption patterns over time influence the distribution of the tax. Because we are considering a carbon tax in different years, we deflate the tax rate to keep it constant in year 2005 dollars. Using the CPI deflator, the tax rates we consider are

8. For those wishing to use our research as a jumping off point for more disaggregated CGE modeling, all data and programs are available at www.aei.org/carbontax.

9. The effect of a different tax rate on consumer goods prices can be approximated by appropriately grossing up (or down) Appendix Table 1.

\$8.73 in 1987, \$12.33 in 1997, and \$14.13 in 2003. The incidence calculations require two types of data. First, to assess the impact of the carbon tax on industry prices and subsequently on prices of consumer goods, we use the Input-Output matrices provided by the U.S. Bureau of Economic Analysis. Second, once we have the predicted price increases for the consumer goods, we need to assess incidence at the household level. For this, we used data from the U.S. Bureau of Labor Statistics Consumer Expenditure Survey for various years. In this section, we explain briefly our use of these two different data sets.

Energy related emissions of CO_2 were 4,821 million tons in 1987, 5,422 million tons in 1997, and 5,800 million tons in 2003. Given the tax rates and ignoring initial reductions in emissions, the tax would raise \$42.1 billion in 1987, \$66.9 billion in 1997, and \$82.0 billion in 2003.[10]

We assume the tax is levied on coal at the mine mouth, natural gas at the well head, and on petroleum products at the refinery. Imported fossil fuels are also subject to the tax. As noted above we assume in all cases that the tax is passed forward to consumers in the form of higher energy prices. Metcalf (2007) estimates that a tax of \$15 per metric ton of CO_2 applied to average fuel prices in 2005 would nearly double the price of coal, assuming the tax is fully passed forward. Petroleum products would increase in price by nearly 13 percent and natural gas by just under 7 percent. The tax is also passed on indirectly to other industries that use these energy sources as inputs.

The procedure for evaluating the effect of a carbon tax as it is passed through the economy is discussed in detail in Fullerton (1995) and Metcalf (1999). We provide a summary of the methodology in the Appendix. The starting point for the analysis is the use of Input-Output matrices available from the Bureau of Economic Analysis. In particular, we use the Summary Make and Use matrices from the I-O tables for 1987, 1997, and 2003. The Make matrix shows how much each industry makes of each commodity and the Use matrix shows how much of each commodity is used by each industry. Using these two matrices for each year, we derive an industry-by-industry transactions matrix which enables us to trace the use of inputs by one industry by all other industries. Various adding-up identities along with assumptions about production and trade allow the accounts to be manipulated to trace through the impact of price changes (and taxes) in one industry on the products of all other industries in the economy.

For each year, we cluster the industry groups provided in the I-O tables into 60 categories. For 2003, we separate out aggregate mining into two separate groups, mining and coal mining using the split provided in the 2002 benchmark I-O files. We do a similar split to break out electricity and natural gas from other utilities. This was not a problem for the 1987 and 1997 benchmark I-O files, where these splits already existed.

Once we obtained the effect of the tax on prices of consumer goods, we

10. An analysis by the Energy Information Administration suggests that a \$15 tax on CO_2 would reduce emissions by about five percent in the short-run (see Energy Information Administration (2006)).

used data from the Consumer Expenditure Survey (CEX) to compute energy taxes paid by each household in the survey. The CEX contains data on household income and expenditures for numerous consumption goods. We combine commodities to work with 42 categories of personal consumption items. Having computed the average price increase for each industry using the Input-Output tables from the Bureau of Economic Analysis, we translate those price increases into corresponding price increases for these consumer items. This is also discussed in detail in the Appendix, and we provide tables showing the recorded price increases in each year for each consumer item as a result of the tax.

While for most industries, the use of national input output tables to compute the average price increase is not problematic, this is not true of the electricity sector, where regional variation in fossil fuel usage for electricity generation may lead to very different price impacts across regions. To account for this, we used a separate methodology to compute the regional electricity price increases which is discussed in Appendix 3. The computed electricity price increases are also shown in Appendix Table 3.

4. RESULTS

Table 1 presents our results for incidence using annual income as our measure of economic welfare. We have grouped households by annual income and sorted the households into ten income deciles from the poorest ten percent of the population to the richest ten percent. Confirming conventional wisdom, the carbon tax is quite regressive when measured relative to current income for all three years. The burden in the lowest decile in 1997 and 2003, for example, is over four times the burden in the top decile when measured as a fraction of annual income.

