The Income Distribution Impacts of Climate Change Mitigation Policy

*By Gbadebo Oladosu and Adam Rose**

Introduction

Mitigating the potentially dramatic impacts of climate change is one of the leading environmental policy concerns of the 21st Century. Since the combustion of fossil fuels is the largest single source of greenhouse gases in industrialized countries, carbon taxes and carbon emission permits are at the forefront of instrument design in this era of incentive-based policies (Weyant, 1999; Rose and Oladosu, 2002). While promising a cost-effective solution, the macroeconomic impact of implementing these instruments is, however, predicted on average to be negative for most policy designs.[1]

The distribution of the cost burden of climate change mitigation policies, like that of nearly all environmental and energy policies, will inevitably be uneven within and across the categories of households and businesses (Rose et al., 1988). The benefits of these policies (avoided damages of climate change) are distributed unevenly as well, and in a different manner than the cost (see, e.g., Oladosu, 2000). Although dozens of studies have investigated potential aggregate economic impacts of climate change policy (see, e.g., Weyant, 1999; IPCC, 2001), very few have examined their distributional impacts.

The purpose of this paper is to analyze the cost-side income distribution impacts of a carbon tax in the Susquehanna River Basin (SRB) Region of the United States. The analysis is undertaken with a computable general equilibrium (CGE) model specially constructed for this purpose in terms of conceptual design and detailed empirical specification of income and consumption relationships (see Oladosu, 2000). The analysis is undertaken at the regional level for two major reasons. First, climate change impacts, a major driver of the pace and shape of mitigation policy, are likely to vary by region in a large country such as the U.S. Moreover, climate impacts are not likely to conform to sub-national political boundaries but rather to major ecosystems, a notable example being a watershed. Second, implementation of climate change mitigation policy will take place at the regional and local levels. In any effort to match remedies to problems in general, and to match beneficiaries to cost-payers in particular, a regional approach will be necessary and will likely shift attention away from artificial boundaries like political jurisdictions (see, e.g., Easterling et al., 1997).[2]

Distributional impacts are important for two reasons. First, from a normative standpoint, previous studies have generally found carbon taxes to be regressive (i.e., to place a disproportionate burden on lower income groups). This is important from the standpoint of equity, or fairness, in its own right. Second, for more pragmatic reasons, the distribution of impacts is important for policy formation and viability, since groups negatively impacted can mobilize opposition (Rose et al., 1988). Bovenberg and Goulder (2002) have pointed out that businesses are likely to have more clout than consumers in this regard. However, accelerating concern about environmental justice (broadly defined) draws attention to lower income and minority households, and effectively mobilizes opposition on their behalf.

Background

A small number of studies have examined the income distribution impacts of carbon taxes or carbon emission permits (see, e.g., Harrison, 1995; Metcalf, 1998; as well as the reviews by Repetto and Austin, 1997; and Speck, 2001). We begin by summarizing the three special features most emphasized to distinguish the impacts of these policies in contrast to the incidence of taxes in general. First, although the initial focus is on a few but very prominent sectors that emit carbon (Coal/Oil/Gas extraction, transportation, and refining), the fundamental role of these products, however, means that carbon reduction policies will eventually ripple throughout the economy, with possibly surprising outcomes. This is one of the major reasons computable general equilibrium models are used.

Second, fossil energy products and most energy-intensive processed goods (food, housing, automobiles) are necessities, making it relatively more difficult to substitute away from them. Spending on necessities is inversely related to income and, hence, all other things being equal, carbon taxes would lean toward being regressive in partial equilibrium terms.

Third, unlike most existing taxes, carbon taxes are not aimed primarily at raising revenue. Moreover, they do not create a distortion in the price system but are intended to correct one. These factors have important implications for the disposition of carbon tax revenues (or revenues from the auction of carbon emission permits), including the possibility of using carbon tax revenues for tax relief that promises to reduce the distortionary nature of the pre-existing tax system. This revenue recycling can take a number of forms (reductions in personal income taxes, corporation income taxes, etc.), with different distributional impacts. Again, however, the final impacts of these alternatives are not a priori obvious when one allows for general equilibrium considerations.

