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Don Fullerton and Garth Heutel

Abstract

Using an analytical general equilibrium model, we find solutions for the effect of energy policy on factor prices as well as output prices. We calibrate the model to the U.S. economy, and we consider a tax on carbon dioxide. 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 can be progressive, U-shaped, or regressive. Results on the sources side are sensitive to parameter values.

KEYWORDS: incidence, climate policy, relative burdens, uses-side, sources-side

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Energy is an integral input to nearly all aspects of economic life. 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 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, highlighting conceptual issues by showing the general effects of each parameter on each result.[1]

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 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 distinguish households using expenditure and income data from the 2008 Consumer Expenditure Survey (CEX), supplemented by capital income data from the 2007 Survey of Consumer Finances (SCF). We then 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. We then apply these price changes to the households in our data to calculate the burdens across income groups and regions. In this paper, we find distributional effects on the uses side (commodity price changes) and sources side (factor price changes). We do not calculate effects through the use of the revenues by government, either for rebates to households or for the indexing of government transfers (as in Rausch et al. 2010).

[1] Besides these two effects, Fullerton (2009) lists and discusses four other distributional effects of environmental policy not considered here: (3) scarcity rents, (4) transition effects, (5) land or stock price capitalization, and (6) distribution of the benefits of environmental protection.

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, et al., 2009, or Hassett, et al., 2009). 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).

On the sources side, however, incidence results are sensitive to 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. A partial equilibrium analysis that focuses only on output prices might understate or overstate the extent to which carbon policy is regressive, by neglecting general equilibrium effects on factor prices.

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 numerical solution. 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. Our model can be interpreted as a complement to a more detailed computational general equilibrium (CGE) model, to examine more closely what drives certain results. As a referee put it, we provide a "model of the model."

In a special case where the two sectors have the same factor intensity and the same substitution parameters, we show that carbon pricing has no effect on the wage-rental ratio. If so, then analysts could focus on product prices alone. With other values for these unknown parameters, however, changes in the wage/rental ratio can offset or exacerbate regressivity on the uses side. We conclude that these production parameters need to be estimated, before these effects on the sources side can be dismissed.

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

I. Model

This model is based on an earlier one from Fullerton and Heutel (2007), which itself is an extension of Harberger (1962). The model is solved by log-linearizing about the initial equilibrium, so it is valid for small changes in the tax rate. 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:

$$X = X(K_X, L_X)$$
$$Y = Y(K_Y, L_Y, Z).$$

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, including a tax or other price on emissions τ_Z. Their factor demand choices can be defined in terms of Allen elasticities of substitution between their inputs, e_{ij}, and revenue shares of inputs (e.g., $\theta_{YK} = rK_Y/p_Y Y$). These relationships follow Mieszkowski (1972) and Allen (1938):

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

We assume perfect competition and constant returns to scale in production.[2] These yield zero profit conditions that can be differentiated to get:

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

[2] These assumptions may be questionable, especially for a dirty industry that is composed in large part by regulated electric utilities. For example, an emissions tax may not fully be passed through to ratepayers if it reduces infra-marginal rents on base-load generating units. In the conclusion, we mention some extensions to the model that could incorporate these concerns.

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 linearized system of equations can be solved to consider how a small 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. As in Harberger (1962), we assume that pollution tax revenue is used to purchase the two goods in the same proportion as the consumer does, so that tax revenue reallocation has no impact on relative prices.

The model's solution for output and factor prices is presented below.[3] 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 additional definitions for convenience. Let $\gamma_K \equiv \lambda_{KY}/\lambda_{KX} = K_Y/K_X$ and $\gamma_L \equiv \lambda_{LY}/\lambda_{LX} = L_Y/L_X$, $A \equiv \gamma_K\gamma_L + \gamma_L\theta_{YK} + \gamma_K(\theta_{YL} + \theta_{YZ})$, $B \equiv \gamma_K\gamma_L + \gamma_K\theta_{YL}$

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

$+ \gamma_L(\theta_{YK} + \theta_{YZ})$, 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, $(\gamma_K - \gamma_L)\sigma_u$, represents the "output effect." The expression $(\gamma_K - \gamma_L)$ is positive whenever the dirty sector is capital-intensive. If so, and assuming the denominator is positive ($D > 0$), then an increase in the pollution tax $(\hat{\tau}_Z > 0)$ will tend through this term 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 these equations represent "substitution effects." The signs of these terms depend 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 case with equal factor intensities $(\gamma_K = \gamma_L)$ *and* equal cross-price terms $(e_{LZ} = e_{KZ})$, it can further be shown that $\hat{w} = \hat{r} = 0$. In this knife's edge case, the sources side can be ignored (as in Burtraw et al. 2009, or Hassett et al. 2009). We look below at actual parameters where the sources side effects may offset or exacerbate regressive effects on the uses side.