Table 1. Distribution of Burden: Annual Income

Decile	1987			1997			2003		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Bottom	2.77	1.23	4.04	3.07	1.42	4.53	2.12	1.60	3.74
Second	2.18	1.10	3.29	2.25	1.19	3.47	1.74	1.31	3.06
Third	1.68	0.96	2.64	1.90	1.08	2.99	1.36	0.99	2.36
Fourth	1.59	0.84	2.45	1.52	0.89	2.42	1.19	0.88	2.06
Fifth	1.19	0.74	1.92	1.21	0.75	1.98	0.97	0.78	1.76
Sixth	1.02	0.66	1.69	1.00	0.69	1.69	0.85	0.68	1.53
Seventh	0.94	0.58	1.51	0.89	0.64	1.53	0.69	0.61	1.30
Eighth	0.83	0.57	1.40	0.78	0.56	1.34	0.61	0.63	1.23
Ninth	0.68	0.52	1.19	0.63	0.51	1.14	0.53	0.49	1.01
Top	0.53	0.49	1.01	0.43	0.43	0.85	0.36	0.45	0.81

Source: Authors' calculations. The table reports the within decile average ratio of carbon tax burdens to income

Table 1 shows that the overall burden distribution has not changed substantially across the sixteen year period when annual income is used to rank households. There is a slight flattening of the average tax rate curve across the three years. The burden has fallen by roughly one third of a percentage point in the bottom three deciles while only falling roughly two-tenths of a percentage point in the top three deciles. The overall burden is declining slightly over time from 1.54 percent of income in 1987 to 1.30 percent by 2003. This in part reflects the greater energy efficiency of the economy. Aggregate energy intensity in the United States (measured as energy consumption relative to real GDP) fell by 23 percent between 1987 and 2003.[11]

Table 1 also shows the burden of the direct and indirect components of the tax in the three years. The direct component of the tax is highly regressive – the average tax rate in the bottom decile is 5.2 times the average tax rate in the highest decile in 1987, 7.1 times in 1997 and 5.9 times in 2003. As with the total burden, the direct burden is declining slightly over the sixteen year period. The overall direct burden declines from 0.79 percent of income in 1987 to 0.73 percent in 1997 and to 0.58 percent by 2003.

The indirect burden is relatively constant over this time period. The regressivity of the indirect portion of the tax has increased slightly with the burden in the lowest decile rising from 2.5 times the burden in the top decile in 1987 to 3.6 times in 2003. That the indirect component of the tax is regressive but to a lesser extent than the direct component is consistent with the observation of Herendeen, Ford, and Hannon (1981) that indirect and direct energy consumption profiles differ in shape.

In summary, had a carbon tax been in effect in 1987, 1997, and 2003, the tax would have looked quite regressive using annual income as a measure of household well being. Using an annual income approach, the regressivity is increasing slightly over this time period. The overall burden falls a bit with the decline primarily attributable to declines in the direct burden of the tax.

Turning to the measures of incidence using consumption as a proxy for lifetime income, the results change dramatically. Table 2 shows the distribution of the carbon tax in the three years when households are sorted by current consumption. Now we find that the total carbon tax is less regressive, with the ratio of average taxes paid by the bottom and the top varying from about 1.7 to 2.0 across the three years. The primary force driving this result is the tendency for consumption to be more evenly distributed than income, especially when one looks at the lower brackets.[12]

The direct and indirect burdens also shown in Table 2 demonstrate that nearly all of this regressivity can be accounted for by the direct component of the tax, since the indirect component is roughly proportional between the top and bottom deciles. Even the direct component is less regressive than when we used

11. See Metcalf (2008) for an analysis of the determinants of changes in energy intensity.

12. This relationship is well known in the literature. Krueger and Perri (2002) for example, document this fact.

Table 2. Distribution of Burden: Current Consumption

Decile	1987			1997			2003		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Bottom	1.41	0.51	1.92	1.37	0.50	1.90	0.98	0.50	1.49
Second	1.37	0.50	1.89	1.18	0.50	1.68	0.92	0.49	1.41
Third	1.12	0.51	1.64	1.09	0.49	1.58	0.84	0.50	1.34
Fourth	1.09	0.52	1.61	0.95	0.51	1.46	0.79	0.50	1.29
Fifth	1.02	0.53	1.55	0.89	0.51	1.40	0.73	0.51	1.24
Sixth	0.91	0.55	1.46	0.82	0.51	1.34	0.65	0.52	1.16
Seventh	0.86	0.55	1.40	0.75	0.51	1.26	0.65	0.51	1.17
Eighth	0.75	0.56	1.31	0.66	0.51	1.17	0.54	0.53	1.07
Ninth	0.71	0.56	1.28	0.58	0.52	1.09	0.48	0.52	1.00
Top	0.57	0.57	1.14	0.46	0.51	0.97	0.37	0.52	0.89

Source: Authors' calculations. The table reports the within decile average ratio of carbon tax burdens to current consumption.

