RESULTS FROM THE JORGENSON-WILCOXEN MODEL

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Dale W. Jorgenson, Peter J. Wilcoxen

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REDUCING US CARBON EMISSIONS:

AN ECONOMETRIC GENERAL EQUILIBRIUM ASSESSMENT

Dale W. Jorgenson
Harvard University

Peter J. Wilcoxen[1]
University of Texas

1. INTRODUCTION

Our approach to EMF-12 differed in three important ways from the methodologies used by other participants. First, our results are based on a highly disaggregated intertemporal general equilibrium model of the United States. Using a disaggregated model allowed us to examine the effects of carbon taxes on narrow segments of the economy, such as particular industries or types of household. Second, all parameters in our model were obtained by econometric estimation using a data set spanning 39 years. Thus, the response of industries and consumers to changes in prices will be consistent with the historical record. Third, we model productivity growth at the industry level and allow it to be an endogenous function of relative prices. Allowing productivity growth to differ across industries permits the model to reflect a conspicuous feature of historical data. Together, these features allow us to shed light on several questions not addressed by most of the other participants. Some of our principle findings are as follows.

In the United States, the effects of a carbon tax will be very similar to the effects of a tax placed solely on coal. Of all fossil fuels, coal is the least expensive per unit of energy and produces the most carbon dioxide when burned. Thus, a tax levied on carbon emissions will raise the cost of coal-based energy far more in percentage terms than the price of energy derived from oil or natural gas. In response to this price change, the demand for coal will fall substantially. The demands for oil and natural gas will also decline, but by much smaller percentages.

Almost all coal consumed in the U.S. is used to generate electric power. As the price of coal rises, electric utilities will convert some generating capacity to other fuels. However, substitution possibilities are fairly limited, particularly in the short run, so the tax will raise the price of electricity significantly. Consumers and firms will substitute other inputs for electricity, leading to a fall in electricity demand.[2] Higher energy prices will lead to slower productivity growth, reduced capital formation, and a reallocation of labor to lower-wage industries, all of which will cause gross national product to be lower than it would have been in the absence of the tax.

The tax rate needed to achieve a fixed absolute emissions target, such as maintaining emissions at 1990 levels, will depend on how fast emissions grow in the absence of the tax. Baseline emissions growth, in turn, will depend on the rate of productivity growth, the rate of capital accumulation, the rate of growth of the labor force, any energy-saving biases in technical change, and the path of world oil prices. More rapid economic growth will generally lead to higher baseline emissions and will thus require higher tax rates if emissions are to be held at a fixed absolute level. Moreover, deeper absolute cuts in emissions will require sharply increasing tax rates.

A carbon tax large enough to have much effect on emissions will raise tens to hundreds of billions of dollars annually. How this revenue is used will affect the overall economic burden of the tax. By using the revenue to lower highly distortionary taxes elsewhere in the economy, the tax could actually increase output and economic welfare. In the remainder of this chapter we present an overview of our model and discuss each of these findings in detail.

2. AN OVERVIEW OF THE MODEL

Our results are based on a set of simulations we conducted using a detailed model of the United States economy designed specifically for examining the effects of energy and environmental policies. One feature of our approach which distinguishes it from many others is that we use a general equilibrium model. General equilibrium models are constructed by dividing the economy into a collection of interdependent sectors which interact through product and factor markets. The behavior of each sector is represented by an appropriate submodel. Prices and wages adjust until demands and supplies are equated in every market and the economy reaches equilibrium. Our model is composed of thirty-five producing sectors, a consumer sector, an investment sector, a government sector and a foreign sector. In this section we present an overview of the model by describing the submodels used to represent each of these sectors. We also discuss our base case simulation.[3]

2.1 Production

Production is disaggregated into the thirty-five industrial sectors listed in Table 1. Most of these industries match two-digit sectors in the Standard Industrial Classification (SIC). Each industry produces a primary product and may produce one or more secondary products. This level of industrial detail makes it possible to measure the effect of changes in tax policy on relatively narrow segments of the economy. Since most anthropogenic carbon dioxide emissions are generated by fossil fuel combustion, a disaggregated model is essential for capturing differences in the response of each sector to a carbon dioxide control policy.