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, which include output and substitution effects described above.[4]

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) emissions. Our model only has two

[4] The incidence of this tax in this model includes the efficiency cost of tax-induced changes in consumption bundles, but not the efficiency cost of tax distortions in factor markets, since total factor supplies are fixed.

sectors, so we must decide which industries of the economy are aggregated under the dirty sector and which under the clean sector. 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 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).[5] These data divide the US economy into 35 sectors (roughly corresponding to two-digit 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%).[6] Of manufacturing industries, the highest emitter of CO_2 is petroleum refining, both absolutely and as a fraction of the value of output.[7] We use our data to isolate petroleum refining, 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 perform a back-of-the-envelope calculation based on estimates of the optimal price on CO_2 from prior papers. A price of $15 per metric ton of CO_2 is often recommended, and we use this price as a starting point (Hassett et al. 2009). The value of θ_{YZ} is 0.0723, based on this price and our definition of the dirty sector of the economy.[8]

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

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

[6] See http://www.epa.gov/climate/climatechange/emissions/downloads09/ExecutiveSummary.pdf, Table ES-2.

[7] 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).

[8] 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. This calculation combines current emissions with the $15/ton price, and so it may overstate the initial level of spending on emissions, but we don't observe actual emissions with that tax. Instead we use this hypothetical initial equilibrium as a starting point from which to calculate the effects of a small change in tax.

initial equilibrium. The total factor income of the economy $(\overline{K} + \overline{L})$ 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

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

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.[9]

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 use estimates of a translog KLEM model of a 35 sector US economy from Jin and Jorgenson (2010) to calculate these elasticities.[10] From this, we find $e_{KL} = 0.1$, $e_{KZ} = 0.2$, and $e_{LZ} = -0.1$. 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.[11]

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

[9] We can show that the price elasticity of demand for the dirty good is $-[\alpha+\sigma_u(1-\alpha)]$, where α is its expenditure share. With our base case $\sigma_u = 1$, this elasticity is –1. We vary this parameter in sensitivity analysis.

[10] To get a single set of parameters, we weight the estimated elasticities across the three dirty industries by the value of total output in each (electricity, transportation, and petroleum refining).

[11] For comparison, de Mooij and Bovenberg (1998) review data from Western European countries and find $e_{KL} = 0.5$, $e_{KZ} = 0.5$, and $e_{LZ} = 0.3$. Their elasticities are all higher than the ones calculated from Jin and Jorgenson (2010), but both sets of elasticities find that capital is a better substitute for pollution than is labor.

with various demographic characteristics. For example, we divide all households into ten deciles by annual income. For each decile, we calculate the fraction of income spent 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. A potential inconsistency is that we use a model with a representative consumer to get price changes and then use those price changes to explore implications of consumer heterogeneity in expenditure and income patterns. The required assumption is that the overall effect on factor and output prices with heterogeneous consumers is the same as in the aggregate model.

We use expenditure and income data from the 2008 Consumer Expenditure Survey (CEX) and the 2007 Survey of Consumer Finances (SCF).[12] The CEX data come from a representative sample of the U.S. population; the SCF oversamples rich households but includes sampling weights. These micro-level data provide much 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 calculate from the CEX the annual 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.). The CEX provides information on the distribution of income sources, including income from wages and salaries, self-employment, and interest, dividends, rental income, and other property income. Yet the CEX's income data are limited, especially on capital income. In particular, capital gains are omitted. When aggregating total capital and wage income reported in the CEX, we find that capital income is less than 5% of total factor income, which indicates that much capital income is missing.

To supplement these capital income data we use the SCF, which provides much more complete capital income data (but no expenditure data, as in the CEX).[13] We impute capital income for each household in the CEX based on the distribution of capital income in both data sets. For instance, for the household in the 75th percentile of the capital income distribution in the CEX (with a reported capital income of about \$230), we assign the value of capital income at the 75th percentile of the distribution in the SCF (about \$2000). In effect, we assume that the underreporting of income in the CEX, though it gets the value of capital income wrong, preserves the household's place in the capital income distribution.

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[12] The CEX is available at http://www.bls.gov/cex/, and the SCF is available at http://www.federalreserve.gov/pubs/oss/oss2/scfindex.html.

[13] We drop households in the CEX with negative reported total income (1.6% of observations). We drop those in the SCF with negative reported capital income (2.5% of those observations). The mean value of reported capital gains income in the SCF is \$5358, while this category is missing in the CEX. The mean value of business income (including farms) in the SCF is \$11316, while it is only \$3252 in the CEX. Our use of the SCF resembles that of Metcalf et al. (2010).

