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ANALYTICAL GENERAL EQUILIBRIUM EFFECTS OF ENERGY POLICY ON OUTPUT AND FACTOR PRICES

Don Fullerton
Garth Heutel

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ABSTRACT

Using an analytical general equilibrium model, we find closed form solutions for the effect of energy policy on factor prices and output prices. We calibrate the model to the US economy, and we consider a tax on carbon. By looking at expenditure and income patterns across household groups, we quantify the uses-side and sources-side incidence of the tax. When households are categorized either by annual income or by total annual consumption as a proxy for permanent income, the uses-side incidence is regressive. This result is robust to sensitivity analysis over various parameter values. The sources-side incidence is also regressive, but this result is sensitive to parameter values. Incidence results across regions are also presented.

Don Fullerton
Department of Finance
University of Illinois
BIF Box#30 (MC520)
515 East Gregory Drive
Champaign, IL 61820
and NBER
dfullert@illinois.edu

Garth Heutel
Department of Economics
University of North Carolina at Greensboro
PO Box 26165
Greensboro, NC 27402-6170
gaheutel@uncg.edu

Energy is an integral input to nearly all aspects of our economy. Energy policies, especially policies aimed at curbing greenhouse gas emissions associated with energy consumption, thus have sizable effects on nearly all participants in our economy. The distribution of these effects, both costs and benefits, across participants is an important consideration of policy design.

The incidence of the costs of energy or climate policy manifests itself in at least two major ways. First, policy affects the “uses side” of income, through product prices. A carbon tax may disproportionately increase the price of gasoline and electricity, two goods that represent a higher share of expenditure for poorer households. The uses side incidence is then regressive. Second, policy affects the “sources side” of income, through factor prices. A carbon tax may be more burdensome to capital-intensive industries and disproportionately reduce the return to capital. If so, and if capital provides a higher share of income for richer households, then the sources side incidence may be progressive.

Many studies of the distributional impacts of climate or energy policy focus on the uses side only, through a partial equilibrium approach. The purpose of this paper is to analyze both the uses side and the sources side incidence of domestic climate policy using an analytical general equilibrium model with closed form solutions that highlight conceptual issues by showing the general effects of each parameter on each result.

Our model is based on the standard (Harberger 1962) tax incidence model, with two factors of production (labor and capital) and two sectors of production (a "dirty" or non-polluting sector and a "clean" sector). We add pollution, modeled as a third input to production in the dirty sector. In earlier papers, we show analytically how output prices and the returns to capital and labor are affected by changes in several types of pollution policy, including a pollution tax, tradable permits, performance standards, or technology mandates.

In this paper, we quantify those analytical results numerically. We calibrate the model to the US economy, and we consider effects of carbon policy. We solve for the impacts on the prices of carbon-intensive goods relative to clean goods, and on the wage and the capital rental rate. Then, using data on households' expenditure patterns and income sources, we use these solutions to calculate the distribution of uses side and sources side costs across income groups and regions.

When families are categorized either by annual income or by total annual consumption, the uses-side incidence of a carbon tax is regressive. Lower-income households spend a higher fraction of their expenditures on carbon-intensive goods than do higher-income households. This result is robust and corroborates many other papers (Burtraw, Sweeney and Walls 2009), (Hassett, Mathur and Metcalf 2009). On the sources side, the incidence results are sensitive to the chosen parameter values. In particular, the regressivity or progressivity on the sources side depends on the elasticities of substitution in production for polluting industries. These elasticities have not been estimated, and thus we present incidence calculations for several alternative values. When categorized by region, the uses-side incidence is again robust; regions that spend more than average on carbon-intensive goods bear a disproportionately high burden (especially the Midwest and the South). The sources-side incidence again depends on substitution elasticity values.

A disadvantage of our methodology lies in its aggregation to only two sectors and two or three factors of production. A more disaggregated model could be more realistic and could be used to calculate more specific effects on prices of each different good and factor. However, more disaggregation and other features would require a computer to solve for results numerically. For us, the aggregation and other simplifications provide the advantage that we can derive analytical solutions for general equilibrium effects on both output and factor prices that hold for any parameters in the model, not just for particular numerical implementations.

The next section presents the model and analytic solutions. Section 2 describes the calibration, and section 3 presents the simulation results.

1. Model

This model is based on an earlier one (Fullerton and Heutel 2007), which itself is an extension of Harberger (1962). We briefly summarize the model here.

The economy consists of two sectors producing two different final goods. One sector, X, uses only capital K_X and labor L_X as inputs; it is labeled the clean sector. The dirty sector, Y, uses both capital and labor (K_Y and L_Y) and a third input, pollution (Z). Production functions have constant returns to scale, but otherwise no particular functional form:

$$X = X(K_X, L_X)$$

$$Y = Y(K_Y, L_Y, Z).$$

Total capital and labor resources are fixed:

$$K_X + K_Y = \overline{K},$$
$$L_X + L_Y = \overline{L}.$$

By totally differentiating these two constraints, we get:

$$\hat{K}_X \lambda_{KX} + \hat{K}_Y \lambda_{KY} = 0, \tag{1}$$
$$\hat{L}_X \lambda_{LX} + \hat{L}_Y \lambda_{LY} = 0, \tag{2}$$

where variables with a hat denote a proportional change (e.g. $\hat{K}_X = dK_X/K_X$), and where λ_{ij} denotes sector j's share of factor i (e.g. $\lambda_{KX} = K_X/\overline{K}$).

Producers of the clean good X face a rental price for capital (r) and a wage price for labor (w). Their factor demand choices are defined by their elasticity of substitution in production, σ_X:

$$\hat{K}_X - \hat{L}_X = \sigma_X(\hat{w} - \hat{r}). \tag{3}$$

Producers of the dirty good Y face prices for all three of their inputs. Their factor demand choices can be defined in terms of Allen elasticities of substitution between their inputs, e_{ij}, and revenue shares of inputs, $\theta_{YK} = rK_Y/p_YY$. These relationships follow (Mieszkowski 1972) and (Allen 1938):

$$\hat{K}_Y - \hat{Z} = \theta_{YK}(e_{KK} - e_{ZK})\,\hat{r} + \theta_{YL}(e_{KL} - e_{ZL})\,\hat{w} + \theta_{YZ}(e_{KZ} - e_{ZZ})\,\hat{\tau}_Z, \tag{4}$$
$$\hat{L}_Y - \hat{Z} = \theta_{YK}(e_{LK} - e_{ZK})\,\hat{r} + \theta_{YL}(e_{LL} - e_{ZL})\,\hat{w} + \theta_{YZ}(e_{LZ} - e_{ZZ})\,\hat{\tau}_Z. \tag{5}$$

Assuming perfect competition and constant returns to scale in production yields zero profit conditions that can be differentiated to get:

$$\hat{p}_X + \hat{X} = \theta_{XK}(\hat{r} + \hat{K}_X) + \theta_{XL}(\hat{w} + \hat{L}_X), \tag{6}$$
$$\hat{p}_Y + \hat{Y} = \theta_{YK}(\hat{r} + \hat{K}_Y) + \theta_{YL}(\hat{w} + \hat{L}_Y) + \theta_{YZ}(\hat{Z} + \hat{\tau}_Z). \tag{7}$$