We derive the behavior of each of the industries from a hierarchical tier-structured transcendental logarithmic cost function. At the highest level, the cost of each industry's output is assumed to be a function of the prices of energy, materials, capital services and labor. At the second level, we take the price of energy to be a function of prices of coal, crude petroleum, refined petroleum, electricity, and natural gas, and the price of materials to be a function of the prices of all other intermediate goods. Given this structure we derive factor demands for capital services, labor and intermediate inputs from each of the thirty-five industries.

We estimated the parameters of each industry submodel econometrically, using a set of consistent inter-industry transactions tables constructed for the purpose. The tables describe the U.S. economy for the period 1947 through 1985.[4] Estimating the production parameters over a long time series ensures that each industry's response to changes in prices is consistent with historical evidence.[5]

An unusual feature of our model is that productivity growth is determined endogenously.[6] Other models used to study global warming, for example, Manne and Richels (1992), take productivity growth to be exogenous. In our model the rate of productivity growth in each industry is determined endogenously as a function of input prices. In addition, each industry's productivity growth can be biased toward some inputs and away from others. Biased productivity growth is a common feature of historical data but is often ignored when modeling production. By allowing for biased productivity growth, our model is able to capture the evolution of industry input patterns much more accurately.

Although we allow for biased productivity growth, we do not impose that technical change be energy-saving in every industry. Most other participants in EMF-12 introduce energy-saving technical change through an exogenous parameter giving the rate of "Autonomous Energy Efficiency Improvements." The extent to which technical change is energy-saving is a source of considerable controversy. Manne and Richels (1992) suggest that engineering analysis shows technical change to energy-saving, while Hogan and Jorgenson (1991) present econometric evidence that aggregate technical change may be slightly energy-using. However, these positions

Table 1: Industry Definitions

Num	Description
1	Agriculture, forestry and fisheries
2	Metal mining
3	Coal mining
4	Crude petroleum and natural gas extraction
5	Nonmetallic mineral mining
6	Construction
7	Food and kindred products
8	Tobacco manufactures
9	Textile mill products
10	Apparel and other textile products
11	Lumber and wood products
12	Furniture and fixtures
13	Paper and allied products
14	Printing and publishing
15	Chemicals and allied products
16	Petroleum refining
17	Rubber and plastic products
18	Leather and leather products
19	Stone, clay and glass products
20	Primary metals
21	Fabricated metal products
22	Machinery, except electrical
23	Electrical machinery
24	Motor vehicles
25	Other transportation equipment
26	Instruments
27	Miscellaneous manufacturing
28	Transportation and warehousing
29	Communication
30	Electric utilities
31	Gas utilities
32	Trade
33	Finance, insurance and real estate
34	Other services
35	Government enterprises

are not necessarily inconsistent. After the sharp increases in energy prices of the 1970's, the U.S. economy became markedly less energy-intensive as producers and consumers substituted away from energy. To the engineers reported by Manne and Richels, this would have appeared as a shift toward energy-saving technology. Hogan and Jorgenson's study reports biases in technical change *after* accounting for movements induced by substitution. Our model is based on the same dataset as Hogan and Jorgenson's work, and so has the technical change properties they describe.

In sum, the salient features of our model of producer behavior are as follows. First, production is disaggregated into thirty-five industries. Second, all parameters of the model are estimated econometrically from an extensive historical data base developed specifically for this purpose. This allows the model to incorporate extensive historical evidence on the price responsiveness of input patterns, including changes in the mix of fossil fuels. Third, the model determines rates of productivity growth endogenously and allows for biased productivity change in each industry.

2.2 Consumption

We represent consumer behavior by assuming that households follow a three-stage optimization process. At the first stage, each household allocates full wealth (the sum of financial and human wealth, plus the imputed value of leisure time) across different periods.[7] We formalize this decision by introducing a representative agent who maximizes an additive intertemporal utility function subject to an intertemporal budget constraint. The portion of full wealth allocated to a particular period is called full consumption. At the second stage, households allocate full consumption to goods and leisure in order to maximize an indirect utility function. This allows us to derive demands for leisure and goods as functions of prices and full consumption. The demand for leisure implicitly determines labor supply, while the difference between current income and consumption of goods implicitly determines savings.