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 in the CEX. Capital income from the SCF is the sum of income from interest, dividends, capital gains, and farm and other business income (but not any capital income within retirement accounts).[14] 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 category "other income," which accounts for less than 1% of total income.

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

(1) Annual Income Decile	(2) % of Income from Wages	(3) % of Income from Capital	(4) % of Income from Transfers	(5) Capital-Wage Ratio (%)	(6) Dirty Good Expenditure as % of Income	(7) Clean Good Expenditure as % of Income
All	69.1	24.6	6.3	35.6	6.6	58.7
1	35.8	5.7	58.5	16.0	47.4	361.0
2	33.9	4.1	62.1	12.0	20.3	141.9
3	55.1	6.5	38.4	11.8	16.7	116.5
4	68.1	7.4	24.5	10.9	13.5	97.3
5	79.9	7.8	12.2	9.8	11.1	84.0
6	83.4	8.8	7.8	10.6	9.6	74.8
7	86.6	9.1	4.3	10.5	8.3	68.0
8	86.8	10.6	2.6	12.2	7.2	62.9
9	84.9	13.2	1.9	15.6	5.9	58.1
10	53.5	45.6	0.9	85.3	2.5	32.6

Overall, about 69% of consumer income is from wages, 25% from capital, and 6% from transfers. These fractions vary by income group. The fraction of income coming from transfers is declining over income deciles (with the exception that the lowest income decile has a slightly lower fraction than the next decile), and the fraction of income coming from capital is increasing (with the same lone exception). Column 5 presents the capital-wage income ratio for each group, excluding any income from transfers. This ratio is U-shaped, with a much higher value for the richest decile.

The fact that the lowest annual income decile has the second-highest capital-wage ratio (16%) indicates one major problem with using annual income to categorize families from rich to poor. The lowest decile includes a lot of

[14] The omission of capital income from retirement accounts understates total capital income. While the SCF includes retirement account withdrawals and balances, it does not show income.

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, though we may want to classify households by the *stock* of lifetime wealth, we instead 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 is 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.[15] Each value is a ratio of that expenditure to annual income, not to total expenditures, so these two values do not add to 100% in each row. The poorest deciles spend more than they earn, and the richest deciles spend less than they earn.[16]

Our earlier distinction between clean and dirty *production* sectors does not present us with an immediate mapping into 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 et al. (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 et al. 2009). For a CO_2 tax of \$15 per metric ton, 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%.[17]

Overall, in Table 2, about 7% of income goes toward these dirty goods, and about nine times as much goes toward clean goods. The pattern of expenditures for these annual income groups is smoother than is the pattern for

[15] Only 65.3% of total income is spent (see the top row of Table 2). This ratio is low, compared to the 85% ratio in data from the National Income and Product Accounts (NIPA) of the Bureau of Economic Analysis (BEA) at http://www.bea.gov/national/nipaweb/SelectTable.asp?Selected=Y (see Table 2.1). Using the CEX data alone, however, the overall ratio of expenditure to income is only 78.7%. We then add some imputed capital income from the SCF, which reduces the overall spending/income ratio from 78.7% to 65.3%.

[16] One reasonable approach would scale all household expenditures upward so that their sum is 85% of income as in the NIPA accounts, but we wish to avoid unnecessary manipulation of the data. A proportional scaling would not change our relative burden results in any case.

[17] 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).

income sources. Higher income households spend a lower fraction of their total income on dirty goods than do lower income households.

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

(1) Expend. Decile	(2) Wage Income as % of Expend.	(3) Capital Income as % of Expend.	(4) Transfer Income as % of Expend.	(5) Capital-Wage Ratio (%)	(6) % of Expend. on Dirty Good	(7) % of Expend. on Clean Good
All	105.8	37.6	9.7	35.6	10.1	89.9
1	42.8	13.5	63.5	31.6	14.5	85.5
2	74.5	13.8	36.6	18.5	15.2	84.8
3	86.3	16.2	26.8	18.7	14.6	85.4
4	103.5	18.0	17.7	17.4	13.9	86.1
5	108.8	20.4	13.8	18.7	13.2	86.8
6	114.4	29.4	10.0	25.7	12.3	87.7
7	118.8	31.2	7.3	26.2	11.5	88.5
8	120.0	38.4	5.7	32.0	10.8	89.2
9	124.6	45.1	3.9	36.2	9.3	90.7
10	93.4	54.7	2.4	58.6	5.9	94.1

