INCOME DISTRIBUTION IMPACTS OF CLIMATE CHANGE MITIGATION POLICY IN THE SUSQUEHANNA RIVER BASIN ECONOMY

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I. 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 to be negative for most policy designs. For example, the latest Intergovernmental Panel on Climate Change Report (IPCC, 2001) identifies a likely range of impacts from -0.2 to -2.0 percent of GDP to meet Kyoto emission targets.[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. We utilize 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).[2,3]

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 (Olson, 1965; Rose et al., 1988). Bovenberg et al. (2005) have pointed out that businesses are likely to have more clout than consumers in this regard. However, accelerating concern about environmental justice (broadly defined)[4] draws attention to lower income and minority households, and effectively mobilizes opposition on their behalf.

In contrast to many previous studies, we found a carbon tax to be progressive in terms of its impacts on the size distribution of personal income. This result stems from several explanatory factors, but the dominating one is a pattern of output, income, and consumption impacts that affect lower income brackets relatively less than higher brackets. This is reinforced by an increase in transfer payments, which favors lower income groups, and decreased corporate profits, which are absorbed primarily by those in higher brackets.

II. SYNTHESIS OF THE LITERATURE

A number of studies have examined the income distribution impacts of carbon taxes or carbon emission permits (see, e.g., Harrison, 1995; Metcalf, 1998; Dinan and Rogers, 2002; 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 (OECD, 1995). 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. Magnitude of the carbon tax or emission permit price, and energy-intensity of the economy. The higher these factors, the larger the overall impact and the more profound income inequalities of impacts can become in relation to the baseline (Hamilton and Cameron, 1994; Symons et al., 1991).
2. The unit upon which the tax is based (e.g., energy equivalent, carbon emissions, or carbon content), the narrowness or breadth of products or entities on which that tax is imposed, and the point in the production or consumption process at which the tax is imposed. These bear on the relative bluntness

or precision of the policy and hence its cost-effectiveness and overall impacts. For example, Barker and Kohler (1998) found a tax on energy as a whole to be regressive but a tax on motor fuels to be progressive (cf., however, Wiese et al., 1995)

3. The extent of factor mobility, which determines the degree to which the impacts result in unemployment and capital retirements. For example, Kopp (1992) noted the regressivity of transitional effects on coal miners having to find jobs in other industries.
4. The degree to which the impacts result in unemployment. Those already in lower income groups are less able to withstand the shocks of both temporary and long-term unemployment (OECD, 1995).
5. The extent to which general equilibrium effects are taken into account to capture production/income distribution/consumption interactions in response to the policy (OECD, 1995). For example, a large decrease in coal production may have a disproportionate effect on income of high-wage unionized miners, but the decrease in their consumption may be for products that are characterized by a predominant number of low-wage earners (see, e.g., Rose and Beaumont, 1988).[5]
6. The extent to which dynamic effects are taken into account (e.g., with respect to savings and investment). The current income distribution has an effect on economic growth, which in turn affects future distribution (Bovenberg et al., 2005). Here progressivity is often thought to have a detrimental effect on future growth, though the effect on future income distribution is ambiguous. Dynamic effects also have a bearing on asset markets, such as the extent to which financial returns are affected and its implications for investments (Harrison, 1994).
7. The use of annual income versus lifetime income as a reference base (e.g., as proxied by consumption). The latter is the more appropriate measure given the long-run nature of the issue (see, e.g., Dinan and Rogers, 2002).
8. The extent to which demographic considerations pertaining to household composition are taken into account (Hamilton and Cameron, 1994); related to this is the demarcation of income groups, especially at the highest and lowest levels (Kopp, 1992).

9. The type of revenue recycling (including lump-sum transfers) and in contrast to alternatives such as budget deficit reduction and individual and corporate tax relief (see, e.g., Goulder et al., 1997; Parry et al., 1998). The latter is usually considered the most regressive.
10. Basic parameters and assumptions of the analytical model (especially price elasticities of demand and supply, elasticities of substitution with respect to inputs and imports, market structure, labor supply elasticities, etc.).These factors determine the ability to shift the tax forward onto customers or backward onto factors of production. In terms of the latter, shifts on to labor are likely to be more regressive than shifts onto capital (see, e.g., Boyd et al., 1995; Bovenberg et al., 2004). Also, the greater the variation in price and income elasticities of demand, the greater the potential progressivity or regressivity.

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

III. MODEL FORMULATION

A. Overview

The most important factors in designing a CGE model for policy analysis 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 economic activities: production, consumption, trade and investment, which are carried out by four institutions: enterprises, households, government, and external agents. The SRB economy is divided into 49 sectors producing an equal number of market goods in the model, and are delineated to highlight climate change and policy sensitivity in the economy. The Electricity sector is further modeled as consisting of five sub-sectors to represent the various types of electricity generation sources in the SRB economy. 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.

Households are represented by a 9-income bracket categorization, and their behavior is modeled using a household production function (HPF) formulation. 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.

B. Supply of Goods and Services

Production activities in the model are specified using the cost function approach.[6] The most common functional form for producer behavior in CGE models is the ordinary constant elasticity of substitution (CES) function. This functional form is strongly separable, and satisfies regularity conditions under positivity and additivity restrictions on the parameters. Although easy to implement, the constancy of substitution elasticities limits flexibility because it requires all input pairs to have the same substitution elasticity. In order to achieve greater flexibility, empirical modelers often use nested forms of the CES, which allow these elasticities to differ across production stages as represented by input pairs.