Totally differentiating each sector's production function and using the assumption of perfect competition yields:

$$\hat{X} = \theta_{XK}\hat{K}_X + \theta_{XL}\hat{L}_X, \tag{8}$$
$$\hat{Y} = \theta_{YK}\hat{K}_Y + \theta_{YL}\hat{L}_Y + \theta_{YZ}\hat{Z}. \tag{9}$$

Lastly, we model consumer preferences for the two goods with the elasticity of substitution in utility, σ_u:

$$\hat{X} - \hat{Y} = \sigma_u(\hat{p}_Y - \hat{p}_X). \tag{10}$$

These ten equations constitute the model. Because the model has eleven unknowns, we choose good X as numeraire, setting $\hat{p}_X = 0$. Then, the system of equations can be solved to consider how an exogenous change in the pollution tax τ_Z affects factor prices w and r and output prices, given by p_Y. The choice of normalization means that all price changes are relative to the price of X. Thus, if $\hat{p}_Y > 0$, the price of good Y increases relative to the price of good X, so consumers who spend more than average on good Y are burdened relatively more than are other consumers on the uses side. Furthermore, the normalization implies that $\hat{w}$ and $\hat{r}$ are always of opposite sign (subtract equation (8) from equation (6)). Sector X has only two inputs, so if one input price rises then the other must fall for those firms to break even, with no change in output price. Yet, this does not imply that owners of one factor will gain and owners of the other will lose. Rather, if $\hat{w} > 0$ and $\hat{r} < 0$, it means that the burden on capital is proportionally greater than capital's share in national income.

The model's solution for output and factor prices is presented below.[1] See our earlier paper for the steps to derive this solution (Fullerton and Heutel 2007).

$$\hat{p}_Y = \frac{(\theta_{YL}\theta_{XK} - \theta_{YK}\theta_{XL})}{D}[A(e_{ZZ} - e_{KZ}) - B(e_{ZZ} - e_{LZ}) + (\gamma_K - \gamma_L)\sigma_u]\hat{\tau}_Z + \theta_{YZ}\hat{\tau}_Z$$

$$\hat{w} = \frac{\theta_{XK}\theta_{YZ}}{D}[A(e_{ZZ} - e_{KZ}) - B(e_{ZZ} - e_{LZ}) + (\gamma_K - \gamma_L)\sigma_u]\hat{\tau}_Z$$

$$\hat{r} = \frac{\theta_{XL}\theta_{YZ}}{D}[A(e_{KZ} - e_{ZZ}) - B(e_{LZ} - e_{ZZ}) - (\gamma_K - \gamma_L)\sigma_u]\hat{\tau}_Z$$

These equations use several additional definitions for convenience. Let $\gamma_K \equiv \lambda_{KY}/\lambda_{KX} = K_Y/K_X$ and $\gamma_L \equiv \lambda_{LY}/\lambda_{LX} = L_Y/L_X$, $A \equiv \gamma_K\gamma_L + \gamma_L\theta_{YK} + \gamma_K(\theta_{YL} + \theta_{YZ})$, $B \equiv \gamma_K\gamma_L + \gamma_K\theta_{YL} + \gamma_L(\theta_{YK} + \theta_{YZ})$, and $D \equiv (\theta_{XK}\gamma_K + \theta_{XL}\gamma_L + 1)\sigma_X + A[\theta_{XK}\theta_{YL}(e_{KL}–e_{LZ})–\theta_{XL}\theta_{YK}(e_{KK}–e_{KZ})] – B[\theta_{XK}\theta_{YL}(e_{LL}–e_{LZ})–\theta_{XL}\theta_{YK}(e_{KL}–e_{KZ})] – (\gamma_K – \gamma_L)\sigma_u(\theta_{XK}\theta_{YL} – \theta_{XL}\theta_{YK})$.

We briefly identify and interpret the effects present in these rather complex equations. In the equations for the factor price changes, $\hat{w}$ and $\hat{r}$, the last term in the bracket, $(\gamma_K - \gamma_L)\sigma_u$,

[1] We omit closed-form expressions for the remaining seven endogenous variables, including the change in pollution ($\hat{Z}$), since our focus here is on incidence through price changes.

represents the "output effect." The expression $(\gamma_K - \gamma_L)$ is positive whenever the dirty sector is capital-intensive. If so, assuming the denominator is positive ($D > 0$), then an increase in the pollution tax ($\hat{\tau}_Z > 0$) will tend to decrease the return to capital r relative to the wage w. The extent to which capital is burdened depends both on $(\gamma_K - \gamma_L)$, the degree of capital intensity, and σ_u, the consumer's ability to substitute away from the taxed sector's output.

The first two terms in the bracket of the equations for factor price changes represent "substitution effects." The sign of these terms depends on the values of the Allen elasticities e_{ij}. In the case of equal factor intensities where the output effect disappears, it can be shown that the substitution effect burdens capital more than it burdens labor whenever $e_{LZ} > e_{KZ}$, that is, whenever labor is a better substitute for pollution than is capital. When the price of emissions rises, and a firm wants to reduce emissions, it may do so and retain the same output level by altering its labor and capital inputs. If it increases labor more than it increases capital, then we say that labor is a better substitute for pollution than is capital. For example, a firm may switch from operating capital machinery that creates pollution and toward using more relatively clean labor inputs.

In the equation for $\hat{p}_Y$, the final term is $\theta_{YZ}\hat{\tau}_Z$. This term represents a "direct" effect from an increased pollution tax: the increased cost of the pollution input is passed into the output price in proportion to pollution's share in production, θ_{YZ}. The rest of the expression represents all of the general equilibrium effects, or "indirect" effects, affecting the output price, including output effects and substitution effects described above.

II. Calibration

We now calibrate this model to the US economy in a way that allows us to consider a tax on carbon dioxide (CO_2). Our model only has two sectors, so we must decide which industries of the economy are aggregated under the dirty sector and which under the clean. Because CO_2 is emitted in the generation of electricity, an intermediate input used by all industries, no output is completely "clean" as is output X in this model. Instead, we choose to label as the dirty industries those that emit the most CO_2 relative to their output.

For information on factor intensities by industry we use data from Jorgenson, et al (2008).[2] These data divide the US economy into 35 sectors (roughly corresponding to two-digit

[2] Available at http://www.economics.harvard.edu/faculty/jorgenson/.

SIC codes). They present the value of capital and labor inputs for each sector through 2006. Most CO_2 emissions come from three industries: electricity generation (38.7%), transportation (30.6%), and manufacturing (23.3%).[3] Of manufacturing industries, the highest emitter of CO_2, both absolutely and as a fraction of the value of output, is petroleum refining.[4] We use our data to isolate this manufacturing sector, along with electricity and transportation. We include these in the dirty sector, and all remaining industries are aggregated to the clean sector.

These definitions give us total factor inputs of labor and capital in the clean and dirty sectors. One more datum is needed to determine the factor intensity parameters, and that is θ_{YZ}, the share of sector Y's output that derives from pollution. Since polluting industries do not pay an explicit price for CO_2 emissions, this parameter cannot be calibrated from data. Instead, we calibrate it based on estimates of the optimal price on carbon from prior papers. A price of $15 per metric ton of CO_2 is often recommended, and we thus use this price as a starting point (Hassett, Mathur and Metcalf 2009). The value of θ_{YZ} is 0.0723, based on this price and our definition of the dirty sector of the economy.[5]

That calibration and the data from Jorgenson et. al. (2008) jointly determine the factor intensity parameters shown in Table 1. Without loss of generality we define a unit of each good as the amount that sells for $1 in the initial equilibrium. The total factor income of the economy $(\bar{K} + \bar{L})$ is also normalized to one. Using these parameters, the clean sector represents about 93% of factor income of the economy. The dirty sector is relatively capital-intensive. Labor accounts for about 61% of total factor income.