Because of the issues discussed earlier with measuring incidence across annual income groups, Table 3 presents the same decompositions across deciles defined by a different measure of "income", namely total annual expenditure (which serves as a proxy for lifetime income). Yet we do not have lifetime breakdowns of wages and capital income. Therefore, in Table 3, all annual income sources do not sum to this measure of income, while all annual expenditures do sum to this measure of income. On average, the sum of all sources of annual income is higher than total annual expenditure. In Table 3, the pattern of spending across clean and dirty goods is qualitatively the same as in Table 2; richer households have a lower ratio for expenditures on dirty goods. In fact, using consumption deciles rather than annual income decile reduces the variance in the fraction spent on the dirty good. The gap between the richest and poorest groups' percentage spent on the dirty good is 9 percentage points in Table 3, versus 45 percentage points in Table 2.

The implications of this phenomenon will be seen below in the simulation results. Briefly, when a CO_2 tax hike increases the relative price of the dirty good, then the tax hike appears less regressive when households are divided into annual consumption groups than when households are divided into annual income groups. This corroborates previous research on the uses-side incidence of energy policy (Hassett et al. 2009) and more generally of consumption taxes (Lyon and Schwab 1995).

Capital income's share is monotonically increasing across the expenditure deciles, and transfer income's share declines across the expenditure deciles. The capital-wage ratio is high for the poorest group compared to the second group, but then shows a roughly increasing pattern through the remaining nine deciles. For all groups, the sum of annual income sources exceeds total spending.

III. Numerical Results

We consider the effects of doubling the CO_2 tax from \$15 to \$30 per ton, that is, a 100% increase in the tax rate ($\hat{\tau}_Z = 1$). The base case results for changes in goods prices and factor prices are presented in the first column of Table 4. Other columns present results from sensitivity analyses, discussed later. In all columns the price of the dirty good changes by more than 7%, while factor prices change by less than one percent. But these results do not imply that effects on the uses side outweigh effects on the sources side, because the 7% output price change applies to only the 6.6% of income spent on the dirty good, while a "small" factor price change may apply to more than half of a group's income. Later we will see that uses effects usually outweigh sources effects, but not always.

Table 4: Simulation Results: Effect on Factor and Output Prices (%)

Change in Price of:	(1) Base Case	(2) Capital a Better Substitute	(3) Labor a Better Substitute	(4) Low Substitution in Utility	(5) High Substitution in Utility
Dirty good, $\hat{p}_Y$	7.20	7.26	7.07	7.23	7.16
Wage rate, $\hat{w}$	0.0718	–0.067	0.35	0.00100	0.14
Return, $\hat{r}$	–0.12	0.11	–0.58	–0.00166	–0.24

In the base case, the change in the relative output price $\hat{p}_Y$ (0.0720) is very close to $\theta_{YZ}\hat{\tau}_Z$ (0.0723, see Table 1), 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 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. Using 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 for 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 (all divided by the group's income). Because our numeraire used in solving the system sets $\hat{p}_X = 0$, these burdens will be positive for every 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 ratio of their expenditures to income increase more than the average, and those groups with a negative value see their ratio of expenditures to income increase less than the average. The calculation is similar for the sources-side incidence: $\hat{w}$ times income from wages plus $\hat{r}$ times income from capital, all divided by total income, minus this ratio 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 decreases more than the average have a positive "burden", while those groups whose income decreases less than the average have a negative burden (a relative gain). Finally, we calculate each group's normalized overall burden by summing the uses side and sources side burdens.

Table 5: Incidence with Base Case Parameters for Annual Income Deciles

Annual Income Decile	Relative Burden from Output Price Changes (%)	Relative Burden from Factor Price Changes (%)	Relative Overall Burden (%)
1	2.936	0.001	2.937
2	0.986	0.001	0.986
3	0.724	-0.012	0.713
4	0.496	-0.020	0.476
5	0.323	-0.028	0.295
6	0.216	-0.029	0.186
7	0.123	-0.031	0.092
8	0.045	-0.029	0.015
9	-0.051	-0.025	-0.076
10	-0.297	0.036	-0.261

These incidence results are presented in Table 5. The pattern of uses-side burdens in the first column is clear: the highest income groups (deciles 9 and 10) 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 0.48% (a 7.2% increase in the price of the good that constitutes 6.6% of total annual income). Thus, Table 5 tells us that the highest income group's price increase under this normalization overall is only about 0.18%, whereas the lowest income group sees an overall price increase of about 3.4%. These results are consistent with those in Hassett et al. (2009), who examine the uses-side incidence of a CO_2 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.