Overall, a large number of other factors, both unique to carbon taxation and applicable to tax policy in general, can have a major bearing on the relative unevenness of impacts

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[1] See footnotes at end of text.

(OECD, 1995; Oladosu and Rose, 2003). It is also important to note several factors that affect the size of the aggregate impact, since it will also have a bearing on the degree to which the baseline income distribution changes. Of course, the size of the aggregate impact can affect the distribution of impacts in highly nonlinear models or where such factors as income elasticities of demand vary strongly across income groups. Major factors include:

1. energy-intensity of the economy
2. magnitude of the carbon tax or emission permit price
3. unit upon which the tax is based
4. narrowness or breadth of products or entities on which the tax is imposed
5. point of initial imposition of the tax (i.e., upstream suppliers of energy or downstream users)
6. ability to shift the tax forward onto customers or backward onto factors of production
7. extent of factor mobility
8. extent to which general equilibrium effects are taken into account
9. extent of production/income distribution/consumption interactions
10. extent to which dynamic effects are taken into account
11. use of annual income versus lifetime income as a reference base
12. extent to which demographic considerations are taken into account
13. type of revenue recycling
14. asset market considerations
15. degree to which the impacts result in unemployment
16. basic parameters and assumptions of the analytical model

In our analysis, we evaluate the influence of nearly all of these factors on income distribution impacts of a carbon tax on the SRB.

Model Formulation

Overview

Several factors need to be considered in designing a CGE model for policy analysis. The most important ones are the issues to be analyzed, size and nature of the economy, and data availability. These factors guide choices in the specification of various segments of the economy in terms of detail and functional forms (see Oladosu, 2000, for full details of the model). This section presents the specification of a static, regional computable general equilibrium (CGE) model of the Susquehanna River Basin (SRB). The model is structured to be consistent with the objectives of assessing the impacts of climate change policies on the regional economy.

The SRB CGE model includes four main types of activities: production, consumption, trade and investment performed by four institutions: enterprises, households, government, and external agents. The SRB economy is divided into 49 sectors and market goods in the model, delineated to highlight climate change and policy sensitivity in the economy. The Electricity sector is further divided into five sub-sectors to represent the various types of electricity generation sources in the SRB economy. Production activities are modeled using non-separable, nested constant elasticity functions (NNCES). Labor, capital, energy and materials are the four aggregate factors of production in the model, with energy and materials being further disaggregated into the 49 component market goods. Consumer behavior in the model utilizes a household production function formulation for both market and non-market goods. Households are represented by a 9-income bracket categorization. Government is disaggregated into Federal and State/Local levels. These governments receive their incomes mainly from five types of taxes: social security, indirect, income, trade, and profit taxes, which are expended on the purchase of market goods and transfers to other institutions. The remainder of aggregate demand is investment goods and net additions to stock. The regional nature of the model necessitates a nested trade structure with the Region and the Rest of the U.S. in the lower nest, and the Rest of the World in the upper nest. This trade structure is tied to the supply of market goods to regional and external markets.

Data requirements for the model include the social accounting matrix, factor demand and supply data, household expenditure and demographic data, capital composition matrix, capital and labor income mapping data, and environmental data among others. With these data and the model specification, necessary parameters for implementing each module are derived using a combination of several approaches. Econometric estimation is used in implementing the indirect utility function for households, while literature synthesis and expert judgments were used in deriving elasticities of substitution for producer and household cost functions. Parameters such as the industry-by-occupation matrix, capital composition matrix, capital income allocation matrix and various other labor supply parameters are based on similar data for the entire or other parts of the United States. Other model parameters were calibrated using economic data specific to the SRB economy. Still other model parameters are directly computable from the various data and calibration features.

The major data source for the model, the IMPLAN database (MIG, 1998), distinguishes 528 industries and market goods, which were aggregated to 49 industries and market goods. For households, expenditures on market goods are disaggregated from the three income brackets of the IMPLAN database to the nine income categories of the SRB CGE following Rose et al. (1994) and Oladosu (2000).