Table 1: Base Case Factor Intensity Parameters

$K_Y = 0.0375$	$L_Y = 0.0291$
$K_X = 0.3515$	$L_X = 0.5819$
$\lambda_{KY} = 0.0963$	$\lambda_{LY} = 0.0477$
$\lambda_{KX} = 0.9037$	$\lambda_{LX} = 0.9523$
$\theta_{YK} = 0.5220$	$\theta_{YL} = 0.4057$
$\theta_{XK} = 0.3765$	$\theta_{XL} = 0.6235$
$\theta_{YZ} = 0.0723$	

[3] See http://www.epa.gov/climatechange/emissions/downloads09/ExecutiveSummary.pdf, Table ES-2.
[4] See http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/industry_mecs.pdf, Table 1. Petroleum refineries emitted 277.6 million metric tons of CO_2 in 2005; the next highest manufacturing industry group was iron and steel mills with 126.0 million metric tons. As a fraction of output, the petroleum industry's emissions are 30% higher than the next highest industry (primary metals).
[5] Total U.S. GNP in 2008 is $14.3 trillion. Our definition of the dirty sector accounts for 6.7% of total factor income, or $0.954 trillion. Annual carbon dioxide emissions from the dirty sector total 4.589 billion metric tons. At $15 per metric ton, the value of these carbon emissions is $68.8 billion, or 7.23% of the value of the dirty sector.

The elasticity of substitution in production for the clean sector, σ_X, is set to one. This value is consistent with estimates of the economy-wide elasticity, and since the clean sector is 93% of the economy, it is a decent approximation of the elasticity we seek. In the "base case", we also set the elasticity of substitution in consumption, σ_u, to one.

The last set of parameters needed are the Allen elasticities of substitution in production for the dirty sector, e_{ij}. Only three of these can be set independently; the rest are determined by these three values and the factor intensities, using equations from Allen (1938). We know of no studies that have estimated these cross-price elasticities directly. Some studies, however, have estimated elasticities between inputs of capital, labor, and energy inputs (including fossil fuels). Using data from Western European countries and reviewing the literature, (de Mooij and Bovenberg 1998) find preferred estimates of $e_{KL} = 0.5$, $e_{KZ} = 0.5$, and $e_{LZ} = 0.3$. These suggest that capital is a slightly better substitute for pollution than is labor. We use these values in our base case, and we vary them to test the sensitivity of results.

Our aggregated model gives us the change in input and output prices for any given policy change. We want to translate those aggregate price changes into effects on real people, to calculate the uses- and sources-side incidence of the policy. To do so, we gather data on the expenditure and income of households with various demographic characteristics. For example, we divide all households into ten deciles by income. For each decile, we calculate the fraction of expenditures on clean vs. dirty goods, and we calculate the fraction of income from capital vs. labor. We can then quantify the burden of this policy change on each group.

We use expenditure and income tabulated data from the 2008 Consumer Expenditure Survey (CEX).[6] The CEX data come from a representative sample of the U.S. population. These micro-level data provide information on expenditures and income sources. We can define groups numerous ways, such as by annual income, race, and region of residence. For each group (say, the lowest income decile), we can calculate the average expenditure on fairly detailed categories, including foods of various types (beef, pork, etc.), housing (mortgage interest, property tax, rent, etc.), and clothing (mens, womens, footwear, etc.). We also can calculate for each group the distribution of income sources, including income from wages and salaries, self-employment, and interest, dividends, rental income, and other property income. We do not

[6] Available at http://www.bls.gov/cex/ .

directly know capital gains income, but we know changes in the values of securities, which may proxy for realized and unrealized capital gains.

Table 2 summarizes the distribution of income and expenditures by annual income decile. Columns two through four present the distribution of income between wage, capital, and transfer income. Wage and salary income are directly reported. Capital income is the sum of income from interest, dividends, rental income, other property income, and net change in securities (to measure capital gains). Wage and capital income sum to less than 100% because of transfer income sources: Social Security, unemployment and workers' compensation, and other public assistance. We omit the categories "other income" and self-employment income, because we cannot identify their mix between capital and labor income (they account for a total of about 5% of income).

Table 2: Sources and Uses of Income for each Annual Income Group

(1) Annual Income Decile	(2) Fraction of Income from Wages	(3) Fraction of Income from Capital	(4) Fraction of Income from Transfers	(5) Capital-Wage Ratio	(6) Fraction of Expenditure on Dirty Good	(7) Fraction of Expenditure on Clean Good
All	88.7%	2.6%	8.6%	3.0%	9.9%	90.1%
1	44.2%	6.0%	49.7%	13.7%	11.1%	88.9%
2	30.0%	1.9%	68.1%	6.4%	12.1%	87.9%
3	42.7%	2.8%	54.5%	6.6%	11.9%	88.1%
4	56.6%	3.0%	40.5%	5.3%	11.8%	88.2%
5	74.8%	3.3%	21.9%	4.4%	11.7%	88.3%
6	86.2%	3.0%	10.8%	3.5%	11.0%	89.0%
7	93.6%	1.9%	4.5%	2.1%	10.4%	89.6%
8	94.8%	2.0%	3.2%	2.1%	10.4%	89.6%
9	96.1%	2.1%	1.8%	2.2%	9.1%	90.9%
10	95.8%	3.1%	1.0%	3.3%	7.1%	92.9%

Overall, about 89% of consumer income is from wages, 3% from capital, and 9% from transfers. This varies somewhat by income group. The fraction of income coming from transfers is declining from the first to the last income decile. For all households above median income, we see a slight positive correlation between income and the fraction of income from capital. For poorer households, however, no such pattern emerges; the capital share of income bounces around from 6% to 2%. Column 5 presents averages for the capital-wage income ratio, excluding any income from transfers. Even this ratio is not monotonic.

The column for capital income indicates one major problem with using annual income to categorize families from rich to poor: the group with the lowest annual income has the highest fraction of income from capital (6%). This group includes a lot of retired individuals who have no labor income and are living off their retirement savings. These individuals may not really be "poor" on a lifetime basis. In other words, we would like to classify households by the *stock* of lifetime wealth, but instead we are classifying them by a *flow* of annual income. If individuals smooth consumption over their lifetime, as pointed out by Poterba (1989), then total annual consumption might be a good proxy for lifetime income (or at least, a better proxy than annual income). We investigate this alternative below.