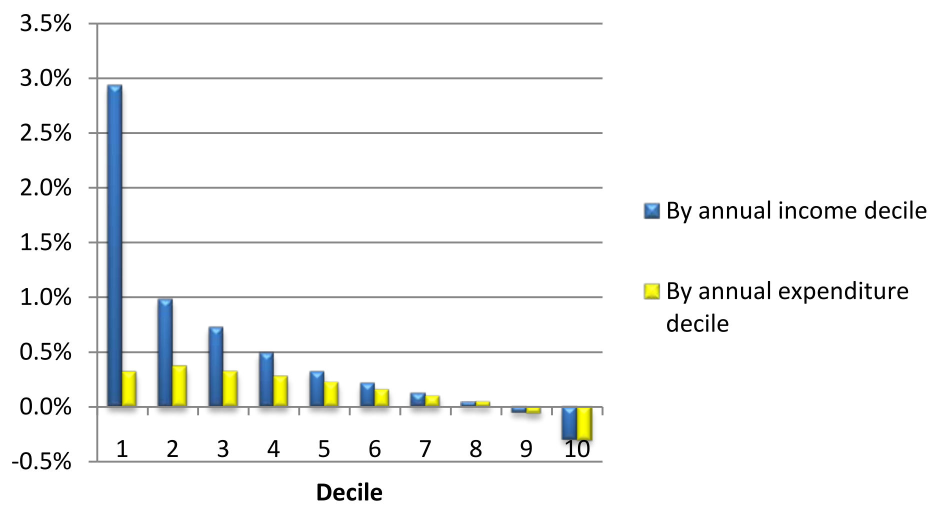
The sources-side burden in the second column of Table 5 is felt most by the highest and lowest income deciles; the positive burdens for the lowest deciles indicate that their incomes fall proportionally more than average. In the base case simulation, $\hat{w} > 0$ and $\hat{r} < 0$, so earning a higher fraction of income from capital tends to increase overall real burdens. Table 2 shows that the capital-wage income ratio is U-shaped across the ten deciles, and so the sources side burden in Table 5 is U-shaped. This effect is muted in the lowest decile, however, because of their high share of income from transfers. Because the sources side burdens are all small relative to the uses side burdens, the overall pattern in the last column mimics the regressive burdens on the uses side.

Table 6: Incidence with Base Case Parameters for Expenditure Deciles

Annual Expenditure Decile	Relative Burden from Output Price Changes (%)	Relative Burden from Factor Price Changes (%)	Relative Overall Burden (%)
1	0.316	0.016	0.333
2	0.366	-0.006	0.360
3	0.319	-0.012	0.307
4	0.273	-0.022	0.251
5	0.218	-0.023	0.195
6	0.157	-0.016	0.141
7	0.099	-0.017	0.082
8	0.046	-0.009	0.036
9	-0.063	-0.005	-0.068
10	-0.303	0.029	-0.273

Table 6 presents the same calculations for income groups defined by annual consumption rather than by annual income. The uses-side incidence in the first column is again regressive, and the sources-side incidence in the second column is again U-shaped. And because the uses side burden again dominates the sources side, the overall burden is still regressive. When groups are defined by annual consumption, the uses-side incidence is *less* regressive than when defined by annual income. The lowest expenditure decile's relative price increase in Table 6 (0.32%) is smaller than the lowest annual income decile's price increase in Table 5 (2.94%). This pattern can be seen in Figure 1, which plots the relative uses-side burdens by income and expenditure deciles. This result occurs because the between-decile variance in the fraction of spending on the dirty good is lower across consumption deciles than across annual income deciles.

Figure 1: Base-Case Relative Burdens on the Uses Side



Sources-side incidence is U-shaped in Table 6 due to the U-shaped pattern of capital-wage income ratios in Table 3, because the wage is rising ($\hat{w}$ = +0.07%), while the return to capital is falling ($\hat{r}$ = –0.12%). Both sets of relative sources-side burdens are plotted in Figure 2.

Sensitivity Analysis

The results in Tables 5-6 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 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.[18] Next, we present alternative incidence calculations for different sets of parameter values. The changes in prices under these alternative parameter values are presented in columns 2 through 5 of Table 4. In columns 2 and 3, all of the parameters are identical to their base case values except for the dirty sector substitution elasticities. In column 2, we set e_{KL} = 0.1, e_{KZ} = 0.5, and e_{LZ} = –0.5. In this column, 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 signs of the price changes in w and r switch from the base case. The second set of results (in column 3) are based on parameters where labor is a much better substitute for pollution than is capital: e_{KL} = 0.1, e_{KZ} = –0.5, and e_{LZ} = 0.5. Under these parameter values, capital bears a larger share of the tax burden than even in the base case, since the fact that labor is a substitute for pollution enables it to avoid more of the burden.