The third stage of the household optimization problem is the allocation of total expenditure among capital services, labor services, and the thirty-five commodities. At this stage, we relax the representative consumer assumption in favor of the approach of Jorgenson, Lau and Stoker (1982) to derive separate systems of demand functions for households of different demographic characteristics. We distinguish among 1344 household types according to demographic characteristics such as the number of household members and the geographic region in which the household is located. The spending patterns of each household type are derived from a hierarchial tier-structured indirect utility function. This allows us to derive household demands for individual commodities.

As with production, the parameters of the behavioral equations for all three stages of our consumer model are estimated econometrically.[8] Our household model incorporates extensive time series data on the price responsiveness of demand patterns by consumers and also makes use of detailed cross-section data on the effects of demographic characteristics on consumer behavior. In addition, an important feature of our approach is that we do not impose that household demands be homothetic. As total expenditure increases, spending patterns may change even in the absence of price changes. This captures an important feature of cross-sectional expenditure data which is often ignored.

2.3 Investment and Capital Formation

We assume there is a single capital stock in the economy which is in fixed total supply in the short run. However, we also assume that capital is perfectly malleable and can be reallocated among industries and between industries and final demand categories at zero cost. Thus, the price of a unit of capital services will be equal in every industry and there will be a single economy-wide rate of return on capital.

In the long run the supply of capital is determined by investment. Our investment model is based on the assumption that investors have rational expectations and that arbitrage occurs until the present value of future capital services is equated to the purchase price of new investment goods. This equilibrium is achieved by adjustments in prices and the term structure of interest rates. New capital goods are produced from individual commodities according to a model identical to those for the industrial sectors so the price of new capital will depend on commodity prices. We estimated the behavioral parameters for new capital goods production using final demand data for investment over the period 1947-1985. Thus, the model incorporates substitution among inputs in the composition of the capital.

2.4 Government and Foreign Trade

The two remaining parts of the model are the government and foreign sectors. To specify government behavior, we begin by computing total government spending on goods and services. We apply exogenous tax rates to taxable transactions in the economy and then add the capital income of government enterprises and non-tax receipts to obtain total government revenue.[9] Next we assume the government budget deficit can be specified exogenously and add the deficit to total revenue to obtain total government spending. To arrive at government purchases of goods and services, we subtract interest paid to holders of government bonds together with transfer payments to domestic and foreign recipients. We then allocate spending among commodity groups according to fixed shares constructed from historical data.

In the modeling the foreign sector we begin by assuming that imports are imperfect substitutes for similar domestic commodities.[10] The mix of goods purchased by households and firms reflects substitution between domestic and imported products. We estimate the price responsiveness of this mixture econometrically from historical data. In effect, each commodity is assigned a separate elasticity of substitution between domestic and imported goods. Since the prices of imports are given exogenously, intermediate and final demands implicitly determine the quantity of imports of each commodity.

Exports are determined by a set of isoelastic export demand equations, one for each commodity, that depend on foreign income and the foreign prices of US exports.[11] Foreign prices are computed from domestic prices by adjusting for subsidies and the exchange rate. The demand elasticities in these equations are estimated from historical data. Without an elaborate model of international trade it is impossible to determine both the current account balance and the exchange rate endogenously so we take the current account to be exogenous and the exchange rate to be endogenous.

2.5 Carbon Dioxide Emissions

For EMF-12, the most important remaining feature of the model is the way in which carbon dioxide emissions are calculated We begin by assuming that carbon dioxide is produced in fixed proportion to fossil fuel use. For each fuel, Table 2 gives total domestic production, heat content per unit and total heat produced.[12] Heat production is measured in quadrillion BTU.