The final two columns in Table 2 present a distribution of expenditures between the clean and dirty outputs. Unfortunately, our earlier distinction between clean and dirty *production* sectors does not present us with an immediate mapping into the distinction between clean and dirty *consumption* goods. Some of the outputs of the industries defined as dirty are used as inputs to industries defined as clean. A complete analysis would account for these inputs, for example by using Input-Output matrices as in Hassett, Mathur and Metcalf (2009). Here, we simply assign final consumption goods into either a clean or dirty category. Four categories of expenditures (out of the 74 total) are labeled as dirty: electricity, natural gas, fuel oil and other fuels, and gasoline. These are the goods whose consumption directly involves the combustion of fossil fuels (save for electricity, some of which is generated by nuclear or renewable sources). This choice is justified by a more complete analysis considering the pass-through of costs through intermediate goods (Hassett, Mathur and Metcalf 2009). For a $15 per metric ton of carbon tax, they find that the prices of these four categories of goods increase by 8-13%, while no other category of goods sees a price increase of greater than 1%.[7]

Overall, 9% of expenditures go toward these dirty goods. The pattern of expenditures for income groups is smoother than is the pattern for income source. Higher income households spend a lower fraction of their total expenditures on dirty goods than do lower income households. The pattern is not quite monotonic, though. Households in the lowest decile spend a slightly lower fraction on dirty goods than do those in the second and third deciles.[8] But the

[7] The exception is air transportation, whose price increases by 1.86%. The CEX tables do not list expenditures on air transportation separately (they are lumped with public transportation).

[8] This point is made in Poterba (1991) and West and Williams (2004) who look at gasoline expenditures. The very poorest households do not own cars.

very richest households spend a considerably lower fraction on dirty goods than do those middle income households, about half of the size in percentage points.

Because of the issues discussed earlier with measuring incidence across annual income groups, Table 3 presents the same income and expenditure decomposition across deciles defined by total annual expenditure. Annual expenditures can proxy for lifetime income. In Table 3, the pattern in spending across clean and dirty goods is the same as in Table 2; richer households spend a lower fraction of their expenditures on dirty goods. In fact, when broken up by consumption decile rather than by annual income decile, the variance in the fraction spent on the dirty good between groups is greater. The gap between the richest and poorest groups' percentage spent on the dirty good is 9 percentage points in Table 3, versus 4 percentage points in Table 2.

This greater disparity is intuitive. Suppose that annual consumption appropriately proxies for lifetime wealth, so that columns 6 and 7 of Table 3 describe relative spending on clean and dirty goods for lifetime wealth deciles. As households receive annual income shocks, some households will transition from one consumption decile to a different annual income decile. For example, a household in the fourth decile of the lifetime consumption/wealth distribution may in 2008 find itself in the lowest annual income decile. If this household perfectly smooths consumption, then it will spend 13.4% of its expenditures on the dirty good. This effect lowers the average fraction of expenditure on the dirty good for the lowest annual income group. Similarly, a household that finds itself in a higher annual income decile than its lifetime income decile spends a higher fraction on the dirty good than other households in that decile, increasing the average for that annual income decile. Thus, the shocks to annual income flatten out the between-group variance in expenditure patterns on clean vs. dirty goods.

The implications of this phenomenon will be seen below in the simulation results. Briefly, when a carbon tax hike increases the relative price of the dirty good, then the tax hike appears more regressive when households are divided into annual consumption groups than when households are divided into annual income groups.

The relationship between expenditure decile and income source is still not monotonic, with the exception that transfer income's share declines across the expenditure deciles. The wage-capital ratio still shows no clear pattern. However, Table 3 does show some evidence that the households in the top two expenditure deciles earn a considerably higher fraction of their income from capital than do other households.[9]

Table 3: Sources and Uses of Income for each Annual Expenditure Group

(1) Expenditure Decile	(2) Fraction of Income from Wages	(3) Fraction of Income from Capital	(4) Fraction of Income from Transfers	(5) Capital-Wage Ratio	(6) Fraction of Expenditure on Dirty Good	(7) Fraction of Expenditure on Clean Good
All	88.7%	2.6%	8.6%	3.0%	9.9%	90.1%
1	53.0%	3.0%	44.0%	5.6%	15.3%	84.7%
2	72.3%	2.4%	25.3%	3.3%	14.7%	85.3%
3	80.9%	2.1%	17.1%	2.5%	13.8%	86.2%
4	84.2%	2.5%	13.3%	3.0%	13.4%	86.6%
5	86.9%	2.4%	10.7%	2.7%	13.2%	86.8%
6	89.3%	2.4%	8.2%	2.7%	12.3%	87.7%
7	91.3%	1.8%	6.9%	1.9%	11.8%	88.2%
8	92.4%	2.4%	5.3%	2.6%	10.8%	89.2%
9	92.6%	3.1%	4.3%	3.4%	9.8%	90.2%
10	94.1%	3.3%	2.6%	3.5%	6.4%	93.6%

III. Numerical Results

The base case results for changes in goods prices and factor prices are presented in Table 4. We consider the effects of doubling the carbon tax from \$15 per ton to \$30 per ton, that is, a 100% increase in the carbon tax rate ($\hat{\tau}_Z = 1$).

Table 4: Base Case Simulation Results

Change in the price of the dirty good, $\hat{p}_Y$	7.21%
Change in the wage rate, $\hat{w}$	0.0419%
Change in the return to capital, $\hat{r}$	–0.0694%

The change in the relative output price $\hat{p}_Y$ is about equal to $\theta_{YZ}\hat{\tau}_Z$, which we called the "direct" effect from passing through the tax increase. The relative changes in the wage and the capital rental rate are small, but we expect them to be small. They come from doubling the

[9] Annual expenditure is a proxy for lifetime income if households smooth consumption. However, households cannot smooth their income streams; the wage-capital income ratio for any particular lifetime income decile will vary over the lifetime. If every decile has the same distribution across ages of those within the decile, however, then the fact that the capital-wage ratio varies with age should not create a bias in our calculation of each decile's capital-wage ratio. Even if a large cohort of 50-60 year olds exists in the overall sample, for example, then the calculated capital-wage ratio of all lifetime income groups will be more similarly dependent on individuals in this age group.

price of an input that represents 7% of a sector, which itself comprises about 7% of the economy. The change in the capital rental rate $\hat{r}$ is negative, and the change in the wage $\hat{w}$ is positive, so capital bears a higher than proportional share of the burden of the tax increase. In our base case parameters, capital is a better substitute for pollution than is labor ($e_{KZ} > e_{LZ}$), so the substitution effect pushes more of the burden onto labor. However, the dirty sector is capital-intensive, so the output effect pushes more of the burden on capital. Here, the output effect dominates the substitution effect.

We then use Table 2 to translate these price changes into relative uses-side and sources-side burdens of different annual income groups. For each income group, we first calculate $\hat{p}_Y$ times expenditures on the dirty good, plus $\hat{p}_X$ times expenditures spent on the clean good. Because our numeraire used in solving the system sets $\hat{p}_X$ = 0, these burdens will be positive for each group. Yet none of these results should imply anything about how much of the burden is on the uses side compared to the sources side; that comparison depends entirely on the choice of numeraire (or equivalently, on whether monetary policy accommodates the increase in output prices or forces the burden to be felt by falling factor prices). Since the choice of numeraire does not affect the real incidence of a tax, the discussion of burdens on the uses side should focus only on who spends relatively more on each good (not on how much of the burden is on the uses side). Similarly,the discussion of sources side should focus only on who earns relatively more from each factor.

For this reason, we normalize the calculated uses side burden for each group by subtracting from it a uses side calculation based on the entire sample. Those groups with a positive value see the cost of their expenditures increase more than the average, and those groups with a negative value see their cost increase less than the average. The calculation is similar for the sources-side incidence. It is $\hat{w}$ times income from wages plus $\hat{r}$ times income from capital, minus this value calculated for the entire sample. Using this procedure, results do not depend on the choice of numeraire. We change the sign of the sources side calculation, however, so that those income groups whose income decrease more than the average have a positive "burden", while those groups whose income decrease less than the average have a negative burden (a relative gain from the carbon tax).