We adopt a constant returns to scale form of the nested CES known as the non-separable, nested constant elasticity of substitution cost function (NNCES)[7]. This is a flexible functional form in the manner of the Almost Ideal Demand System (AIDS) and the Translog, but unlike these functional forms satisfies global regularity under the same parameter restrictions as the ordinary CES. The NNCES in our model is specified as a two-stage technology in equations 1 and 2:[8,9]

$$\hat{C}_i = a_i \, \hat{XO}_i \left(\sum_n a_{n,i} \, \hat{P}_{n,i}^{(1-\gamma_i)} \right)^{\frac{1}{(1-\gamma_i)}} \qquad (1)$$

where XO_i is total output, and $P_{n,i}$ is the unit cost function of the n^{th} nest:

$$\hat{P}_{n,i} = \left(\sum_f \lambda_{f,n,i} \left(b_{f,i} \hat{P}_{f,i} \right)^{(1-\sigma_{n,i})} \right)^{\frac{1}{(1-\sigma_{n,i})}} \tag{2}$$

$\alpha_{n,i}$ and $\lambda_{f,n,i}$ are share parameters, and γ_i and $\sigma_{n,i}$ are elasticities of substitutions.

Factor shares in production costs, $SH_{f,i}$, from which factor demands are computed are derived by an application of Shepard's Lemma as:

$$SH_{f,i} = \frac{\partial \ln C_i}{\partial \ln P_{n,i}} \times \frac{\partial \ln P_{n,i}}{\partial \ln P_{f,i}} = \sum_n SH_{n,i} \times SH_{f,n,i} \tag{3}$$

where $SH_{n,i}$ is the share of the n^{th} nest in total cost, and $SH_{f,n,i}$ is the share of factor f in the cost of the n^{th} nest for sector i.

The NNCES cost function is used to model production activities for 48 of the 49 main sectors in the model (i.e. excluding electricity), and each of the five electricity sub-sectors. Total electricity production is then computed as an aggregate of sub-sector electricity output using the ordinary CES function. Prices paid by producers per unit aggregate factor demand are determined according to the following rules. Labor demand in each sector is a Leontief aggregation of occupational types, which implies that sectoral labor price paid $P_{l,i}$ is given as:

$$P_{l,i}(1 - \sum_{gv} tr_{ts,l,gv}) = \sum_{ocp} iocp_{i,ocp} WG_{ocp,i} \tag{4}$$

where $tr_{ts,l,gv}$ is the social security tax rate (ts) on labor paid to governments (gv), $iocp_{i,ocp}$ is the industry-by-occupation (*ocp)* coefficient matrix, l is an index for labor, and $WG_{ocp,i}$ is the occupational wage rate paid in sector i, determined as a linear function of average wage rate, W_l,.

There is only one type of capital in the economy, but we capture sectoral differences in return rates by specifying the return rate on capital in each sector , $P_{k,i}$, as the average capital return rate in the economy, W_k. multiplied by a sectoral distortion factor. Material and energy are aggregate intermediate inputs, and therefore their unit prices in each sector are functions of market goods prices. Components of these aggregate factors are assumed to substitute for each other smoothly using a CES specification of their unit cost functions.

Each sector's overall unit output price is determined from an average cost equation, inclusive of taxes. Since producer technologies are of the constant returns to scale form, this pricing rule is also equivalent to marginal cost pricing.

C. Intraregional and Interregional Trade

The SRB fits the description of a small, open economy, meaning import and export prices can be taken as determined by external markets. We adopt the convention in CGE models of capturing less than perfect substitution between domestic and foreign goods by using the constant elasticity of substitution (CES) function. For exports, the negative of the elasticity of substitution in the ordinary CES becomes producers' elasticity of transformation between regional and foreign sales leading to a constant elasticity of transformation (CET) function specification.

Regional prices of exports and imports are specified as world (and national) prices plus percentage tax/tariffs. As a small open economy, it is adequate to take external prices as given. However, external price adjustments can serve as proxies for interregional effects of climate change policies in the absence of an interregional model (see, e.g., Kamat et al., 1999).

D. Factor Supply

The four factors of production in the SRB CGE model are energy, materials, capital and labor. Energy and materials are intermediate inputs that have been specified as part of the production processes. Capital supply is not directly linked to any ownership structure in the model, and therefore no elaborate supply equations are specified. In addition, because malleability and mobility of the capital stock is intimately linked to the short- and long-run behavior of the economy, its behavior is further dealt with under the specification of equilibrium and closure conditions of the SRB CGE model (as noted below).

In the case of labor, the model distinguishes six occupational groups, and attempts to capture labor-leisure decisions of households in a realistic way. Total population for each income bracket, TP_{hh}, is specified as the net of initial population, PO_{hh}, migration, MG_{hh}, and mortality, MR_{hh}:

$$TP_{hh} = PO_{hh} + MG_{hh} - MR_{hh} \tag{5}$$

Employment in each household category, LS_{hh}, is then the net (of illness and voluntary unemployment) available labor in each household type, LV_{hh} and involuntary unemployment, UE_{hh}:

$$LS_{hh} = lc_{hh}\left(LV_{hh} - UE_{hh}\right) \tag{6}$$

where lc_{hh} is a shift parameter that captures approximation errors resulting from different data sources, labor supply aspects such as part-time and overtime employment, and differences in the valuation of individual household labor supplies in the market. The occupational distribution of household labor is derived by applying a household-by-occupation coefficient matrix.

E. Income Allocation and Distribution

Institutions receiving factor incomes are households, government, external agents, and enterprises. Labor income net of social security taxes is allocated entirely to the nine household types according to their labor supply. It is infeasible in the model to directly link household labor supply by occupation type to its actual industry of employment. Therefore, the approach taken is to relate household occupational income receipts from individual sectors to average occupational wage rates. Capital income in each sector is allocated to depreciation, retained earnings, profit taxes, and dividend payments to external agents and households. Dividends are allocated using an industry-by-institution capital income allocation matrix.