Elasticities of substitution and transformation are the main parameters that need to be specified for import and export functions in the SRB CGE model. Without the requisite time-series or cross-sectional data for estimating these parameters, we synthesized the literature to determine the appropriate range of values (see, e.g., Reinert and Roland-Holst, 1992; and Shiells and Reinert, 1993).

Carbon Tax Policy Modeling

At the 1997 Kyoto conference of parties, the United States committed to a reduction of its carbon equivalent emission of GHGs to 7.0 percent below 1990 levels between 2008-2012. Estimates of the marginal value of a ton of carbon or carbon tax/permit price to achieve comparable targets vary widely from a low of $5 to a high of $250 (Weyant, 1999; Rose and Oladosu, 2002). We have chosen to evaluate a carbon tax rate of $25 per ton of carbon, a level often cited as being an upper-bound for a U.S. commitment to a GHG reduction treaty, with the case of $100 per ton of carbon simulated as part of a sensitivity analysis. The determination of the tax rate is exogenous to the SRB economy, and we also assume the same tax rate applies elsewhere in the U.S. (and implicitly to major trading partners).

Given that fossil fuels consumption is the major source of carbon emissions in the U.S., upstream consumption taxes on crude oil, natural gas and coal are simulated using the SRB CGE model. Other carbon emitting activities such as agriculture and land-use activities have not featured prominently in the carbon tax/permit market discussion, so we have omitted these from consideration.

Implementation of a product tax requires that the carbon tax be converted to an ad valorem tax. Since emission factors and energy content of fossil fuels vary within a very narrow range, tax rates can be easily calculated once fossil fuel prices are known.

A multitude of possible carbon tax scenarios can be formulated depending on the treatment of trade effects, revenue recycling assumptions, tax rates and types, as well as time horizon considerations. Table 1 summarizes the carbon tax scenarios simulated using the SRB CGE model. The base scenario (Scenario 0) is a $25/ton ad valorem, upstream consumption tax on Coal, Crude Oil and Natural Gas, with the proceeds going into general government spending. Fuel prices and emission factors on which tax rates are based are presented in Table 2.

Table 1
Alternative Carbon Tax Scenarios

Case	Tax Rate ($/ton)	Type of Tax	Other Characteristics
0	25	Consumption	Revenue goes into general government spending
A	25	Production	Revenue goes into general government spending
B	25	Consumption	Lump sum transfer of tax revenue to households
C	25	Consumption	Tax revenue used to offset personal income tax
D	100	Consumption	Revenue goes into general government spending

Results

Aggregate and Sectoral Impacts

A $25/ton carbon consumption tax, with proceeds going into general government spending is our Reference Case—Case 0). Overall impacts on the economy are measured by Gross Regional Product (GRP), which is projected to decline by 0.30 percent in the short run. Long-run changes in this variable are a little over two times that for the short run. Real producer price index declines by 0.24 percent in the short run and by 0.33 percent in the long run. Average factor prices also change significantly, except for the short-run capital return rate. Average wage and capital return rates decline by 1.02 percent in the long run. The short-run wage rate declines by 0.44 percent, though labor supply response (employment) to wage rate changes was small in both cases, with the largest decline of 0.23 percent in the long-run. Total revenue resulting from the carbon tax is around $700 million in both instances.

Table 2
Principal Carbon Tax Scenarios

Consumption Tax Conditions:

Sector	Fuel Price	Emission Factor	Percent Tax
Coal	$26.8/short ton	0.027 ton/mmbtu	53
Crude Oil	$17.2/barrel	0.021 ton/mmbtu	18
Natural Gas	$2.8/mcf	0.015 ton/mmbtu	13

General Closure Conditions:

Sectoral occupational wage rates are linear functions of a freely adjusting average wage rate

Sectoral government expenditures are constant shares of total government spending, while government balance is fixed at the benchmark level

Transfers are constant shares of transferors' income

External Closure:

Import and export prices adjust to maintain 1995 relative domestic and external prices

External agents savings adjust to maintain a zero overall balance of payments

Short-run Closure Rules:

Capital stock is fixed by sector, and sectoral return rates adjusts freely

Long-run Closure Rules:

Capital is mobile across sectors, and sectoral return rate is a linear function of average rate of return in the economy

Total capital stock is flexible, and relative wage and capital return rate is constant

Note: *mcf* = thousand cubic feet; *mmbtu* = million British thermal units.