Table 5: Incidence Calculations, Base Case Parameters, Income Deciles

Annual Income Decile	Relative Expenditure Burden	Relative Income Burden
1	0.0819%	0.0210%
2	0.1574%	0.0241%
3	0.1422%	0.0194%
4	0.1341%	0.0137%
5	0.1275%	0.0063%
6	0.0761%	0.0013%
7	0.0340%	-0.0025%
8	0.0314%	-0.0030%
9	-0.0595%	-0.0035%
10	-0.2035%	-0.0026%

These incidence results are presented in Table 5. The pattern of uses-side burdens is clear: the highest income groups (the top two deciles) suffer a smaller than average share of this burden. Their cost of goods decreases relative to the average, because they spend a lower than average fraction on the dirty good. With our choice of numeraire, the average increase in overall price is about 0.72% (a 7.2% increase in the price of the good that constitutes 10% of total expenditure). Thus, Table 5 tells us that the highest income group's price increase under this normalization overall is only about 0.51%, whereas the second-to-lowest income group sees an overall price increase of about 0.87%. These results are consistent with those in Hassett, Mathur and Metcalf (2009), who examine the uses-side incidence of a carbon tax. They find that the relative burden is monotonically decreasing across the income deciles. Burtraw, et al (2009) find the same result of uses-side regressivity for a cap-and-trade policy.

The sources-side burden is also regressive; the positive values for the lowest income deciles indicate that those households' incomes fall proportionally more than average. In the base case simulation, $\hat{w} > 0$ and $\hat{r} < 0$, so earning a higher fraction of income from capital tends to decrease overall real income. Because of transfers, however, the sources-side incidence is not fully determined by just the capital-wage income ratios shown in Table 2. The highest value of that ratio is for the lowest income decile, though the highest relative income burden is for the second-to-lowest income decile. The sources-side incidence results in Table 5 derive primarily from the increase in the fraction of income from wages across the income deciles.

Table 6: Incidence Calculations, Base Case Parameters, Expenditure Deciles

Annual Expenditure Decile	Relative Expenditure Burden	Relative Income Burden
1	0.3897%	0.0152%
2	0.3419%	0.0067%
3	0.2792%	0.0029%
4	0.2518%	0.0018%
5	0.2328%	0.0006%
6	0.1680%	-0.0004%
7	0.1343%	-0.0017%
8	0.0601%	-0.0017%
9	-0.0068%	-0.0013%
10	-0.2581%	-0.0018%

Table 6 presents the same calculations for annual consumption deciles instead of annual income deciles. Both the uses-side and sources-side incidences are regressive. When defined by annual consumption groups, however, the uses-side incidence is *more* regressive than when defined by annual income, and the sources-side incidence is *less* regressive than when defined by annual income. The lowest expenditure decile's relative price increase is greater than is the lowest income decile's, and the highest expenditure decile's relative price decrease is greater than is the lowest income decile's. This pattern can be seen in Figures 1 and 2. This result occurs because the between-decile variance in the fraction of spending on the dirty good is higher across consumption deciles than across income deciles. In addition, sources-side regressivity is lower in Table 6 than in Table 5 primarily due to the increased fraction of income from capital as annual consumption increases.

Sensitivity Analysis

The results in Tables 4-6 are calculated using our base case parameter values. Some of these parameters are based on solid information about factor shares or consumption shares, but some of the elasticity parameters are known with little precision. Thus, sensitivity analysis is in order. In particular, the elasticities of substitution in production for the dirty sector have not been directly estimated. Next, we present alternative incidence calculations for two different sets of parameter values. All of the parameters are identical to their base case values except for the dirty sector substitution elasticities. In the first set of results (in columns 2 and 3), we set e_{KL} = 0.5, e_{KZ} = 1, and e_{LZ} = –0.5. Capital is a much better substitute for pollution than is labor; in fact, labor is a complement for pollution rather than a substitute. As we expect, under these parameters, labor ends up relatively worse off with a pollution tax increase. The resulting price changes are $\hat{p}_Y$ = 7.32%, $\hat{w}$ = –0.20%, and $\hat{r}$ = 0.33%. The second set of results (in columns 4 and 5) are based on parameters where labor is a much better substitute for pollution than is labor: e_{KL} = 0.5, e_{KZ} = –0.5, and e_{LZ} = 1. The price changes under these parameter values are $\hat{p}_Y$ = 7.04%, $\hat{w}$ = 0.41%, and $\hat{r}$ = –0.68%.