F. Household and Other Demand

Household income (measured in terms of annual rather than lifetime income) is specified as the sum of primary factor income receipts and transfers from other institutions. Household income taxes and savings/borrowings are fixed shares of total income. Net income available to each household category for market goods purchases is the sum of income minus savings, transfers, and taxes. A Linear Expenditure System (LES), combined with household production functions, is used to specify each household's spending behavior (see Oladosu, 2000).

G. Model Construction

The construction of the SRB CGE model requires an enormous amount of data. This is especially daunting for a regional CGE model, since few economic and other relevant data are collected at that level. Therefore, many model parameters are based on scaled down national data or data for similar economies or regions.

Data requirements for the model include the social accounting matrix (see Appendix), 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. The bi-proportional matrix balancing procedure (Miller and Blair, 1985) was also employed in adapting these data to the SRB. Other model parameters were calibrated using economic data specific to the SRB economy.

The major data source for the model, the IMPLAN database (MIG, 1998), distinguishes 528 industries and market goods, which were aggregated to the 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 model as described below. The base year for data in the model is 1995.The construction of the special income distribution components of the model is presented in Appendix A.

Elasticities of substitution and transformation are the main parameters that need to be specified for cost, Armington and CET functions employed in modeling production and trade activities 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 studies by Li, 1994; Deardoff and Stern, 1986; Reinert and Roland-Holst, 1992; and Shiells and Reinert, 1993). The choice of Allen elasticities of substitution used in the cost functions was also based on these studies.

H. Model Calibration

The data and exogenous parameters presented in the foregoing sections of this chapter are combined with the model specification to carry out the following tasks. Model calibration is conducted to derive the remaining parameters of the model. Based on the assumption that the base year economy is in equilibrium, certain values of these parameters are implied by the data. The calibration process is quite simple in most cases as it merely involves calculating parameter values using base year endogenous variable values and other exogenous parameters. Calibration of the NNCES producer cost functions involved several additional steps. Calibration of the NNCES cost function involved an optimization procedure adapted from Rutherford (1999).

IV. CARBON TAX POLICY MODELING

A. Overview

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 (Manne and Richels, 1999; MacCracken et al., 1999; 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.[10] 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. Denoted by *t*, the percentage tax for each fuel can be calculated according to the following equation:

$$t = \frac{emission\ \ tax\ \ rate \times emission\ \ factor \times energy\ content}{price} \tag{7}$$

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.

Time horizon is an important factor in the determination of the economic impacts of a carbon tax. The time profile can be divided into two periods: pre- and post-target period. In the case of a regional economy, where the tax rate is exogenous, the time horizon issue is couched in terms of short- to long-run post-tax adjustment behavior. A static model such as the SRB CGE model can be used to evaluate the regional impacts of a carbon tax in these time dimensions. This study conducted both short- and long-run simulations. The former represents adjustments to the tax over a period of less than three years (i.e. the capital stock is fixed), while the latter represent shifts in the long-run growth path of the economy.

As a small, open economy, interregional effects will be important determinants of the economic effects of a carbon tax on the SRB. We dealt with this issue by interpreting the policy as a cooperative global carbon tax initiative that preserves relative regional and external prices.[11]

Another issue that has generated much interest in the carbon policy debate is the “double-dividend” hypothesis. The hypothesis states that in addition to reducing negative externalities, carbon tax revenues could be used to increase economic efficiency by removing existing distortions in the economy through recycling. The strong form of the hypothesis suggests that efficiency gains from recycling could be large enough to drive the economy towards higher than pre-tax efficiency. The weak form focuses on reducing efficiency losses under the tax through revenue recycling.[12] We examined the "double-dividend" hypothesis by evaluating the carbon tax under different assumptions about government use of the carbon tax revenue.

B. Scenario Formulation

The above considerations lead to a multitude of possible carbon tax scenarios depending on differences in the treatment of trade effects, revenue recycling assumptions, tax rates and types, as well as time horizon considerations. Tables 1 and 2 summarize 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 government spending of the revenues. Fuel prices and emission factors on which tax rates are based are also shown in Table 1. Closure rules are specified for the labor market, government, external agents and transfers. Short- and long-run time horizons are reflected through the formulation of different closure rules for capital mobility and determination of return rates. Our long-run simulations are based on the following characteristics of a steady-state equilibrium. At long-run steady state equilibrium, investments in the economy are just enough to account for depreciation and to keep the output to labor ratio constant. This condition is expressed as:

$$\dot{K}_t = n \tag{8}$$

where K_t is the capital stock per unit of effective labor force, $\dot{K}_t = dK/dt$, and n is the effective growth rate of the labor force (including both population and labor productivity increases).This requirement implies that total savings and investment must meet the following condition:

$$I_t = S_t = (n + \delta)K_t \tag{9}$$

where S_t and I_t are savings and investment per unit of effective labor, n is as defined above, and δ is the depreciation rate of capital. Since both of these parameters remain constant along the steady state growth path, this translates to a linear relationship between savings and the capital stock. In addition, on the steady-state growth path, all relative prices remain constant. Although, policy changes may cause shifts in the steady-state path and lead to relative price and capital-labor ratio changes, the relationship between investments and the capital stock would still hold on the new long-run path since both n and δ are exogenous. In addition, the new growth path will be characterized by the same or a new set of constant relative prices and capital-labor ratio.

The above discussion suggests that long-run behavior can be reflected in a static model in at least two ways. One is to impose the relationship in equation 9, while the other is to specify constant relative wage and capital return

Table 1. Principal Carbon Tax Scenario

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.