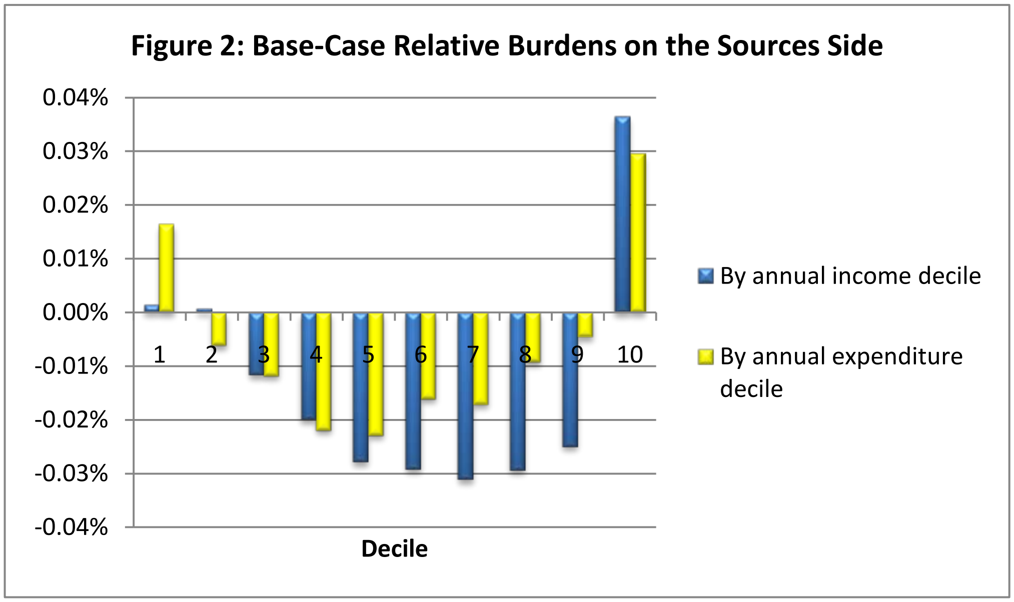


Table 7 presents the resulting incidence calculations across annual expenditure groups. Columns 2 and 3 present the relative burdens from the uses

[18] We calibrated elasticities for our model based on estimates in Jin and Jorgenson (2010) that were based on a somewhat different model, with more sectors, and where firms use labor, capital, and energy. Our dirty sector uses labor, capital, and pollution (which is not the same as energy, because firms can reduce their pollution per unit of energy).

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 (relative to Table 6), even with this large change of production substitution elasticities. The households with the lowest expenditures 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 the U-shaped burdens associated with the base case parameters in Table 6 (where the reduction in r hurts capital owners in the highest and lowest income deciles). In column 3 of Table 7, the return to capital rises (as shown in column 2 of Table 4), so the richest and poorest deciles see their incomes rise relative to the average, while the middle deciles see their incomes fall 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 expenditure group has the highest capital/wage income ratio, and thus it gains the most on the sources side under this parameterization. Here, instead of offsetting the uses side, the sources side exacerbates the regressivity of the uses side.

Table 7: Incidence for Expenditure Deciles, Sensitivity Analysis on Production Parameters

	Capital a better substitute for pollution		Labor a better substitute for pollution	
(1) Annual Expenditure Decile	(2) Relative Output Price Burden (%)	(3) Relative Factor Price Burden (%)	(4) Relative Output Price Burden (%)	(5) Relative Factor Price Burden (%)
1	0.319	-0.016	0.311	0.081
2	0.369	0.005	0.360	-0.029
3	0.321	0.011	0.313	-0.056
4	0.276	0.020	0.268	-0.106
5	0.220	0.021	0.214	-0.111
6	0.158	0.015	0.154	-0.078
7	0.099	0.016	0.097	-0.083
8	0.046	0.009	0.045	-0.045
9	-0.064	0.004	-0.062	-0.023
10	-0.305	-0.027	-0.297	0.143

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 in column 5 are opposite to those in column 3 and are in the same direction as in the base case.

Here, because the wage rate rises, the poorest and richest deciles have more burden relative to the average, and the middle deciles have less burden relative to the average. The highest income group has the most capital and is therefore burdened the most, so the sources-side incidence is more progressive than in the base case results. The degree of progressivity is higher than in the base case, since the magnitudes of the factor price changes are higher in this simulation than in the base case.