Figure 1

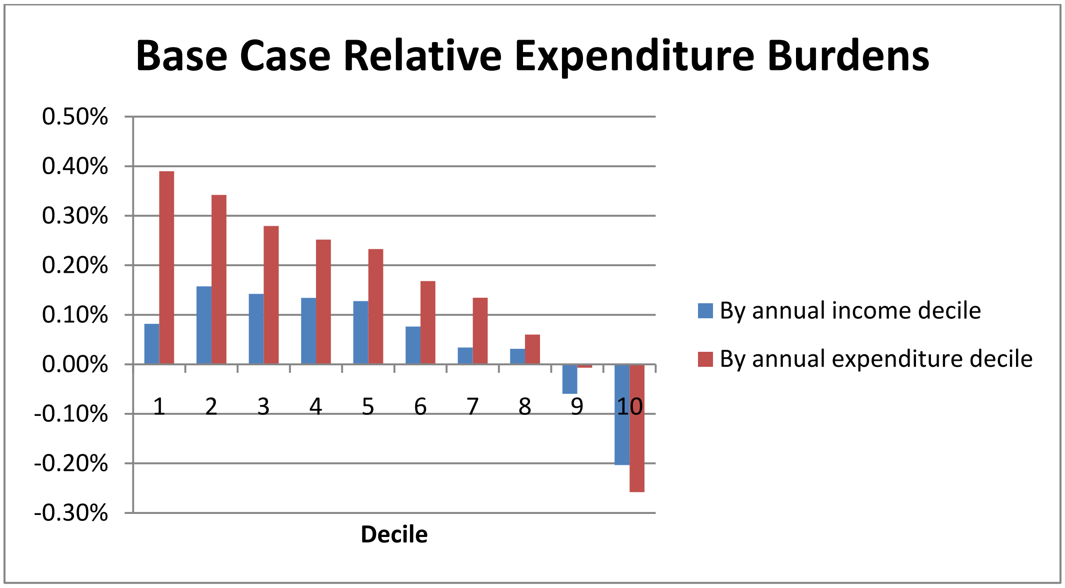

Figure 2

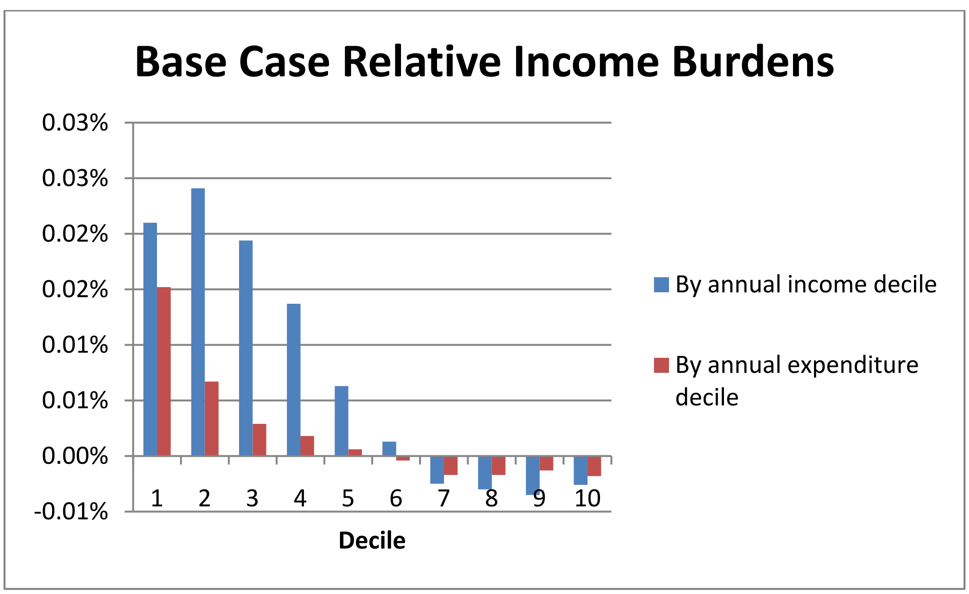

Table 7 presents the resulting incidence calculations across annual income groups. Columns 2 and 3 present the relative burdens from the uses side and sources side for the first set of alternative parameter values, where capital is a better substitute for pollution than is labor. The uses-side incidence results are not affected very much, even with this large change of production substitution elasticities. The households with the lowest income tend to see higher than average increases in their costs, indicating a regressive uses-side incidence. However, under these parameter values the sources-side incidence results are starkly different from those in the base case results from Table 5. Here, the richest households (those with a lot of labor income) see their incomes decrease relative to the average, while the poorest households (those with capital) see their incomes increase relative to the average. Under these parameters, capital is a better substitute for pollution than is labor, so the pollution tax increase means that labor is made relatively worse off. The highest annual income groups tend to have a higher than average fraction of their income from labor, and thus they are worse off under this parameterization.

Table 7: Incidence Calculations, Annual Income Groups, Sensitivity Analysis

	Capital a better substitute for pollution		Labor a better substitute for pollution	
(1)	(2)	(3)	(4)	(5)
Annual Income Decile	Relative Expenditure Burden	Relative Income Burden	Relative Expenditure Burden	Relative Income Burden
1	0.0832%	-0.1002%	0.0800%	0.2055%
2	0.1598%	-0.1150%	0.1537%	0.2358%
3	0.1444%	-0.0926%	0.1389%	0.1899%
4	0.1361%	-0.0654%	0.1309%	0.1341%
5	0.1294%	-0.0299%	0.1244%	0.0614%
6	0.0773%	-0.0061%	0.0743%	0.0126%
7	0.0345%	0.0121%	0.0332%	-0.0249%
8	0.0319%	0.0141%	0.0307%	-0.0289%
9	-0.0604%	0.0166%	-0.0581%	-0.0340%
10	-0.2066%	0.0125%	-0.1987%	-0.0257%

Columns 4 and 5 present incidence calculations under the parameter values that make labor a much better substitute for pollution than capital. Again, the uses-side incidence results are virtually no different than in the base case; the burden is regressive. However, the sources-side incidence results are the opposite to those from columns 2 and 3 but are in the same direction as in the base case. Here, because the return to capital falls, the poorest households see their income decrease relative to the average, and the richest households see their income increase relative to the average. As in the base case results, the sources-side incidence is regressive. Whereas the base case $\hat{w}$ was 0.042%, and $\hat{r}$ was –0.069%, these larger elasticities yield $\hat{w}$ = 0.41%, and $\hat{r}$ = –0.68% (ten times as big). The degree of regressivity is therefore higher than in the base case, as the magnitudes of the factor price changes are higher in this simulation than in the base case.

Table 8 presents the same sensitivity analysis for expenditure deciles, and it shows qualitatively the same results. Again, uses-side regressivity is somewhat higher and sources-side regressivity is somewhat lower compared to annual income deciles.

Table 8: Incidence Calculations, Annual Expenditure Groups, Sensitivity Analysis

	Capital a better substitute for pollution		Labor a better substitute for pollution	
(1) Annual Expenditure Decile	(2) Relative Expenditure Burden	(3) Relative Income Burden	(4) Relative Expenditure Burden	(5) Relative Income Burden
1	0.3956%	-0.0725%	0.3805%	0.1486%
2	0.3471%	-0.0320%	0.3339%	0.0656%
3	0.2835%	-0.0137%	0.2726%	0.0281%
4	0.2557%	-0.0086%	0.2459%	0.0175%
5	0.2364%	-0.0026%	0.2273%	0.0054%
6	0.1705%	0.0020%	0.1640%	-0.0041%
7	0.1363%	0.0080%	0.1311%	-0.0165%
8	0.0610%	0.0082%	0.0587%	-0.0169%
9	-0.0069%	0.0061%	-0.0066%	-0.0126%
10	-0.2620%	0.0086%	-0.2520%	-0.0176%

In our base case and in columns (4)-(5) where the wage rises, then capital bears a relatively higher burden than labor. Richer households bear less burden on the sources side, because their income is labor intensive. This result may be counterintuitive, as one might expect that richer households depend more on capital for their income than on labor. And it holds whether households are grouped by annual income or by annual consumption as a proxy for lifetime income – where one might expect that the problems with using annual income groups are lessened. Yet it must be emphasized that the income data (especially capital income data) in the CEX are very imperfect, and so these results must be cautiously interpreted. As discussed earlier, the sources-side incidence is primarily driven by the share of income from wages, which increases with both income decile and with consumption decile.

An additional sensitivity analysis we perform involves varying the elasticity of substitution in utility, σ_u. In the base case this value is one. The analytical solutions of the model show that the value of this parameter affects the strength of the output effect. As with the elasticities of substitution in production for the dirty sector, the true value of this parameter is not known. We choose two alternate values for σ_u: 0.5 and 1.5. For each value, we calculate the incidence across income and expenditure deciles. The substitution elasticities in production are kept at the base case values. When $\sigma_u = 0.5$, the price changes are $\hat{p}_Y = 7.24\%$, $\hat{w} = -0.0270\%$, and $\hat{r} = 0.0447\%$. When $\sigma_u = 1.5$, they are $\hat{p}_Y = 7.18\%$, $\hat{w} = 0.11\%$, and $\hat{r} = -0.18\%$ (factor price effects are reversed). In both simulations the dirty sector is capital-intensive, and so the output effect makes capital worse off. When $\sigma_u = 0.5$, the output effect is small and dominated by the substitution effect (which makes capital better off since $e_{KZ} > e_{LZ}$). When $\sigma_u = 1.5$, the output effect is large and dominates the substitution effect, so capital bears relatively more of the burden of the carbon tax increase. The uses-side incidence $\hat{p}_Y$ does not vary much with σ_u.