Table 2. Alternative Carbon Tax Scenarios

Case	Tax Rate ($/ton)	Type of Tax	Other Characteristics
0	25	Consumption	Tax revenues used for general government spending
A	25	Production	Tax revenues used for 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	Tax revenues used for general government spending

rate. We have adopted the second option in specifying long-run carbon tax scenarios rather than the steady state growth condition because the latter is more appropriate within an explicitly dynamic model.

V. RESULTS

A. Aggregate Impacts

A $25/ton carbon consumption tax, with the carbon tax revenue 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 those 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.[13] Total revenue resulting from the carbon tax is around $700 million in both instances.

B. Sectoral Impacts

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 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 increased 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, increased, 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. The remaining sectors, excluding Health Services and Other Services sectors, are projected to incur output declines of less than 1.00 percent.

The pattern of effects changes slightly in the long run. Crude Oil and Coal prices increase more than in the short run, while Natural Gas prices change by almost the same amount short run. Output prices increase for all three primary fuel sectors in the long run instead of the decreases observed for Crude Oil and Coal prices in the short run. Supply and output price increases for Petroleum Products were also more pronounced, but those for Electric Services are slightly less severe. The different behavior of electricity prices can be attributed to the replacement of more fossil fuel intensive technologies with less intensive ones in the long run, whereas Petroleum Refining has very limited fossil fuel substitution possibilities. Price changes are also more severe in the long run for other sectors of the economy. Sectoral output reductions are generally greater in the long run than in the short run, corresponding to the observed higher decline in the overall economy. In the short run we observe energy use reductions of over 10 percent in Crude Oil, Coal and Electricity Services, while all other sectors had reductions of between 0.77 percent and 6.00 percent. Except for a few sectors, energy use reductions are much higher in the long run.[14]

C. 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 LES household utility functions, expenditures on subsistence commodity consumption adjusts 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 the income effects under the tax are more favorable to the lower income groups than to higher ones. As shown in Table 5, 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 decrease. 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.

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.[15] 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

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

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 per Capita	$Δ	-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 per Capita	$Δ	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

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, indicating the tax is mildly progressive, which is consistent with the relative per capita welfare effects.

D. Sensitivity Tests

We now summarize the results of alternative carbon tax scenario simulations specified in Table 2. 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 except in Cases B and C.

Case A. Production Tax

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, which is shown to be the case. Impacts are slightly less severe and generate less tax revenue than Case 0. This indicates that the carbon production tax has a smaller base than the consumption tax.

Cases B and C: Alternative Revenue Recycling Options

These cases examine alternative carbon tax revenue recycling approaches against the weak and strong from of the double-dividend hypothesis.[16] In Case B, the carbon tax revenue was transferred to households in a lump sum as on 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.[17] The income distribution impacts of the two revenue-recycling options are not surprising. Lump sum transfers enhance progressivity more than income tax reduction, because the former returns relatively more to lower income households than the latter.

Case D: Higher Carbon Tax Rate

In Case D, the tax rate was raised four-fold, and the lump sum revenue return was again based on benchmark household income shares. The macroeconomic impacts, however, decline by less than four-fold in relation to Case 0, indicating a nonlinear response, a type of resiliency in the economy in adjusting to the negative force. The increase in negative impacts in relation to Case 0 is not as great in the long-run, indicating the adjustment process increases in effectiveness over time.[18]

VII. SUMMARY AND COMPARISON

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 tests indicate our results are robust.

How do our results compare to those of other studies, and what explains the differences? The distributional impacts differ from most of the literature, where the consensus is that a broad-based carbon tax is moderately regressive. Some researchers have found the carbon tax to be either moderately regressive or progressive, however, depending on the underlying assumptions (see Jorgenson and Wilcoxen, 1993). Note also that the results here contradict some of the aggregate and distributional results of the authors' own study of impacts of a permit trading scheme (essentially equivalent to a carbon tax) at the national level for the U.S. (see Rose and Oladosu, 2002).

Since we are most familiar with our own national study (which is also more consistent with most of the literature), we will use it as a reference point to explain why our results here differ. Our discussion will focus on those of the 10 explanatory factors introduced in Section II above that have the greatest influence on the results:

A. The energy intensity of the Susquehanna River Basin economy is on average higher than that of the U.S., due to the relatively higher composition of manufacturing, older factories and power plants, and relatively cheaper electricity. This helps explain why a carbon tax less than 20% as great as the permit price in the Rose and Oladosu U.S. Study yields greater aggregate impacts on Gross Product.

B. An emissions tax has the greatest possible precision in policy terms, since it focuses directly on the goal of reducing carbon emissions. Other things equal, this would result in relatively lower aggregate economic impacts. The tax in the U.S. Study was applied to carbon emissions, while the tax in this study is applied to fossil fuels based on carbon content, a more standard policy design. Still, the latter is more blunt and therefore produces relatively larger negative impacts.

C. The income brackets differ between our SRB study and U.S. Study. The former has more detail in the lower income brackets, and the latter had more detail in the upper brackets. The U.S. results showed middle-income groups suffering the greatest income loss. However, the highest income bracket in the present study is only $70K+, as opposed to the $500K+ in the U.S. Study. In line with this distinction we observe from our results that as government income increased, due to the carbon tax revenue, transfers to households also increased. Although quite small in absolute terms, the relative effect of these increases on lower income households is significant. For example, the lowest income group received an increase of 1.25 percent in transfers from the Federal Government in the short-run, so that when reductions in employment income are subtracted, total income for this group actually increased by 0.36 percent. In other words, the distributional effects of increases in government transfers would not have been evident if income and expenditure for these lower income groups had not been separately modeled. Thus, the U.S. Study exaggerates the regressivity by focusing on a household income bracket with relatively few members. If we compare our results here with the weighted income brackets of the U.S. Study, the progressivity of the two studies is similar.