Table 3. Distribution of Burden: Lifetime Consumption

Decile	1987			1997			2003		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Bottom	1.11	0.52	1.63	1.14	0.52	1.61	0.67	0.50	1.16
Second	0.94	0.53	1.48	0.90	0.51	1.42	0.66	0.51	1.16
Third	0.96	0.53	1.49	0.85	0.50	1.36	0.76	0.51	1.24
Fourth	1.09	0.53	1.62	0.90	0.50	1.40	0.72	0.51	1.23
Fifth	1.05	0.53	1.59	0.91	0.51	1.42	0.81	0.50	1.30
Sixth	0.97	0.53	1.51	0.90	0.51	1.41	0.71	0.50	1.22
Seventh	0.95	0.53	1.49	0.87	0.51	1.37	0.66	0.51	1.18
Eighth	0.94	0.55	1.48	0.83	0.51	1.34	0.56	0.51	1.08
Ninth	0.73	0.55	1.28	0.71	0.51	1.22	0.49	0.53	1.02
Top	0.65	0.56	1.21	0.60	0.52	1.11	0.41	0.52	0.93

Source: Authors' calculations. The table reports the within decile average ratio of carbon tax burdens to lifetime consumption.

current income to construct average tax rates. This result was similarly reported in Bull, Hassett, and Metcalf (1994) who found that the lifetime calculation changed the results because the proportion of energy in total consumption (or ratio of energy consumption to income) varied significantly over the life cycle, with the elderly low income individuals, in particular, having relatively large current energy consumption. The ratio of direct taxes paid by the bottom and top deciles ranges between about 2.5 and 3.0 across the three years. This is nearly half the ratio when we used current income as the welfare measure. The indirect burden is slightly progressive in 1987 but becomes essentially proportional in the latter two years. Clearly, direct consumption has the characteristics usually associated with a necessity, while indirect consumption has a more varied distribution.

Turning to the measures of average tax burdens using lifetime consumption (Table 3), we see that this correction flattens the distribution even more. Indeed, the burden in 2003 is now slightly progressive over the bottom half of the income distribution. The incidence of the total carbon tax is nearly proportional, with the ratio of burden in the lowest to top decile varying from 1.2 to 1.5 across the three years. Both the direct and the indirect components of the tax are the least regressive using this measure. As with the current consumption proxy for lifetime income in 1987, the indirect tax using our lifetime income measure is marginally progressive.

In summary, incidence calculations based upon annual income imply much steeper regressivity than do calculations based upon lifetime income measures. Moreover, the inter-temporal variation in incidence is reduced substantially using measures based on lifetime consumption rather than those using income. We suspect this occurs in large part because transitory income shocks exacerbate the apparent regressivity of the tax when measured against income.

We next turn to a regional analysis of the incidence of the tax. Policy makers are often concerned that a tax might disproportionately burden one region or part of the country at the expense of another. To measure the geographic burden of the tax, we group households by region and measure their average tax rate using weighted averages of the tax burdens.[13] Results are shown in Table 4.[14] Variation in the average tax rates peaks in 1997 and is quite modest by 2003. The maximum difference in the average rate across regions is just 0.85 percentage points in 1987. The maximum difference rises to nearly 1.1 percentage points in 1997 and then falls to under one-half of a percentage point in 2003. It is quite remarkable how small the differences are across the regions given the variation in weather conditions and driving patterns across the regions.

The bulk of the variation across regions in carbon tax payments arises from the direct portion of the tax. A closer look at the data reveals that the high regional burden for the East South Central region for instance is due to the relatively higher consumption of gasoline per household in that region, relative to others. By itself, this would have lead to much larger burdens of the carbon tax on consumers in this region. However, the other direct energy consumption items such as natural gas, electricity and home heating oil even out the variation in the tax across regions to some extent. For instance, gas consumption is highest in East North Central, electricity in West South Central and home heating oil in New England.

13. As with the distributional tables for income, we drop the bottom five percent of the income distribution from the analysis before carrying out the regional analysis.