Table 9: Incidence Calculations, Annual Income Groups, Sensitivity Analysis

	Low substitution in utility		High substitution in utility	
(1)	(2)	(3)	(4)	(5)
Annual Income Decile	Relative Expenditure Burden	Relative Income Burden	Relative Expenditure Burden	Relative Income Burden
1	0.0823%	-0.0135%	0.0816%	0.0550%
2	0.1580%	-0.0155%	0.1567%	0.0633%
3	0.1428%	-0.0125%	0.1416%	0.0509%
4	0.1347%	-0.0088%	0.1335%	0.0360%
5	0.1280%	-0.0040%	0.1269%	0.0165%
6	0.0765%	-0.0008%	0.0758%	0.0034%
7	0.0341%	0.0016%	0.0339%	-0.0067%
8	0.0315%	0.0019%	0.0313%	-0.0077%
9	-0.0598%	0.0022%	-0.0593%	-0.0091%
10	-0.2044%	0.0017%	-0.2027%	-0.0069%

Table 9 presents the incidence calculations for these alternative parameter values defined over annual income deciles, and Table 10 presents them defined over annual expenditure deciles. As in the previous sensitivity analyses, the value of σ_u does not affect the uses-side incidence; it is regressive for both alternate values of σ_u and for both definitions of deciles. The value of σ_u does, however, affect the sources-side incidence. When σ_u is low, as in Columns 2 and 3 of Tables 9 and 10, the output effect hurting capital is small and dominated, so the burden on capital is low. Since the poorest households receive a higher proportion of income from capital, they bear less of the burden in these scenarios. On the other hand, when σ_u is high, the burden on capital owners is increased since the output effect dominates. Thus, poorer households bear relatively more of the burden. All of these findings hold for both annual income and annual expenditure deciles, although the degree of sources-side regressivity or progressivity is larger for annual income deciles than for annual expenditure deciles.

Table 10: Incidence Calculations, Annual Expenditure Groups, Sensitivity Analysis

	Low substitution in utility		High substitution in utility	
(1) Annual Expenditure Decile	(2) Relative Expenditure Burden	(3) Relative Income Burden	(4) Relative Expenditure Burden	(5) Relative Income Burden
1	0.3913%	-0.0098%	0.3880%	0.0399%
2	0.3434%	-0.0043%	0.3405%	0.0176%
3	0.2804%	-0.0019%	0.2781%	0.0076%
4	0.2529%	-0.0012%	0.2508%	0.0047%
5	0.2338%	-0.0004%	0.2318%	0.0015%
6	0.1687%	0.0003%	0.1673%	-0.0011%
7	0.1348%	0.0011%	0.1337%	-0.0044%
8	0.0604%	0.0011%	0.0599%	-0.0045%
9	-0.0068%	0.0008%	-0.0067%	-0.0034%
10	-0.2592%	0.0012%	-0.2570%	-0.0047%

Middle-Aged Heads of Household

Annual income is a poor proxy for lifetime income. Annual consumption may be a better proxy, but even this measure fails to show a consistent pattern in the capital–wage income ratio. A large part of the problem is that individuals have different income patterns at different stages of their lives. Retirees have low income but high savings, and college students have low income but high borrowing. Some evidence for this pattern appears in the CEX data. The mean age of the head of the household varies considerably by annual income decile. The overall mean age is 49.6 years. The youngest average age is in the second-richest annual income decile (45.3 years), and the oldest average age is in the fourth-poorest annual income decile (58.9 years). The six lowest annual income deciles all have mean ages younger than the other four income deciles. The range of mean ages is not as large when households are divided into consumption deciles instead of income deciles; mean age ranges from 47.2 years to 53.1 years.

An alternative method of overcoming this life-cycle problem is by focusing on only one age group for head of household. We choose households whose heads are 41-50 years old.[10] Table 11 summarizes the income and expenditure data across the ten annual income deciles of these households. Overall, these households receive a higher fraction of their income from wages and less from capital or transfers than do other households. The fraction of expenditures on dirty goods is identical to that for all households. Across income deciles, the decreasing fraction of income from transfers is again seen. Here, though, the dropoff is much steeper than it is for all households; this fraction drops to single-digit percentages by the third decile. This is likely because these households are not receiving nearly as much Social Security retirement income as all other households. The capital-wage ratio and the fraction of income from capital both reach their maximum in the poorest decile. Across deciles, these values do not exhibit a clear pattern. The second-highest value in each column occurs in the richest decile.

Table 11: Sources and Uses of Income for each Annual Income Group Household with Heads aged 41-50 only

(1) Annual Income Decile	(2) Fraction of Income from Wages	(3) Fraction of Income from Capital	(4) Fraction of Income from Transfers	(5) Capital-Wage Ratio	(6) Fraction of Expenditure on Dirty Good	(7) Fraction of Expenditure on Clean Good
All	96.7%	1.4%	1.9%	1.4%	9.9%	90.1%
1	45.4%	3.9%	50.7%	8.6%	12.1%	87.9%
2	80.4%	1.5%	18.0%	1.9%	12.4%	87.6%
3	92.6%	1.1%	6.3%	1.1%	12.7%	87.3%
4	96.1%	1.1%	2.8%	1.1%	11.5%	88.5%
5	97.4%	0.8%	1.9%	0.8%	11.2%	88.8%
6	96.8%	1.6%	1.6%	1.7%	11.0%	89.0%
7	98.3%	0.7%	1.0%	0.8%	10.2%	89.8%
8	98.1%	0.7%	1.2%	0.7%	9.8%	90.2%
9	98.4%	1.2%	0.4%	1.2%	9.0%	91.0%
10	97.7%	2.1%	0.2%	2.2%	6.8%	93.2%

[10] Another approach, which we do not pursue here, is to attempt to create a synthetic cohort of households using multiple years of the CEX. See Jorgenson and Slesnick (2008), who create a synthetic cohort from the CEX based on date of birth.

Table 12 presents the incidence calculations for these households. Columns 2 and 3 present results using the base case parameters, columns 4 and 5 are from the alternative substitution elasticity values where capital is a much better substitute for pollution than is labor, and columns 6 and 7 are from the alternative substitution elasticity values where labor is a much better substitute for pollution. As before, the uses-side burden is regressive and consistent across parameter values. In the base case, the sources-side incidence is also regressive. The highest value in the relative income burden occurs for the poorest decile. However, the pattern is non-monotonic. The fifth, seventh, eighth, and ninth deciles bear a smaller than average share of the burden, while all other deciles bear a larger than average share. The positive value for the highest decile arises because of that decile's higher than average income share from capital. This represents some slight evidence that the richest households bear a higher sources-side burden because of their larger-than-average income share from capital.

Table 12: Incidence Calculations, Household with Heads aged 41-50 only

	Base Case		Capital better substitute for *Z*		Labor better substitute for *Z*	
(1) Annual Income Decile	(2) Relative Expenditure Burden	(3) Relative Income Burden	(4) Relative Expenditure Burden	(5) Relative Income Burden	(6) Relative Expenditure Burden	(7) Relative Income Burden
1	0.1568%	0.0233%	0.1592%	-0.1111%	0.1531%	0.2279%
2	0.1771%	0.0069%	0.1798%	-0.0330%	0.1729%	0.0677%
3	0.1971%	0.0015%	0.2001%	-0.0072%	0.1925%	0.0147%
4	0.1166%	0.0000%	0.1184%	-0.0001%	0.1138%	0.0002%
5	0.0946%	-0.0007%	0.0960%	0.0033%	0.0923%	-0.0068%
6	0.0763%	0.0002%	0.0774%	-0.0007%	0.0745%	0.0015%
7	0.0172%	-0.0011%	0.0174%	0.0052%	0.0167%	-0.0106%
8	-0.0090%	-0.0010%	-0.0092%	0.0049%	-0.0088%	-0.0101%
9	-0.0699%	-0.0009%	-0.0710%	0.0041%	-0.0683%	-0.0084%
10	-0.2230%	0.0001%	-0.2264%	-0.0006%	-0.2177%	0.0013%

Regional Incidence

Incidence can be defined across groups defined in ways other than annual income or annual expenditure. We look also at incidence across regions. The CEX microdata are used to tabulate expenditure and income data by the four census regions. Table 13 summarizes these tabulations, breaking up the clean and dirty industries in the same way as in Table 2. Households in the West region earn a substantially higher fraction of their income from capital and less from transfers. Households in the West spend a lower fraction of their expenditures on dirty goods, and households in the South spend a higher fraction on the dirty good, compared to the average. A reason is that households in the South spend more than elsewhere on electricity for their air conditioners.