Still, the overriding reason for the progressivity of the results is the fact that a carbon tax results in unevenly distributed sectoral output changes, as well as income and consumption patterns. The sectors affected most, both directly and indirectly, causes the impacts to be relatively greater on middle- and higher-income groups (e.g., unionized coal miners, utility shareholders). This contrasts with the lower impacts on food, housing, and service sectors, which make up a larger portion of the consumption basket of lower income brackets. The decrease in business profits due to the imposition of the carbon tax reinforces the result because its incidence is felt more strongly by the upper income bracket.

Overall, we can support the results presented in this paper, subject to a modest number of caveats. One major limitation is that we did not incorporate all 10 explanatory factors into the analysis. For example, we did not include asset market and other dynamic considerations, which may cause our results to change over a longer time horizon than was considered. Another stems from the fact that we have rather coarse resolution at upper income scales, so there is the possibility that those in very high-income brackets (which we were not able to distinguish) are impacted relatively less than we project; however, this would only render the results regressive in terms of less than one percent of the population.[19]

We 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 progressivity should only be ventured if the vast majority of determining factors line up on one side of the issue or the other.

APPENDIX A. CONSTRUCTION OF INCOME DISTRIBUTION FEATURES

A Social Accounting Matrix (SAM) is a tabular account of an economy over a specified period, usually a year. Rows of the SAM represent receipts, while columns represent payments, so that the intersection of rows and columns are transactions among different actors in the economy. The SAM for the SRB CGE model (see Appendix Table 1) is based on the 1995 county level Impact Analysis for Planning (IMPLAN) database (MIG, 1998). Given the focus on distributional effects in this study, the IMPLAN SAM needed to be modified to reflect distributional features. Since the IMPLAN database lacks the necessary tools and data for doing this, external data sources were used to derive income distribution parameters to allocate labor and capital incomes in the model.

Value-added accounts show payments to primary factors (labor and capital), and their allocation among various economic agents. The capital row and column in the table were aggregated from the IMPLAN database, which classified capital income into Proprietary, Other Capital-Related, and Enterprise Income. The income allocation procedure in this study differs from that implied by the IMPLAN database in two major ways. First, this study uses nine household income brackets compared to IMPLAN's three. Second, income distribution is linked to the industry of factor use in this study, while income is first aggregated across all sectors and then distributed according to fixed shares in the IMPLAN database. The IMPLAN approach invokes the assumption that all economic agents share factor incomes according to the same fixed proportions in all sectors of the economy. The capital income allocation approach in the SRB CGE model incorporates differential sectoral income distributions.

An industry-by-destination capital income distribution matrix is constructed to perform the allocation of capital income as specified in the SRB CGE model. The main tasks in the construction of this matrix are calculation of control totals, compilation of an initial capital income distribution matrix, and the application of the RAS procedure to balance it. The steps involved in dealing with these tasks are adapted from Rose et al. (1994), Li et al. (1999), and Oladosu, (2000), and are illustrated by Figure A1. The estimation procedure results in a complete set of distribution coefficients that, along with sectoral capital incomes and return rates, were used to calculate a complete capital income allocation matrix.

Labor income receipts by the nine income brackets are shown at the intersection of household rows and labor column of the SAM, while employee social security deductions are shown at the intersection of the labor column and government rows. The major database used to construct the wage and salary distribution matrix is the U.S. Industry-by-Occupation Matrix (BLS, 1999), which consists of employment by occupational categories for sixty-seven industries. The steps involved in construction of our model are summarized in Figure A2.

The population profile by income groups (in thousands) is:

< $5,000	241
$5 to $10,000	735
$10 to $15,000	708
$15 to $20,000	714
$20 to $30,000	1419
$30 to $40,000	1250
$40 to $50,000	950
$50 to $70,000	1174
> $70,000	613

Data requirements for estimating the parameters of the linear expenditure system (LES) are commodity prices and expenditures, household characteristics, and climate change indexes. Complete expenditure system parameters have been estimated using a variety of data types in the literature.

The expenditure and demographic database for estimating the parameters of the SRB CGE Indirect Utility Function (IUF) is the U.S. Consumer Expenditure Survey Data Extracts prepared by Sabelhaus (1996) for the years 1980 to 1994, obtained from the NBER (1999). There are two files for each quarter of the spanned years, which contain annual family and member records for households entering the survey process in that quarter. Considerable processing of these data files was necessary before use for econometric estimation. The particular price index used in this study is the U.S. Urban Consumer Price Index (BLS, 1999).