The primary effect of the consumption tax is to increase energy costs, and consequently shift sectoral marginal cost functions upward. Intuitively, the extent of this effect would vary with the share of energy in production, implying that large energy users would feel the effects of the tax most. Although this sectoral distinction is important, it is merely a starting point for examining the effect of the tax on producer behavior. A subtle but crucial factor is the extent of substitution possibilities among energy sources, as well as between energy and other inputs. This factor influences how much increased energy costs would increase production costs. Also, the demand-side effects of income and price changes throughout the economy could induce sectoral price changes in either direction.

The highest price increases in the short run are for the energy sectors. Supply prices increase by 52.50 percent for Coal, 9.36 percent for Crude Oil, 12.01 percent for Natural

Gas, 5.90 percent for Petroleum Products, 3.28 percent for Electric Services, and 3.22 percent for Gas Utilities. Output prices for these sectors, except those of Crude Oil and Coal, also increase, meaning that supply-side effects of the tax dominated the demand-side effects. For Coal and Crude Oil, the reverse is the case. Results for the remaining sectors of the economy suggest a dominance of demand-side effects of the energy price increases. Output changes are consistent with the observed price changes. The highest output reductions are for Coal, Crude Oil, Petroleum Products, and Electric Services: 22.90 percent, 5.03 percent, 3.44 percent, and 1.09 percent, respectively. All but two of the remaining sectors are projected to incur output declines of less than 1.00 percent.

Consumption and Income Distribution Impacts

Household (personal) income distribution effects of the carbon tax are driven by several factors. Income changes in the economy affect household disposable income. In turn, household income changes are determined by the allocation of labor and capital incomes as well as transfers. Labor income depends on household labor supply, which is influenced by the wage rate and labor supply elasticities. The average wage rate received by each household group also depends on the occupational composition of its working members. Since capital income allocation is based on fixed shares, changes in sectoral capital income are transmitted proportionally to households. Producer price changes affect household commodity costs, depending on substitution possibilities among inputs, as well as the market goods composition of commodities. Finally, the allocation of expenditures, and the resulting commodity demands are simultaneously determined. Given the linear expenditure system household utility functions, expenditures on subsistence commodity quantities adjust for cost changes before supernumerary expenditures are allocated to individual commodities according to marginal expenditure shares.

Distributional impacts are presented in Tables 3 and 4 for our Reference Case (Case 0). Table 3 shows that in the short run the first four income groups increase most of their commodity demands, while the last five groups decrease most of their demands. However, Fuel/Utilities decline in all households. These results suggest that income effects under the tax are more favorable to the lower income groups than to higher ones. As shown in Table 4, the former are projected to experience an income increase of just under 0.40 percent and the latter groups reductions of between 0.37 percent and 0.66 percent. Given the accompanying cost decreases that also favor the first four groups, lower income households are able to secure increased consumption of commodities of up to 0.80 percent in cases such as Housing by the $5K-$10K bracket. The opposite result for Fuel/Utilities implies that its price increase more than offsets all the positive income effects.

Long-run household results reflect the same factors as discussed above, but the patterns of results differ considerably for several reasons (see the bottom half of Table 3). First, income decreases now occur in all households, although not nearly as much for the lower income groups. Second, the cost-of-living index for most of the lower income groups increase, while those for some of the higher income groups de-

Table 3
Short- and Long-Run Consumption Effects of a $25/ton Consumption Carbon Tax: Government Expenditure of Tax Revenue (percent change)