14. The states in each region are as follows: New England: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island; Midatlantic: New Jersey, New York, Pennsylvania; South Atlantic: West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida, District of Columbia, Maryland, Delaware; East South Central: Kentucky, Tennessee, Missouri, Alabama, Mississippi; East North Central: Wisconsin, Illinois, Michigan, Indiana, Ohio; West North Central: North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa; West South Central: Texas, Oklahoma, Arkansas, Louisiana; Mountain: Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico; Pacific: California, Oregon, Washington, Alaska, Hawaii.

Table 4: Regional Distribution of Burden: Annual Income

Region	1987			1997			2003		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
New England	0.89	0.73	1.59	0.82	0.64	1.43	0.73	0.76	1.47
Mid Atlantic	1.11	0.74	1.81	0.98	0.76	1.71	0.75	0.76	1.50
South Atlantic	1.22	0.72	1.90	1.22	0.80	1.98	0.87	0.77	1.62
East South Central	1.35	0.69	2.01	1.66	0.87	2.48	1.19	0.75	1.92
East North Central	1.23	0.71	1.91	1.08	0.75	1.79	1.05	0.76	1.79
West North Central	1.48	0.91	2.35	1.04	0.81	1.81	0.84	0.77	1.59
West South Central	1.35	0.79	2.11	1.61	0.82	2.39	1.08	0.78	1.84
Mountain	1.22	0.74	1.93	1.11	0.85	1.93	0.85	0.91	1.73
Pacific	0.81	0.71	1.50	0.74	0.69	1.40	0.74	0.81	1.54

Source: Authors' calculations. The table reports the within region average ratio of carbon tax burdens to income. Regions are defined in footnote 14.

The indirect results suggest that consumers in different regions of the country buy similar mixes of non-energy commodities. There is little variation across regions, with the highest burdens of the tax on households in the Mountain region, perhaps driven by greater use of cars and other means of transportation.

5. CONCLUSION

This paper measures the incidence of carbon taxes using a lifetime incidence framework. We analyze the household burden of a $15 per metric ton tax on CO_2 in constant 2005 dollars at three different points in time. The burden is measured ranking households by current income, current consumption and lifetime consumption as the basis for the incidence measures. The methodology involves first working with the economy-wide Input-Output tables from the Bureau of Economic Analysis to assess how the $15 tax would affect the industrial sector, in particular the prices of energy goods and other industrial goods in which these energy goods serve as inputs. We then use this information to calculate the increase in prices of consumer goods as a result of the tax. Once we obtain the price increase in 42 categories of consumer goods, we calculate the burden of the tax on households using consumption data from the Consumer Expenditure Survey.

As the paper discusses, energy taxes have different incidence effects across the lifecycle. Therefore, it is important to measure the burden of taxes in terms of lifetime incidence, not just their burden in a given year. To take account of the lifetime incidence, we use two proxies. First we use current consumption following work of Poterba (1989). Second we use lifetime-corrected consumption introduced in Bull et al. (1994) and explained in detail in the Appendix to that paper.

Our results suggest that when the total lifetime effect of a carbon tax is taken into account, the regressivity of the tax decreases. This is particularly true when we use lifetime-corrected consumption to rank households, rather than current consumption. While the direct tax effect continues to be regressive to varying extents depending upon the incidence measure we use, the indirect effect is much more proportional, thus mitigating the effect of direct taxes on total taxes. This is especially true for the year 1987 when the indirect tax appears to be mildly progressive.

In addition to looking at the economic incidence of the tax, we studied the incidence of the tax across regions. These data show that the variation across regions is relatively modest with the variation decreasing over time.

Our results suggest that a carbon tax is far less regressive than is generally assumed when the analysis is done on a lifetime basis. This suggests that concerns over the distributional impact of a shift to a carbon tax may be overstated. It should be emphasized that we have not addressed how the revenues of the tax are utilized, either to lower other taxes, reduce the deficit, or finance new spending. Metcalf (2007) presents an analysis of a carbon tax reform that is distributionally neutral when evaluated in an annual income framework. The results of this analysis suggest that such a reform may be progressive when analyzed in a lifetime income framework.

Our results also suggest an interesting area for future research. If a carbon tax applies only to indirect energy consumption, then it would be almost distributionally neutral, and accomplish that without any additional changes to the tax code. Future research should explore whether environmental objectives could be achieved with such a tax, and evaluate the other economic consequences of applying the tax to the indirect base only.