Table 13: Sources and Uses of Income for each Region

(1) Region	(2) Fraction of income from wages	(3) Fraction of income from capital	(4) Fraction of income from transfers	(5) Capital-Wage Ratio	(6) Fraction of Expenditure on Dirty Good	(7) Fraction of Expenditure on Clean Good
Northeast	88.9%	2.2%	8.9%	2.4%	9.5%	90.5%
Midwest	88.5%	2.3%	9.3%	2.6%	10.3%	89.7%
South	88.5%	2.6%	8.9%	3.0%	11.2%	88.8%
West	89.3%	3.4%	7.3%	3.8%	8.2%	91.8%

Table 14 presents the incidence calculations across regions. We present the results for the base case parameter values (in columns 2 and 3) as well as for the two sets of alternative production elasticities from Table 7 (in columns 4-7). Across all parameter values, the uses-side incidence results do not qualitatively vary. Households in the Northeast and in the West bear relatively less of the uses-side burden than do households in the Midwest and the South (since these latter two regions spend a higher than average fraction of expenditures on the dirty good). On the sources side, the incidence results again depend on parameter values. In the base case, households in the West are made somewhat worse off than average, since they receive a higher fraction of their income from capital. This disparity is even larger in the second set of alternative parameter values (columns 6 and 7), where labor is a much better substitute for pollution than capital. The incidence result is reversed in columns 4 and 5, where capital is a much better substitute for pollution than is labor. Here, households in the West see an income increase relative to the average, because they earn a higher fraction of their income from capital. The variance in relative income burdens across regions is much lower than the variance in relative expenditure burdens, and much lower than the variance in relative income burdens across income or expenditure deciles.

Table 14: Incidence Calculations, Regions, Sensitivity Analysis

	Base Case		Capital better substitute for *Z*		Labor better substitute for *Z*	
(1)	(2) Relative Expenditure Burden	(3) Relative Income Burden	(4) Relative Expenditure Burden	(5) Relative Income Burden	(6) Relative Expenditure Burden	(7) Relative Income Burden
Northeast	-0.0335%	-0.0004%	-0.0340%	0.0020%	-0.0327%	-0.0042%
Midwest	0.0231%	-0.0002%	0.0234%	0.0008%	0.0225%	-0.0016%
South	0.0948%	0.0001%	0.0962%	-0.0005%	0.0925%	0.0009%
West	-0.1217%	0.0003%	-0.1235%	-0.0015%	-0.1188%	0.0030%

IV. Conclusion

We use an analytical general equilibrium tax incidence model to examine the uses-side and sources-side distribution of burdens from a carbon tax. Our model shows that, for our base case parameter values, the uses-side costs are relatively more burdensome on those who spend more than average on dirty goods (electricity, natural gas, gasoline, heating oil). This reinforces previous findings that the uses-side incidence is regressive (Hassett, Mathur and Metcalf 2009, Burtraw, Sweeney and Walls 2009). The base case results suggest that the sources-side costs are relatively more burdensome on those who earn a higher than average fraction of their income from capital (because carbon-intensive industries tend to be more capital-intensive). This implies a regressive burden when households are divided by annual income or annual expenditure. Also, however, this result is sensitive to calibrated parameter values that are not known.

Many extensions to the model are possible. One could consider imperfect factor mobility, more sectors, more final goods, intermediate goods, market power, or other refinements. The effect of market power or industry regulation may be of particular relevance to a carbon tax, since electric utilities are large emitters and are often highly regulated monopolists. One could also more carefully model the policy, rather than just modeling it as a tax.[11] A more complex CGE model may present more specific results, but at the expense of analytical solutions that our simple two-sector model allows.[12]

[11] See Burtraw, Walls and Blonz (2009) for an analysis of how the choice of allocation of carbon permits to the electricity sector affects the distribution of costs across income groups and regions.

[12] For example, Rausch et al. (2009) use a CGE model with a detailed structure of the U.S. energy sector to investigate the distributional impacts of a carbon tax.

References

Allen, R.G.D. *Mathematical Analysis for Economists.* New York: St. Martin's, 1938.

Burtraw, Dallas, Margaret Walls, and Joshua Blonz. "Distributional Impacts of Carbon Pricing Policies in the Electricity Sector." *American Tax Policy Institute Conference on U.S. Energy Taxes* (2009).

Burtraw, Dallas, Richard Sweeney, and Margaret Walls. "The Incidence of U.S. Climate Policy: Alternative Uses of Revenues from a Cap-and-Trade Auction." *National Tax Journal* 62, no. 3 (September 2009): 497-518.

de Mooij, Ruud, and Lans Bovenberg. "Environmental Taxes, International Capital Mobility and Inefficient Tax Systems: Tax Burden vs. Tax Shifting." *International Tax and Public Finance* 5, no. 1 (February 1998): 7-39.

Fullerton, Don, and Garth Heutel. "The General Equilibrium Incidence of Environmental Taxes." *Journal of Public Economics* 91, no. 3-4 (April 2007): 571-591.

Harberger, Arnold. "The Incidence of the Corporation Income Tax." *Journal of Political Economy* 70, no. 3 (June 1962): 215-240.

Hassett, Kevin, Aparna Mathur, and Gilbert Metcalf. "The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis." *Energy Journal* 30, no. 2 (2009): 155-177.

Jorgenson, Dale, Mun Ho, and Kevin Stiroh. "A Retrospective Look at the U.S. Productivity Growth Resurgence." *Journal of Economic Perspectives* 22, no. 1 (Winter 2008): 3-24.

Jorgenson, Dale, and Daniel Slesnick. "Consumption and Labor Supply." *Journal of Econometrics* 147, no. 2 (December 2008): 326-335.

Mieszkowski, Peter. "The Property Tax: An Excise Tax or a Profits Tax?" *Journal of Public Economics* 1, no. 1 (April 1972): 73-96.

Poterba, James M. “Lifetime Incidence and the Distributional Burden of Excise Taxes.” *American Economic Review* 79 (May 1989): 325-30.

Poterba, James, "Is the Gasoline Tax Regressive?", in D. Bradford, ed., Tax Policy and the Economy 5, Cambridge, MA: MIT Press (1991), 145-64.

Rausch, Sebastian, Gilbert Metcalf, John Reilly, and Sergei Paltsev. "Distributional Impacts of a U.S. Greenhouse Gas Policy: A General Equilibrium Analysis of Carbon Pricing." *American Tax Policy Institute Conference on U.S. Energy Taxes*, Washington DC (2009).

West, Sarah, and Roberton Williams. "Estimates from a Consumer Demand System: Implications for the Incidence of Environmental Taxes." *Journal of Environmental Economics and Management* 47, no. 3 (May 2004): 535-558.