	$0K-$5K	$5K-$10K	$10K-$15K	$15K-$20K	$20K-$30K	$30K-40K	$40K-$50K	$50K-$70K	>$70K	Overall
Short-Run Commodity Demands										
Food	0.30	0.38	0.45	0.41	-0.10	-0.05	-0.12	-0.31	-0.38	-0.07
Housing	0.79	0.80	0.64	0.61	-0.07	-0.14	-0.19	-0.31	-0.32	-0.09
Fuel/Utilities	-0.41	-0.64	-0.30	-0.40	-0.43	-0.34	-0.33	-0.56	-1.03	-0.52
Household Operation	0.67	0.69	0.67	0.59	-0.21	-0.19	-0.33	-0.53	-0.46	-0.22
Clothing/Jewelry	0.36	0.43	0.49	0.49	-0.13	-0.29	-0.13	-0.31	-0.37	-0.17
Transportation	0.04	-0.06	0.09	0.00	-0.47	-0.34	-0.23	-0.34	-0.52	-0.34
Health	0.76	0.75	0.70	0.68	-0.10	-0.25	-0.10	-0.28	-0.30	-0.04
Recreation	0.53	0.70	0.78	0.96	-0.10	-0.13	0.01	-0.11	-0.03	0.04
Others Commodities	0.69	0.73	0.71	0.75	-0.10	-0.16	-0.24	-0.44	-0.38	-0.15
Long-Run Commodity Demands										
Food	0.07	0.09	0.13	0.05	-0.39	-0.23	-0.45	-0.65	-0.77	-0.39
Housing	0.46	0.54	0.40	0.36	-0.37	-0.51	-0.51	-0.66	-0.66	-0.41
Fuel/Utilities	-1.16	-1.56	-0.92	-1.07	-0.87	-0.64	-0.63	-0.94	-1.67	-1.00
Household Operation	-0.14	-0.14	-0.06	-0.09	-0.90	-0.98	-1.16	-1.41	-1.36	-1.04
Clothing/Jewelry	0.04	0.06	0.02	-0.02	-0.52	-0.83	-0.49	-0.68	-0.80	-0.59
Transportation	-1.69	-2.01	-1.43	-1.33	-1.72	-1.34	-0.78	-1.01	-1.62	-1.31
Health	0.44	0.50	0.44	0.39	-0.45	-0.71	-0.40	-0.55	-0.53	-0.35
Recreation	-0.12	-0.12	-0.12	0.04	-0.79	-0.89	-0.62	-0.80	-0.88	-0.71
Others Commodities	0.31	0.39	0.27	0.34	-0.48	-0.60	-0.83	-0.99	-0.84	-0.63

crease. Thus, both Fuel/Utilities and Transportation demand decline more in all households than in the short-run. Demand increases by the first four income groups are now projected only for Food, Housing, Health, Clothing/Jewelry, and Other Commodities. Decreases in all other commodities are more severe for all groups than in the short run.

except in Cases B and C.

A production tax on carbon emitting products as simulated in this study is different from the consumption tax mainly in its trade effect. The consumption tax implicitly imposes the tax on both domestic demand/sales and imports, while the production tax imposes the same tax on domestic sales/demand and exports. Given that domestic and external prices adjust to maintain their base year relative levels, one would expect the results of both cases to be similar, with impacts being slightly less severe and generating less tax revenue in Case A.

Table 4
Short- and Long-Run Welfare Effects of a $25/ton Consumption Carbon Tax: Government Expenditure of Tax Revenue

		$0K-$5K	$5K-$10K	$10K-$15K	$15K-$20K	$20K-$30K	$30K-40K	$40K-$50K	$50K-$70K	>$70K	Overall
Short Run:	**Units**										
Per Capita Income	(%Δ)	0.36	0.37	0.37	0.36	-0.37	-0.42	-0.42	-0.64	-0.66	-0.44
Utility	(%Δ)	0.94	0.21	0.29	0.22	-0.28	-0.15	-0.18	-0.22	-0.12	-0.06
Eq. Variation/Capita	$	-5.50	-24.39	-46.01	-63.11	24.14	25.67	31.60	79.44	169.65	24.82
Gini Coefficient	(%Δ)	-	-	-	-	-	-	-	-	-	-0.15
Theil Index	(%Δ)	-	-	-	-	-	-	-	-	-	-0.14
Long Run:	**Units**										
Per Capita Income	(%Δ)	-0.27	-0.26	-0.25	-0.25	-0.96	-1.04	-1.04	-1.27	-1.30	-1.06
Utility	(%Δ)	-0.40	-0.11	-0.09	-0.06	-1.08	-0.67	-0.71	-0.56	-0.33	-0.51
Eq. Variation/Capita	$	2.48	13.47	14.85	19.32	94.90	115.81	128.85	207.32	456.75	121.49
Gini Coefficient	(%Δ)	-	-	-	-	-	-	-	-	-	-0.16
Theil Index	(%Δ)	-	-	-	-	-	-	-	-	-	-0.15