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APPENDIX

1. Using the Input-Output Accounts[15]

The Input-Output accounts trace through the production of commodities by industries and the use of those commodities by industries. The Bureau of Economic Analysis provides two kinds of matrices that help us to track such transactions through the economy. The Make-matrix, M_{IxC}, shows how much each industry makes of each commodity, and the Use-matrix, U_{CxI}, shows how much of each commodity is used by each industry. Combining these two, we can derive the industry-by-industry transactions matrix by dividing each entry of M_{IxC} by its column sum and multiplying the resulting matrix by the use matrix, U_{CxI}. Using the resulting matrix, it is possible to trace the use of inputs by one industry by all other industries. Further, it is also possible to trace through the impact of price changes in one industry on the products of all other industries in the economy. Below we detail some of the steps involved.

Tracing price changes through the economy on the basis of Input-Output accounts dates back to work by Leontief (1986). The model makes a number of important assumptions, the most important of which are (1) goods are produced and sold in a perfectly competitive environment such that all factor price increases are passed forward to consumers, (2) domestic and foreign goods are sufficiently different so that the price of domestic goods can adjust following changes in factor prices (Armington, 1969) and (3) input coefficients (the amount of industry *i* used in the production of industry *j*) are constant. Thus, input substitution is not allowed as factor prices change. This last assumption means that price responses are only approximate as they don't allow for product mix changes as relative prices change. In effect, the Input-Output accounts can be used to trace first-order price effects through the economy.

Two sets of equations define the basic Input-Output accounts. The first set relates the demand for goods from an industry to the value of output from that industry:

15. This section is based on based on Fullerton (1995) and Metcalf (1999).

$$\begin{aligned}
&x_{11}p_1 + x_{12}p_1 + ... + x_{1N}p_1 + d_1p_1 = x_1p_1 \\
&x_{21}p_2 + x_{22}p_2 + ... + x_{2N}p_2 + d_2p_2 = x_2p_2 \\
&. \\
&. \\
&. \\
&x_{N1}p_N + x_{N2}p_N + ... + x_{NN}p_N + d_Np_N = x_Np_N
\end{aligned} \tag{1}$$

Where x_{ij} is the quantity of the output from industry i used by industry j, p_i is the unit price of product i, d_i is the final demand for output i and x_i is the total output of industry i. These N equations simply say that the value of output from each industry must equal the sum of the value of output used by other industries (intermediate inputs) plus final demand. Without loss of generality, we can choose units for each of the goods so that all prices equal 1. This will be convenient as the expenditure data in the Input-Output accounts can then be used to measure quantities prior to any taxes that we impose.

The second set of equations relates the value of all inputs and value added to the value of output:

$$\begin{aligned}
&x_{11}p_1 + x_{21}p_2 + ... + x_{N1}p_N + v_1 = x_1p_1 \\
&x_{12}p_1 + x_{22}p_2 + ... + x_{N2}p_N + v_2 = x_2p_2 \\
&. \\
&. \\
&. \\
&x_{1N}p_1 + x_{2N}p_2 + ... + x_{NN}p_N + v_N = x_Np_N
\end{aligned} \tag{2}$$

Where v_i is value added in industry i. Define $a_{ij}=x_{ij}/x_j$, the input of product i as a fraction of the total output of industry j. The system [2] can be written as

$$\begin{aligned}
&(1-a_{11})p_1 - a_{21}p_2 - ..... - a_{N1}p_N = v_1/x_1 \\
&-a_{12}p_1 + (1-a_{22})p_2 - .... - a_{N2}p_N = v_2/x_2 \\
&. \\
&. \\
&. \\
&-a_{1N}p_1 - a_{2N}p_2 - .... - a_{NN}p_N = v_N/x_N
\end{aligned} \tag{3}$$

These equations can be expressed in matrix notation as

$$(I - A')P_1 = V \tag{3A}$$

Where I is an NxN identity matrix, A is an NxN matrix with elements a_{ij}, P_I is an $Nx1$ vector of industry prices, p_i, and V is the $Nx1$ vector whose ith element is v_i/x_i. Assuming that $(I - A')$ is nonsingular, this system can be solved for the price vector:

$$P_I = (I - A')^{-1} V \quad [4]$$

With the unit convention chosen above, P_I, will be a vector of ones. However, we can add taxes to the system in which case the price vector will now differ from a vector of ones as intermediate goods taxes get transmitted through the system. Specifically, let t_{ij} be a unit tax on the use of product i by industry j. In this case, the value of goods used in production (grossed up by their tax) plus value added now equals the value of output:

$$\begin{aligned}
&x_{11} p_1 (1 + t_{11}) + x_{21} p_2 (1 + t_{21}) + ... + x_{N1} p_N (1 + t_{N1}) + v_1 = x_1 p_1 \\
&x_{12} p_1 (1 + t_{12}) + x_{22} p_2 (1 + t_{22}) + ... + x_{N2} p_N (1 + t_{N2}) + v_2 = x_2 p_2 \\
&. \\
&. \\
&. \\
&x_{1N} p_1 (1 + t_{1N}) + x_{2N} p_2 (1 + t_{2N}) + ... + x_{NN} p_N (1 + t_{NN}) + v_N = x_N p_N
\end{aligned} \quad [5]$$