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. These results are presented in columns 4 and 5 of Table 4. The substitution elasticities in production are kept at the base case values. When $\sigma_u = 0.5$, the relative price changes in w and r are very close to zero, indicating a proportionally-shared burden between labor and capital. When $\sigma_u = 1.5$, capital bears a higher share of the burden than in the base case. In all of these cases the dirty sector is capital-intensive, and so the output effect makes capital worse off. When $\sigma_u = 0.5$, the output effect burden on capital is small and completely offset by the substitution effect (which helps capital, 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 CO_2 tax increase. The uses-side incidence $\hat{p}_Y$ does not vary much with σ_u.

Table 8 presents incidence calculations for the alternative parameter values of σ_u. This parameter does not affect the uses-side incidence, which is regressive for both alternate values of σ_u. It does, however, affect the sources-side incidence. When σ_u is low, as in columns 2 and 3 of Table 8, the output effect hurting capital is small and dominated by the substitution effect, so the burden on capital is roughly proportional (to three decimal places). On the other hand, when σ_u is high, the burden on capital owners is increased since the output effect dominates. Thus, the richest and poorest households bear relatively more of the burden.[19]

Middle-Aged Heads of Household

Annual income is a poor proxy for lifetime income. Annual consumption may be a better proxy, but even this case leaves us with only one year's capital-wage income ratio. This measure may fail to capture the desired long-term capital-wage income ratio for each permanent income group. A large part of the

[19] All of the findings from Table 7 and 8 hold for annual income deciles as well as annual expenditure deciles, though those results are not presented.

problem is that individuals have different income patterns at different stages of their lives. Retirees have low annual income but high a capital share, while college students have low annual income but high borrowing. Some evidence for this pattern appears in the CEX data. The ten annual income deciles have average ages that range from 45.3 years to 58.9 years, whereas the ten annual consumption deciles have average ages that range only from 47.2 years to 53.1 years.

Table 8: Incidence for Expenditure Deciles, Sensitivity Analysis on Substitution in Utility

	Low substitution in utility		High substitution in utility	
(1)	(2)	(3)	(4)	(5)
Annual Expenditure Decile	Relative Output Price Burden (%)	Relative Factor Price Burden (%)	Relative Output Price Burden (%)	Relative Factor Price Burden (%)
1	0.318	0.000	0.315	0.030
2	0.368	0.000	0.364	-0.013
3	0.320	0.000	0.317	-0.024
4	0.274	0.000	0.272	-0.044
5	0.219	0.000	0.217	-0.046
6	0.158	0.000	0.156	-0.032
7	0.099	0.000	0.098	-0.034
8	0.046	0.000	0.045	-0.018
9	-0.063	0.000	-0.063	-0.009
10	-0.304	0.000	-0.301	0.058

An alternative method of overcoming this life-cycle problem is to focus on only one age group for head of household. We choose households whose heads are 41-50 years old.[20] Table 9 summarizes the income sources and expenditure data across the ten annual expenditure deciles of these households. Overall, these households have a lower capital-wage ratio (25.1%) than do all households (35.6%, in Table 3). The fraction of expenditures on dirty goods (10.2%) is virtually identical to that for all households (10.1%, Table 3). Across expenditure deciles, the decreasing fraction of income from transfers is again seen. Here, though, this fraction drops to single-digit percentages by the second decile, and overall, transfers are only 2.6% rather than 9.7% of expenditure (Table 3). These 41-50 year old household heads are not receiving nearly as much Social Security retirement income as all other households in Table 3.

The big difference in Table 9 compared to Table 3 is that the capital-wage income ratio is clearly rising with income (in an almost monotonic fashion). In

[20] Another approach, which we do not pursue here, is to attempt to create a synthetic cohort of households using multiple years of the CEX, as in Jorgenson and Slesnick (2008).

Table 3, it was U-shaped. While using expenditure deciles in Table 3 may capture permanent income, each decile still contains young and old with very different income sources. The 41-50 year olds in Table 9 may have income sources that better reflect their long run income sources.

Table 9: Sources and Uses of Income for each Annual Expenditure Group, Households with Heads aged 41-50 only

(1) Annual Expend. Decile	(2) Wage Income as % of Expend.	(3) Capital Income as % of Expend.	(4) Transfer Income as % of Expend.	(5) Capital-Wage Ratio (%)	(6) % of Expend. on Dirty Good	(7) % of Expend. on Clean Good
All	125.5	31.5	2.6	25.1	10.2	89.8
1	94.9	7.7	26.7	8.1	15.2	84.8
2	125.2	11.3	9.9	9.0	15.4	84.6
3	131.8	12.6	8.0	9.6	14.6	85.4
4	137.2	22.3	3.3	16.2	14.0	86.0
5	141.3	16.9	2.5	12.0	13.2	86.8
6	140.3	29.7	2.0	21.2	12.1	87.9
7	133.1	35.4	1.5	26.6	11.7	88.3
8	142.7	34.2	1.4	23.9	10.8	89.2
9	131.4	31.3	0.8	23.8	8.9	91.1
10	101.5	44.3	0.5	43.6	5.9	94.1

Table 10 presents the incidence calculations for these 41-50 year old household heads. 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 progressive, in contrast to the U-shaped result from the base case for all households (Table 6). Under the alternate substitution parameters, the sources-side burden is regressive when capital is a better substitute for pollution, and progressive when labor is a better substitute for pollution.