APPENDIX TABLE 1. AGGREGATE SOCIAL ACCOUNTING MATRIX FOR THE 1995 SRB ECONOMY (million $)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
1 Industry	0	227734	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18356	91366	337455
2 Goods	79045	0	0	0	0	0	0	0	349	3244	5174	7252	12436	15290	14793	21696	19732	8685	26732	17472	1183	0	0	233084
3 Labor	109461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	109461
4 Capital	65024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65024
5 Dividend	0	0	0	36936	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36936
6 Depreciation	0	0	0	18192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18192
7 Ret. Earnings	0	0	0	3493	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3493
8 Indirect Tax	15152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15152
9 $0K-$5K	0	0	85	0	47	0	0	0	0	0	0	0	1	1	1	2	2	254	47	139	0	12	10	599
10 $5K-$10K	0	2	789	0	433	0	0	0	0	1	1	2	6	7	7	16	15	2361	436	1286	0	110	91	5563
11 $10K-$15K	0	4	1259	0	690	0	0	0	0	1	2	3	10	12	11	26	23	3765	696	2051	0	175	145	8873
12 $15K-$20K	0	5	1765	0	968	0	0	0	0	2	3	5	13	16	16	36	33	5277	975	2874	0	245	203	12436
13 $20K-$30K	0	12	11290	0	3521	0	0	0	0	4	7	9	27	33	32	71	65	3127	1935	0	0	261	1135	21529
14 $30K-$40K	0	15	13881	0	4329	0	0	0	1	5	8	11	33	40	39	88	80	3845	2379	0	0	321	1395	26469
15 $40K-$50K	0	15	13429	0	4188	0	0	0	1	5	8	11	32	39	38	85	77	3720	2301	0	0	310	1350	25608
16 $50K-$70K	0	17	26000	0	11920	0	0	0	2	22	35	49	143	176	170	382	348	3400	1659	0	0	303	2579	47204
17 >$70K	0	15	23647	0	10841	0	0	0	2	20	32	44	130	160	154	348	316	3092	1509	0	0	275	2346	42932
18 Federal Govt.	0	39	14690	4656	0	0	0	2519	20	183	293	410	1755	2157	2087	4854	4415	6591	0	4663	0	45	60	49435
19 State Govt.	0	3708	2627	1561	0	0	0	12632	73	682	1088	1525	929	1142	1105	2118	1926	3054	11692	8649	0	7	1043	55561
20 Investment	0	682	0	0	0	18192	3493	0	0	0	0	0	450	553	535	7519	6838	0	0	0	0	145	9197	47606
21 Inventory	0	835	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1255	0	61	351	2502
22 Rest of World	9238	0	0	187	0	0	0	0	19	176	280	393	804	988	956	1577	1434	494	531	3239	308	207	0	20831
23 Rest of U.S.	59535	0	0	0	0	0	0	0	131	1218	1942	2722	4762	5855	5664	8387	7628	1770	4668	5979	1011	0	0	111272
24 Total	337455	233084	109461	65024	36936	18192	3493	15152	599	5563	8873	12436	21529	26469	25608	47204	42932	49435	55561	47606	2502	20831	111272	