This set of equations can be manipulated in a similar fashion to the equations above to solve for the price vector:

$$P_I = (I - B')^{-1} V \quad [6]$$

where B is an NxN matrix with elements $(1+t_{ij})a_{ij}$.

We regrouped industries in the Input-Output Accounts into 60 industry groupings. For the years 2003 and 1997, a separate industry for coal mining was created out of the industry group including all mining. This was done using the split between mining and coal provided in the 1994 benchmark Input-Output accounts. For the year 1987, we used the benchmark Input-Output table which already has coal mining as a separate industry.

Tax rates are computed as the ratio of the required tax revenue from the industry divided by the value of output from that industry. For the carbon tax, the tax rate on coal equals

$$t_{4.} = \frac{\alpha_C R}{\sum_{j=1}^{N} x_{4j}} \quad [7]$$

where R is the total revenue from the carbon tax and α_C the share of the tax collected from the coal industry (industry 4). Based on carbon emissions in 2003, the share of the tax falling on the coal industry is 0.361. The taxes for oil and natural gas are computed in a similar manner.

Equation [6] indicates how price changes in response to the industry level taxes. We next have to allocate the price responses to consumer goods. The Input-Output accounts provide this information by means of the Personal Consumption Expenditures (PCE) Bridge tables for each year that show how much of each consumer item is produced in each industry. Let Z be an NxM matrix, where z_{ij} represents the proportion of consumer good j $(j=1,..,M)$ derived from industry i $(i=1,....,N)$. The columns of Z sum to 1. An example of the Z-matrix is provided in Appendix Table 2 for a subset of consumer goods. If P_c is a vector of consumer goods prices (an $Mx1$ vector), then

$$P_C = Z'P_1 \qquad [8]$$

The consumer prices derived using this methodology are then applied to consumption data in the CEX. The consumer prices derived using this methodology are provided in Appendix Table 1 for all three years.

Appendix Table 1. Consumer Goods Price Increases as a Result of the Carbon Tax

	CEX categories	1987	1997	2003
1	food at home	0.57%	0.65%	0.70%
2	food at restaurants	0.47%	0.56%	0.58%
3	food at work	0.61%	0.75%	0.86%
4	tobacco	0.54%	0.60%	0.67%
5	alcohol at home	0.47%	0.56%	0.58%
6	alcohol on premises	0.47%	0.56%	0.58%
7	clothes	0.53%	0.52%	0.40%
8	clothing services	0.75%	0.38%	0.41%
9	jewelry	0.54%	0.45%	0.43%
10	toiletries	0.87%	0.85%	0.72%
11	health and beauty	0.70%	0.38%	0.42%
12	tenant occupied non-farm dwellings	0.14%	0.21%	0.31%
13	other dwelling rentals	0.65%	0.41%	0.42%
14	furnishings	0.64%	0.62%	0.55%
15	household supplies	0.78%	0.77%	0.71%
16	electricity	10.18%	13.15%	12.55%
17	natural gas	16.87%	16.61%	12.28%
18	water	1.20%	0.73%	0.63%
19	home heating oil	7.67%	10.33%	9.56%
20	telephone	0.20%	0.21%	0.26%
21	domestic services	0.70%	0.41%	0.49%
22	health	0.44%	0.37%	0.39%
23	business services	0.14%	0.21%	0.50%
24	life insurance	0.28%	0.21%	0.31%
25	automobile purchases	0.67%	0.59%	0.90%
26	automobile parts	0.70%	0.64%	0.65%
27	automobile services	0.75%	0.34%	0.40%
28	gasoline	9.67%	7.64%	7.73%
29	tolls	0.65%	0.30%	0.64%
30	automobile insurance	0.14%	0.21%	0.31%
31	mass transit	0.95%	0.70%	0.90%
32	other transit	0.96%	0.50%	0.62%
33	air transportation	1.93%	1.82%	1.86%
34	books	0.43%	0.32%	0.34%
35	magazines	0.45%	0.31%	0.49%
36	recreation and sports equipment	0.52%	0.56%	0.42%
37	other recreation services	0.60%	0.36%	0.51%
38	gambling	0.39%	0.28%	0.31%
39	higher education	0.56%	0.27%	0.30%
40	nursery, primary and secondary education	0.60%	0.33%	0.34%
41	other education services	0.62%	0.26%	0.30%
42	charity	0.74%	0.43%	0.41%

Notes: 1. Values for alcohol have been set equal to the value for food on premises in each year.
2. These price increases are calculated using a tax of $15 per metric ton of carbon dioxide.