Whereas the capital-wage ratio for all households in Table 3 varies from 0.185 to 0.586 (a factor of three), the ratio for 41-50 year olds in Table 9 varies from 0.081 to 0.436 (a factor of more than five). If capital income is an important lifetime source of income for the well-to-do, and if the return falls as much as 0.58% (column 3 of Table 4 and last column of Table 10), then the sources side could be particularly progressive. In fact, the sources-side burden here is sufficiently progressive that it comes close to offsetting the regressivity of the uses side burden: the *overall* burden is much less regressive than in any other simulation. If the return rises 0.11% (column 2 of Table 4 and column 5 of Table 10), then the sources side could be regressive – exacerbating the regressive effects of carbon pricing on the uses side. We conclude that general equilibrium effects are potentially important.

Table 10: Incidence for Households with Heads aged 41-50 only

	Base Case		Capital better substitute for pollution		Labor better substitute for pollution	
(1) Annual Expend Decile	(2) Relative Output Price Burden (%)	(3) Relative Factor Price Burden (%)	(4) Relative Output Price Burden (%)	(5) Relative Factor Price Burden (%)	(6) Relative Output Price Burden (%)	(7) Relative Factor Price Burden (%)
1	0.358	-0.007	0.361	0.006	0.351	-0.031
2	0.374	-0.024	0.377	0.022	0.367	-0.116
3	0.314	-0.027	0.317	0.025	0.308	-0.132
4	0.274	-0.019	0.277	0.018	0.269	-0.094
5	0.211	-0.029	0.213	0.027	0.207	-0.140
6	0.135	-0.013	0.137	0.012	0.133	-0.062
7	0.106	-0.001	0.107	0.001	0.104	-0.003
8	0.041	-0.009	0.041	0.009	0.040	-0.045
9	-0.098	-0.004	-0.099	0.004	-0.096	-0.022
10	-0.312	0.033	-0.315	-0.030	-0.306	0.158

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 data along with imputed capital income from the SCF data are used to tabulate expenditure and income data by the four census regions. Results are summarized here. Households in the West region have a substantially higher capital-wage ratio (42% vs. an average of 35.6%). Households in the West spend a lower fraction of their expenditures on dirty goods (8.4%), and households in the South spend a higher fraction on the dirty good (11.3%), compared to the average (10.1%, Table 3). A reason is that households in the South spend more than elsewhere on electricity for their air conditioners. The incidence results follow from these facts. On the uses side, the West faces a lower burden (0.125% less than average) and the South faces a higher burden (0.087% higher than average). The deviations from a proportional burden on the sources side are small, but the West's burden is somewhat higher than the average (0.009%).

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. In general, the uses-side costs are relatively more burdensome on low income households, 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 et al. 2009, or Burtraw et al. 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 relatively capital-intensive). This implies a U-shaped burden when households are divided by annual expenditure or by annual income. This result is sensitive to chosen parameter values for substitution elasticities that are not known. The burden on the sources side can even be regressive if the wage falls relative to the rental rate, such as when capital is better than labor as a substitute for pollution.

Many extensions to the model are possible, including more sectors, more final goods, intermediate goods, market power, or other refinements.[21] In particular, consideration of imperfect factor mobility could significantly affect the results; the transition costs for both capital and labor are likely to be large components of the overall burden of any policy. 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. The particular policy could be modeled more carefully, rather than just looking at a simple tax.[22] A more complex CGE model may allow more specific results, but at the expense of analytical solutions made possible by our simple two-sector model.[23] Finally, this model does not incorporate the benefits of pollution reduction, which themselves may be progressive or regressive.

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[21] Capital may bear none of the burden, for example, in a dynamic model with capital accumulation, or in an open economy with international mobility where the world-wide rate of return is fixed (though see Gravelle and Smetters, 2006).

[22] See Burtraw et al. (2010) 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.

[23] For example, Rausch et al. (2010) use a CGE model with a detailed structure of the U.S. energy sector to investigate the distributional impacts of a carbon tax.

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