The welfare impacts of the tax on each income bracket are depicted by various measures in Table 4. The equivalent variation in per capita terms is slightly U-shaped in the short run but displays an obvious progressive pattern in the long run.[3] Overall, the welfare effects on the cost side of a carbon tax are negative and more pronounced in the long run than in the short run. The relatively better outlook of lower income households in terms of percent changes in the per capita welfare measure may be explained as follows (in addition to the consumption pattern effects noted above). Although, employment across all household groups declines, higher income households lose more, because they tend to belong to higher wage occupations and sectors that suffer higher declines in output. Second, dividend reductions resulting from economic contraction can be expected to hit higher income households harder than lower income ones.

The Gini coefficient and the Theil index results represent single parameter measures of the changes in income inequality among income groups due to the carbon tax. The calculations are based on expenditures rather than income (because the former is considered a more consistent metric), and are expressed as percentage changes over the benchmark. These indexes declined by around 0.15 percent in both the short and long run, meaning the tax is mildly progressive, which conforms to the relative per capita welfare effects.

Sensitivity Tests

We performed alternative carbon tax scenario simulations specified in Table 1. Discussion of these alternative scenario results focuses on their main areas of differences from the Reference Case Scenario. Except for Case D, aggregate effects (in terms of GRP and employment) are about the same as Case 0. Distributional impacts vary only slightly as well

Cases B and C examine alternative carbon tax revenue recycling approaches against the weak and strong form of the double-dividend hypothesis. In Case B, the carbon tax revenue was transferred to households in a lump sum as an equal percentage of benchmark household income shares. In Case C, carbon tax revenues were used to reduce household income tax rates by a little over 4 percent for each bracket.[4] Lump sum transfers enhance progressivity more than income tax reduction, because the former returns relatively more to lower income households.

In Case D, the tax rate was raised four-fold, and the lump-sum revenue return was again based on benchmark household income shares. However the macroeconomic decline is less than four-fold in relation to Case 0, indicating a nonlinear response, or a type of economic resiliency.[5]

Summary

We found that the aggregate impacts of a carbon tax on the Susquehanna River Basin were negative but modest: approximately a one-third of one percent reduction in GRP in the short run for all scenarios (including revenue recycling) and approximately double that much in the long run. The energy sectors, especially Coal and to some extent Oil Extraction, bear the brunt of the impacts. In terms of consumption patterns, though households are projected to spend less on nearly all goods and services, the largest shifts are away from Fuels/Utilities and Private Transportation in both the short and long run. Still, however, lower income groups spend relatively more of their income on Food, Housing, and Health Services than prior to the imposition of the tax. In terms of household distributional effects, the carbon tax is mildly progressive when measured in terms of income bracket changes, per capita equivalent variation, and Gini coefficient changes based on expenditure patterns. Moreover, various sensitivity test indicate our results are robust.

We do, however, refrain from suggesting the carbon tax progressivity we found in the SRB generalizes to all other regions. Given the number, complexity, and, in some cases, idiosyncrasy of factors affecting the outcome, analysis should be undertaken on a case by case basis. Some a priori hypotheses on the relative regressivity/progressivity should only be ventured if the vast majority of determining factors line up on one side of the issue or the other.