We calculated the carbon content of each fuel by multiplying the numbers in Table 2 by figures from the Environmental Protection Agency on the amount of carbon emitted per million BTU produced from each fuel.[13] Total carbon emissions were then calculated using figures on

Table 2: Domestic Production and Heat Content of Fossil Fuels

Fuel	Unit	Domestic Production	MBTU per Unit	Total QBTU
Coal	ton	916.9×10^6	21.94	20.1
Oil	bbl	3033.2×10^6	5.80	17.6
Gas	kcf	17.8×10^9	1.03	16.8

total fuel production. Table 3 shows data for each fuel in 1987. For comparability with other studies, we measure CO_2 emissions in tons of contained carbon.[14]

Table 3: Carbon Emissions Data for 1987

Item			Fuel	
		Coal	Oil	Gas
Unit of Measure		ton	bbl	kcf
Heat Content	10^6 BTU/unit	21.94	5.80	1.03
Emissions Rate	kg/10^6 BTU	26.9	21.4	14.5
	kg/unit	590.2	124.1	14.9
Domestic Output	10^9 units	0.92	0.30	17.9
Carbon Emissions	10^6 tons	595.3	414.1	268.6

All prices in our model are normalized to unity in 1982, so quantities do not correspond directly to physical units. Moreover, the model has a single sector for oil and gas extraction. To convert the oil and gas data in Table 3 into a form appropriate for the model we added carbon production for crude petroleum and natural gas and divided by the industry's output for 1987 to obtain the industry's carbon coefficient. Similarly, the coefficient for coal was obtained by dividing total carbon production from coal by the model's 1987 value for coal mining output. These coefficients were used to estimate carbon emissions in each simulation.

2.6 The Base Case

To assess the effect of a carbon tax we must first determine the future path of the U.S. economy in the absence of the tax. To construct such a scenario, which we will call a "base case", we adopted a set of default assumptions about the time path of each exogenous variable in the absence of changes in government policy. Since our model is based on agents with perfect foresight values must be specified far into the future. Through 1990-2050, we forecast values of the exogenous variables on the basis of their behavior in the sample period. After 2050 we assume the variables remain constant at their 2050 values to allow the model to converge to a steady state by the year 2100.[15]

Our projections for 1990-2050 were made as follows. First, all tax rates are set to their values in 1985, the last year in our sample period. Next, we assume that foreign prices of imports in foreign currency remain constant in real terms at 1985 levels. We then project a gradual decline in the government deficit through the year 2025, after which the nominal value of the government debt is maintained at a constant ratio to the value of the national product. Finally, we project the current account deficit by allowing it to fall gradually to zero by the year 2000. After that we project a current account surplus sufficient to produce a stock of net claims on foreigners by the year 2050 equal to the same proportion of national wealth as in 1982.

Some of the most important exogenous variables are those associated with growth of the U.S. population and corresponding changes in the economy's time endowment. We project population by age, sex and educational attainment through the year 2050, using demographic assumptions consistent with Social Security Administration projections.[16] After 2050 we hold population constant, which is roughly consistent with Social Security projections. In addition, we project the educational composition of the population by holding the level of educational attainment constant beginning with the cohort reaching age 35 in the year 1985. We transform our population projection into a projection of the time endowment by assuming that the pattern of relative wages across different types of labor remains as it was in 1985. Since capital formation is endogenous in our model, our projections of the time endowment effectively determine the size of the economy in the more distant future.

3. A SUMMARY OF RESULTS

One policy often proposed for slowing global warming is to stabilize greenhouse gas emissions at 1990 levels. This corresponds to EMF-12 scenario 4, so we begin our discussion there. Subsequent sections will examine the effects of more stringent emissions targets, the consequences of using carbon tax revenue in different ways, and the sensitivity of results to assumptions embodied in the base case scenario.