Appendix Table 2. Bridge Matrix For 2003 For a Sub-Set of Consumption Goods

Industry Groups	Food at Home	Food at Restaurants	Food at Work	Tobacco products	Clothes	Clothing Services
Farms	0.0436	0.0000	0.0469	0.0000	0.0000	0.0000
Forestry, fishing, and related activities	0.0048	0.0000	0.0035	0.0000	0.0000	0.0000
Oil and gas extraction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Coal Mining	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mining, except oil and gas	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Support activities for mining	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Electric Utilities	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Natural Gas Utilities	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other Utilities	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Food and beverage and tobacco products	0.5204	0.0000	0.7894	0.5768	0.0000	0.0000
Textile mills and textile product mills	0.0000	0.0000	0.0000	0.0000	0.0056	0.0000
Apparel and leather and allied products	0.0000	0.0000	0.0000	0.0000	0.4085	0.0000
Wood products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Paper products	0.0000	0.0000	0.0000	0.0000	0.0091	0.0000
Printing and related support activities	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Petroleum and coal products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Chemical products	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000
Plastics and rubber products	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
Nonmetallic mineral products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

2. A Lifetime-Corrected Incidence Measure

This section presents our derivation of the lifetime-corrected incidence measure. The starting point is the assumption that the expected consumption and income streams for people with vastly different human capital stocks are likely to be very different. Hence we first classify people into different sub samples based on their education levels. Within each education class, we then calculate average consumption for people in different age groups. The "typical" path of lifetime consumption can therefore be proxied by the average consumption for each age group within an education class, starting from the youngest to the oldest. Using this path of lifetime consumption, we then derive the present value of lifetime consumption for each education class.

Once we have the present value of lifetime consumption for each education class, we can use this to derive the lifetime consumption for any individual in the sample. For instance, suppose that an individual is a 35 year old Ph.D whose current consumption is 80 percent of the average for her age and education group. If the present value of lifetime consumption for a Ph.D is \$1 million, then her lifetime consumption is calculated as 80 percent of \$1 million or \$800,000. We can use a similar technique to derive lifetime measures of income, direct and indirect taxes for every individual in the sample. Below, we present the mathematical derivation of our lifetime measures.

For each observation in the CEX sample, we know the age and education level. We first assign each observation to a particular education group, *e*, where *e* goes from 1 to 11 (1=no schooling, 11=doctorate). Then within the education group, we calculate the average of consumption for different age groups, *a*. We include all individuals above 20 years of age. Let $\overline{C}^a(e)$ be the average consumption for all individuals in education group *e* and age *a*. (We can similarly define $\overline{Y}^a(e)$, $\overline{D}^a(e)$ and $\overline{I}^a(e)$, respectively for income, direct taxes and indirect taxes).

Let $\hat{C}(e)$ denote the present value of lifetime consumption for all individuals in the same education group. This is derived as the present discounted value of average consumption across all age groups within the same education group, as shown below.

$$\hat{C}(e) = \sum_{a=a_o}^{A} \left(\frac{1}{1+r}\right)^{(a-a_0)} \overline{C}^a(e)$$

where $a_o = 20$, A is the highest age group and r=5%.

To compute the lifetime consumption for each individual, we take the ratio of their actual consumption, $C_i^a(e)$, to the average for their age and education group, and then multiply this ratio by the computed present value of lifetime consumption for their education class. Therefore,

$$\hat{C}_i^{\,a}(e) = \frac{C_i^a(e)}{\overline{C}^a(e)} \hat{C}(e)$$

We can compute similar measures for income ($\hat{Y}^a(e)$), direct ($\hat{D}^a(e)$) and indirect taxes ($\hat{I}^a(e)$).

Finally, we can compute the lifetime-corrected incidence of direct carbon taxes as a proportion of consumption as follows;

$$\lambda_{D_i}^a(e) = \frac{\hat{D}_i^{\,a}(e)}{\hat{C}_i^{\,a}(e)}$$

Similar measures can be computed for the lifetime-corrected incidence of indirect and total carbon taxes.