A major limitation of the analysis is that it pertains to only one side of the ledger. Also important is the distribution of benefits from the damages avoided by carbon emission reductions. Although this aspect is beyond the scope and space limitations of this paper, we can report on the overall conclusion reached in Oladosu (2000)—that the benefits of the SRB carbon tax are projected to be slightly progressive, i.e., potential damages would fall relatively harder on low income groups, and their avoidance would thus help these groups relatively more. Of course, timing considerations are important when combining the cost and benefit sides. The benefits of the carbon tax imposed in 2010 will be small in that year but will increase over time. Thus, cost considerations are likely to dominate the distributional impacts in the near term.

Endnotes

[1] The Kyoto Protocol allows for trading of individual country emission quotas to implement its overall target. From a business decision and tax revenue standpoint, a carbon tax and carbon emission permits are equivalent when the latter are auctioned. Note also that although President Bush has deemed Kyoto to be "dead," state and local governments throughout the U.S. are making commitments to reduce greenhouse gases (CCAP, 2002). This includes a recent agreement by the New England Governors, which provides for emissions trading between the states to meet their targets.

[2] The Susquehanna River Basin (SRB) is located in south central New York, nearly all of central Pennsylvania, and a small portion of north central Maryland. An economic trading area, consisting of 68 counties in these three states, conforms roughly to the SRB. Total population of the Region is about 8 million and Gross Regional Product about 200 million. The Susquehanna River flows 444 miles from Lake Otsego near Cooperstown in New York into the Chesapeake Bay and drains 27,500 square miles. The SRB accounts for 43 percent of the Chesapeake Bay's drainage area and is made up of 60 percent forest land. The Susquehanna River is the longest commercially non-navigable river in North America.

[3] Equivalent variation (EV) is a measure of the willingness to pay to avoid the policy or the equivalent amount of income households would be willing to give up to match the effect of the policy on their welfare. Convention is to express EV as a positive amount, but it denotes a decrease in welfare.

[4] The absence of a dynamic model is the reason we did not simulate corporate tax relief/revenue recycling as well. For an excellent example of such analysis see Bovenberg and Goulder (2002).

[5] Two additional simulations tested the sensitivity of the results to energy substitution elasticities. In the first, elasticities were reduced by 50 per cent, thus making it more difficult to minimize the impact of energy price increases in production costs. The result is an increase in negative impacts and a lower reduction in energy use compared to Case 0. Coal and Crude Oil outputs declined by less than in Case 0, and Natural Gas output slightly more because it became more difficult to shift to the latter (less carbon-intensive) fuel. However, the sectoral and price impacts are only slightly different from Case 0, and the overall impact on the economy was virtually the same. The long-run impacts were, however, significantly more negative than in Case 0, because decreased substitution possibilities were of a greater absolute magnitude. Our second simulation made it 100 percent easier to substitute away from energy, and therefore we would expect, and it is confirmed, that there are greater reductions in consumption of fossil fuels compared to Case 0. Overall, negative impacts on the economy were only slightly worse in the short run in this case than Case 0, while the long-run results were substantially less severe, reflecting significant nonlinearities in the model. Note also that the progressivity results are not due to any extreme values of elasticities of substitution between capital and labor. The capital stock declined by about the same amount as labor in the long-run, and the return rate declined by less or equal to the wage rate in both the short and long-run.

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[8] In this sense, managerial economies of scale are similar to economies of scope (Baumol, Panzar, and Willig 1982).

[9] Since nuclear units are considered "must-run" generation, lower capacity factors can be attributed to less efficient operation, rather than withholding.

[10] The moral hazard problem has no efficient solution (Ross 1973). The buyer can induce "good" behavior on the part of the generator, but at a cost (Holmström 1979).

[11] Further, these diseconomies of scope will increase as the generator becomes more risk-averse.

[12] However, this may also introduce an opposing moral hazard problem. For example, the utility might find it cheaper to purchase fuel on behalf of the generator, rather than compensate the generator for having to bargain for a good fuel price. In this situation, for example, the utility may not have any incentive to ensure that the fuel is of sufficiently high quality. These types of moral hazard problems should resolve themselves if the contract horizon is long enough (if the utility continually buys poor-quality fuel for the generator, the reliability of the plant will suffer).

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