3.1 Stabilizing Emissions

To implement scenario 4 we introduced a tax on the carbon content of primary fossil fuels. The tax rate varied from year to year but was always chosen to be exactly enough to hold U.S. carbon dioxide emissions at their 1990 value of 1576 million tons. We returned the revenue raised by the tax to households as a lump-sum rebate. The carbon tax we obtained is shown as a function of time in Figure 1. Base case emissions increase over time so the tax grows gradually over the next few decades. By 2020 our forecast of the US population crests and growth begins to slow, reducing the rate of carbon tax growth.[17] The tax produces significant reductions in carbon emissions, as shown in Figure 2. By 2020 emissions are sixteen percent lower than they would have been without the tax. The tax also produces significant revenue: $31 billion annually by 2020.[18]

Figure 1: Carbon Tax Under Scenario 4

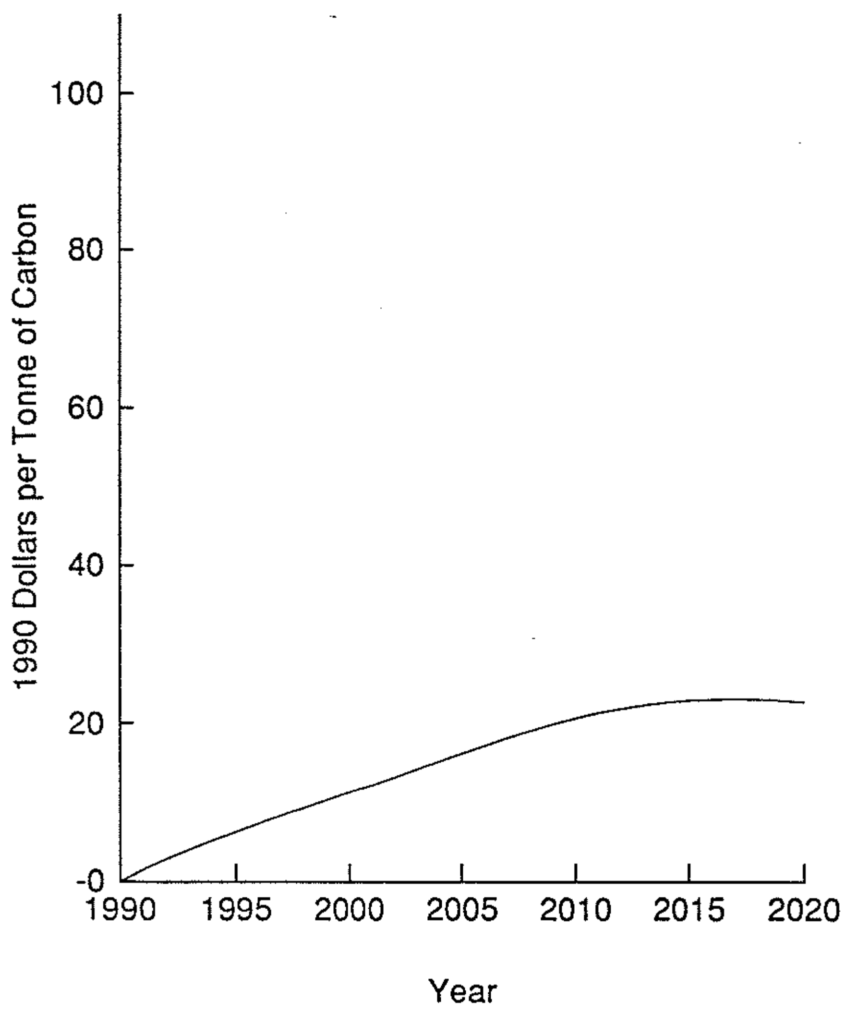
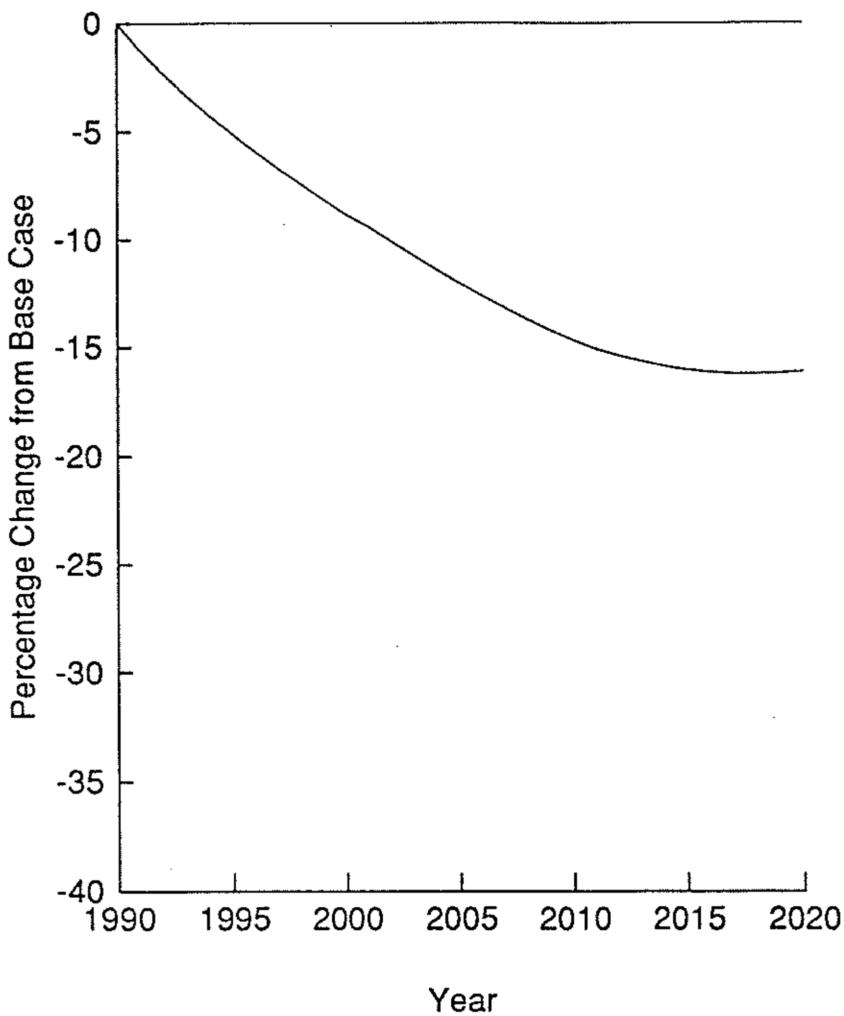