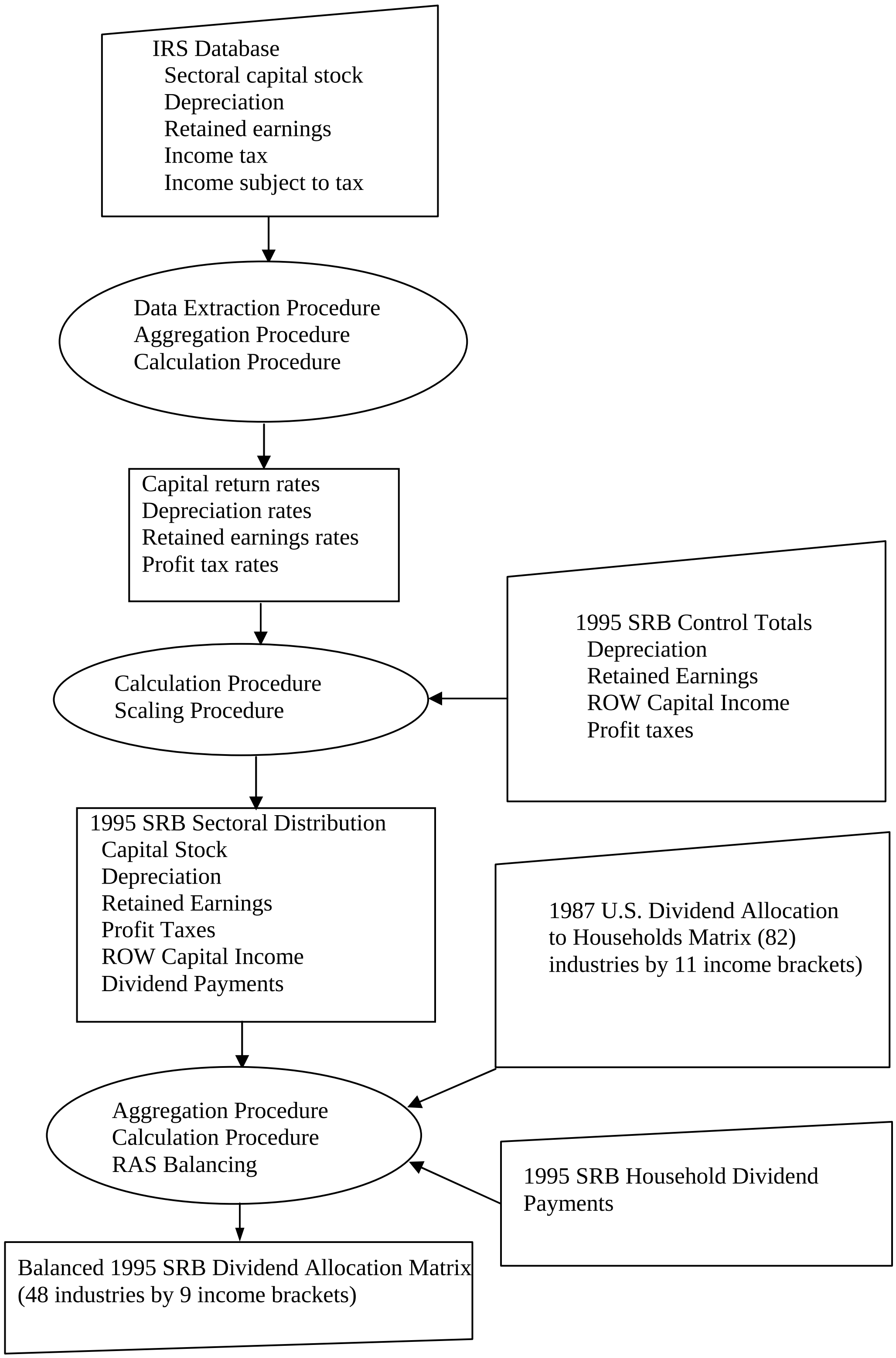

Figure 1. Procedure for Constructing the Capital Income Allocation Matrix

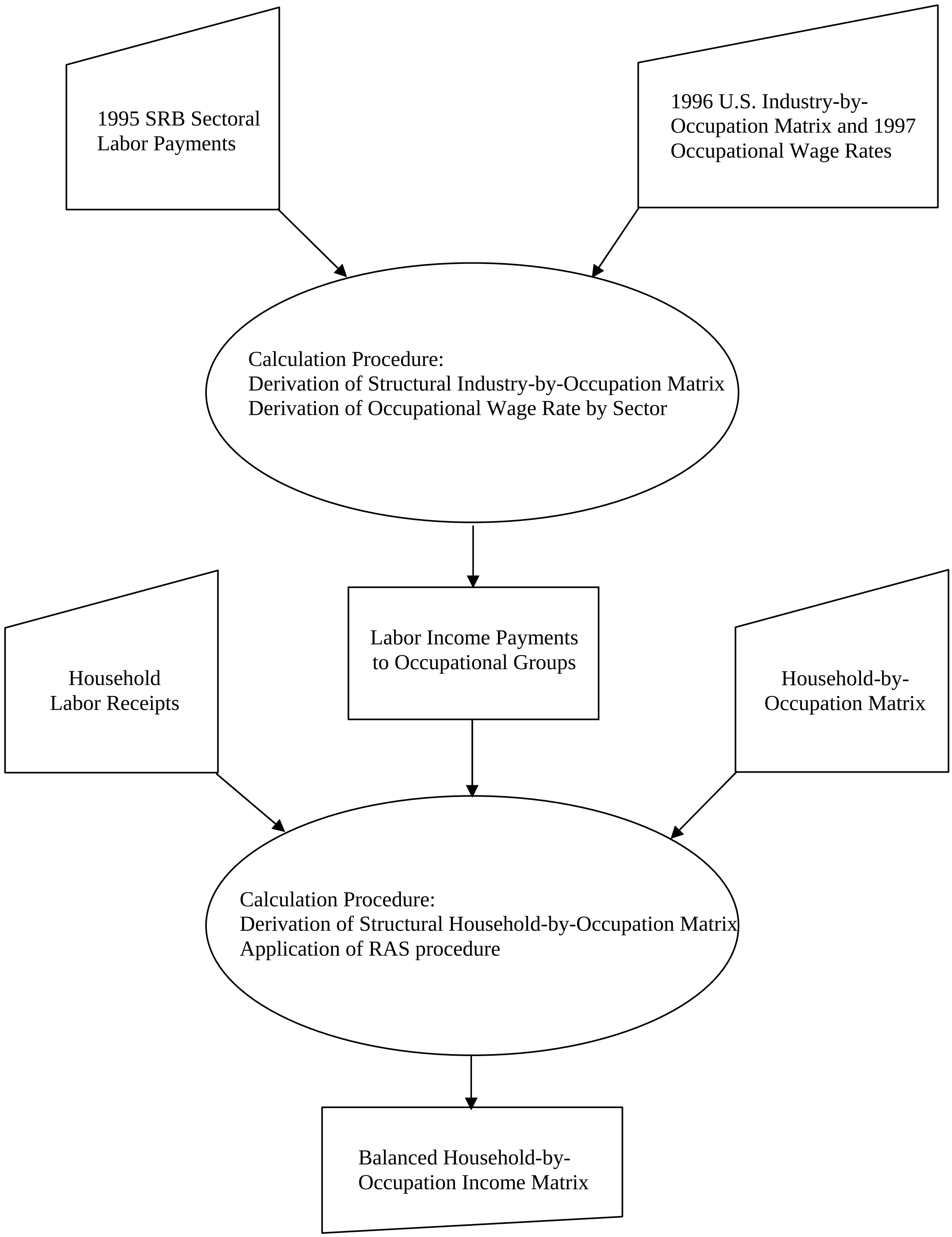

Figure 2. Procedure for Derivation of Labor Income Allocation Data

ENDNOTES

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[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 (see Pezzey, 1992). For a discussion of other aspects of these policy instruments relating to policy design and enforcement (e.g., enactment, information requirements, uncertainty)(see Kerr, 2002). 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; Peterson and Rose, 2005). This includes a recent agreement by the New England Governors, which provides for emissions trading between the states to meet their targets.

[2] Very few studies of climate change policy have been undertaken at the regional level and even fewer along natural boundaries, exceptions being the MINK Study of the Midwestern U.S. (Rosenberg et al., 1993) and the McKenzie (Canada) River Basin Study (Cohen, 1993). Neither of these analyses evaluated income distribution impacts to any significant extent. Aggregate impacts of a carbon tax on the SRB Region can be found in Kamat et al. (1999) and Oladosu (2000).

[3] 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.

[4] *Environmental justice* has tended to focus on hazardous facility siting and consequent environmental damage, but the principle can readily be extended to environmental issues in general, including the distribution of the costs of environmental protection.

[5] These interactions are well illustrated by the work of Miyazawa (1976), who also presented a reduced form "interrelational" multiplier that, in an input-output framework, depicts the effect on one income group stemming from a unit change in income of another income group. A similar though more comprehensive formulation is described in Robinson and Roland-Holst (1988) in the context of a CGE model.