To compute the incidence across income or consumption groups, we can repartition the sample into deciles of lifetime income or consumption and then take the average across each decile of the incidence for members of that decile.

3. Methodology for Computing Regional Electricity Price Increases

For most industries, the use of national rather than regional input-output tables to model the impact of a carbon tax will make little difference to the analysis. However, for the electricity industry, the price changes due to a carbon tax could vary considerably from region to region. In states with a lot of coal fired generation, costs will go up by more than those where generation is largely gas-fired or hydro powered. To account for this in our analysis, we obtained additional data on electricity generation, emissions and pricing from Dallas Burtraw et al. (2002). These data are available for the 13 NERC sub regions for various years.[16] These regions cover the entire nation, except the states of Hawaii and Alaska. For our study, we used the years closest to our years of analysis. For 1997 and 1987, we used data from 1998, and for 2003, we used data from 2004. The price data were inflation adjusted to reflect values for the year for which the analysis was being performed.

The data show the extent of carbon emissions involved in electricity generation. To obtain the regional price impacts, we first transformed the carbon emissions data for each region into carbon dioxide emissions by multiplying by 44/12. Then we applied the tax rate for each particular year to the emissions for that year for each region. For instance, in 1987 the total CO_2 emissions for the ECAR region covering Michigan, Indiana, Ohio, West Virginia and Kentucky were 479.66 MMT. To this, we applied the CO2 tax of $8.73 per metric ton of CO_2, to yield total carbon tax revenue for this region of $4187.42 million. The total electricity generation for the ECAR region for that year was 553.80 million MWH, yielding revenue per MWH as $7.56. As a fraction of the residential price of electricity that year, $49.04, we conclude that the carbon tax would increase the

16. These are the 13 NERC sub regions as they were defined in 1999: ECAR, ERCOT, MAAC, MAIN, MAPP, NY, NE, FRCC, STV, SPP, NWP, RA, CNV. Recently, some of the regions have been combined bringing the total to about 10. For a map of the different regions, see http://www.rff.org/Documents/RFF-RPT-haiku.pdf (Page 2)

price of electricity for residential consumers by more than 15 percent.[17] We did this for each region (and each year) to obtain the corresponding price increase for that region. Appendix Table 3 shows the computed electricity price increases for each of the NERC sub regions as a result of the carbon tax.

Once we obtained these price increases, we then computed the carbon tax for each individual in the CEX by allocating to them the electricity price increase for the region that they belonged to, along with the national price increases for all the other industries.[18] The incidence calculations using this methodology show the carbon tax to be slightly more regressive than when we used the national electricity price increases.

Appendix Table 3. Regional Electricity Price Increases Due to Carbon Tax

NERC Region	States Covered	1987	1997	2003
ECAR	Michigan, Indiana, Ohio, West Virginia, Kentucky	15.59%	20.14%	20.86%
ERCOT	Texas	13.02%	16.82%	14.41%
MAAC	Maryland, DC, Delaware, New Jersey, Pennsylvania	7.98%	10.31%	9.40%
MAIN	Illinois, Wisconsin, Missouri*	6.55%	8.46%	16.12%
MAPP	Minnesota, Iowa, Nebraska, South Dakota, North Dakota	15.51%	20.03%	21.67%
NY	New York	4.75%	6.14%	4.23%
NE	Vermont, New Hampshire, Maine, Massachusetts, Connecticut, Rhode Island	5.61%	7.25%	5.01%
FRCC	Florida	11.29%	14.59%	11.12%
STV	Tennessee, Alabama, Georgia, South Carolina, North Carolina, Virginia, Mississippi	11.40%	14.73%	14.52%
SPP	Kansas, Missouri*, Oklahoma, Arkansas, Louisiana	13.41%	17.32%	13.59%
NWP	Washington, Oregon, Idaho, Utah, Montana	6.22%	8.04%	9.11%
RA	Arizona, New Mexico, Colorado, Wyoming	12.37%	15.98%	12.82%
CNV	California, Nevada	3.94%	5.09%	5.17%

* Missouri is a part of MAIN and SPP. We have approximated this by allocating half of the total electricity consumption for the state to each of the two regions.

17. The electricity price impacts were rescaled to match the national electricity price increase that we obtained from our input-output analysis.

18. Since we have missing state identifiers for some observations in the CEX sample, we were unable to allocate the regional price impacts to these observations. In this case, the electricity price increase was assumed to be the same as the national price increase (Appendix Table 1).