[6] First, many theoretical properties and results that are difficult to specify under the primal approach become relatively easy under the dual approach, e.g., the application of Shepard's Lemma to derive input demand functions. Second, cost and price data are readily available for empirical implementations of the dual, while quantities that are necessary for implementing the primal are not. Third, cost data provide a single unit of measurement for goods and services of different physical measurements.

[7]This functional form has several advantages in the specification of production activities in a CGE model. First, it offers the same kind of input substitution flexibility associated with inherently flexible functional forms such as the Translog. Second, unlike these other functional forms, regularity conditions are maintained globally under the simple positivity and additivity requirements. Third, flexibility of the N-stage NNCES function has been proven by induction by Perroni and Rutherford (1993).

[8] In the following specifications, upper case letters are used to represent endogenous variables, while exogenous variables and parameters are in lower case.

[9] The various forms of the class of CES functions implemented in the SRB CGE model are specified in their *calibrated* share form (Rutherford, 1995). This form normalizes every variable in the CES function to 1 in the benchmark, so that resulting demand and supply equations are simple expressions that facilitate the calibration of the CES function in empirical implementation. All normalized variables in the model are indicated by a cap (^).

[10] Due to huge information and administration costs, environmental taxes are often implemented as product, rather than direct waste, taxes; however, the two taxes may not be equivalent. First, product taxes are only capable of inducing "output" effects, while direct waste taxes induces both "output' and "substitution" effects (Fullerton and Hong, 1999). However, the "substitution" effect is muted when wastes have a stable relationship to outputs, as is generally the case with carbon emissions. This implies that the carbon product tax may be considered a good proxy for carbon emission taxes in this case. Second, product taxes may lead to either inadequate or excess coverage of emission sources depending on the point at which taxes are imposed in the economy. Upstream product taxes provide greater coverage of emission sources than downstream taxes, but may impose unnecessary tax burdens on non-carbon emitting uses of carbon products. Finally, the product tax can be implemented as an output or as a consumption tax. In a partial equilibrium context, both taxes are equivalent, but in a second-best, general equilibrium context, their economic effects may differ substantially. The output tax is simulated as part of sensitivity analysis in this study.

[11] For lack of better information, this assumes that the relative impacts on the prices of goods and services are comparable in the SRB and the rest of the U.S. Note, however, that this does not eliminate changes in SRB trade patterns due to a carbon tax because such changes are due to both income (through balance of payments constraints) and price effects. We are able to model the former as discussed below.

[12] As Fullerton and Metcalf (1997) pointed out, this issue is primarily about who captures the "scarcity rents" generated under environmental policies. Resolving the double-dividend hypothesis involves distributional aspects that are related to the issue of tax incidence. When neither consumer demand nor producer supply are perfectly elastic or inelastic, the burden of a tax i.e. producer and consumer surplus losses, is borne by both agents. This suggests that both producer and consumer approaches to recycling carbon tax revenue should be examined. Theoretical and empirical results suggest that the hypothesis cannot be validated as a general issue, but depends on many other factors. These include pre-existing distortions in the economy, and how revenue recycling assumptions deals with these distortions (Fullerton and Metcalf, 1997; Goulder, 1995; Bovenberg and Goulder, 1996, Parry et al., 1999). Metcalf (1998) suggested that the tax revenue could be used to improve the progressivity of the tax system by adjusting the way revenues are rebated to households.

[13] Investment is projected to increase substantially under the tax—1.93 percent in the short run and 3.56 percent in the long run. This investment behavior corresponds to an increase in net savings in the economy due to a combination of several factors. First, the government deficit is held fixed in the face of changes in government

income. Second, there is a sizable increase in the capital account balance. Relative external and regional prices are constant, and a zero overall balance of payments condition holds. These conditions imply that the increase in capital accounts balance would be matched by a decline in the current account balance. Since current account transactions are dominated by the net of exports and imports, changes in exports and imports in Figure 1 confirm this expectation. Corresponding to a higher decline in exports than imports, a higher capital accounts balance is observed in the long-run. Thus, despite a decline of around 1.00 percent in household incomes, there is a net increase in overall savings to finance the observed increased investment in the economy.

[14] Recall that relative external and regional prices are fixed at their benchmark levels, which maintains the terms of trade for the regional economy. At the sectoral level, this would ordinarily imply that the relative demands for regional goods and the net balance of exports and imports are constant. However, the overall picture is complicated by the modeling of multi-product sectors, and the multi-level structure of trade in the SRB CGE model. The constant terms of trade and zero balance of payments condition imply that offsetting current account and external savings changes occur. This means that the behavior of exports and imports are not independently determined by relative prices alone but also involve income effects (recall endnote 11). Thus, the trade results (not shown) consist of a few sectors with the same pattern of changes in external and regional transactions, while most sectors do not show this pattern. The Coal sector is the prime example of the former. Except in a few sectors, the direction of changes in regional and external transactions is the same as would be expected. In the short-run, trade in Coal, Crude Oil, and Petroleum Products declined the most. Trade declines in other sectors were small, with the largest being around 3.00 percent. In the long run, the above three energy sectors still experienced the largest trade changes, while trade in some sectors, especially the Agricultural sectors, expanded.

[15] 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.

[16] Although the SRB dos not conform to political jurisdictions, fiscal policyinnovations is still a possibility, though it is likely to be expanded to the State level. Many examples of interregional cooperation at both sub-state and state levels exist for a combination of environmental and tax policy, including the recent GHG emission permit agreement among New England governors.

[17] 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 et al. (2004).

[18] 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 theshort and long-run.

[18] 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 thus 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.

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