Figure 2: Reduction in Emissions Under Scenario 4



The direct effect of the tax is to increase purchasers' prices of coal and crude oil. By 2020, for example, the tax reaches $22.71 per ton of carbon. This amounts to a tax of $14.75 per ton of coal, $3.10 per barrel of oil or $0.37 per thousand cubic feet of gas. Figure 3 shows the effect of the tax on purchasers' prices of each industry's output in 2020. The price of coal rises by forty-seven percent, the price of electricity rises by almost seven percent (coal accounts for about thirteen percent of the cost of electricity), and the price of crude oil rises by around four percent. Other prices showing significant effects are those for refined petroleum and natural gas utilities. These rise, directly or indirectly, because of the tax on the carbon content of oil and natural gas.

Changes in relative prices affect demands for each good and lead to changes in industry outputs. Figure 4 presents percentage changes in industry outputs in 2020 relative to the base case. Most sectors show only small changes in output. Coal mining is an exception: its output falls by almost thirty percent. Coal is affected strongly for three reasons. First, coal emits the more carbon dioxide than oil or natural gas per unit of energy produced. Thus, the absolute level of the tax per unit of energy content is higher on coal than other fuels. Second, the tax is very large relative to the base case price of coal: at the mine mouth the tax increases coal prices by around fifty percent. Oil is far more expensive per unit of energy so in percentage terms its price is less affected by the tax. In fact, the price of crude oil rises only about ten percent. Third, the demand for coal is relatively elastic. Most coal is purchased by electric utilities which can substitute other fuels for coal when the price rises. Moreover, the demand for electricity itself is relatively elastic so when the price of electricity rises, demand for electricity (and hence demand for coal) falls substantially.

For the rest of the economy, the main result of the tax is to increase the prices of electricity, refined petroleum and natural gas, each by a few percent. This would have two effects. First, higher energy prices would mean that capital goods (which are produced using

Figure 3: Change in Prices at 2020 Under Scenario 4

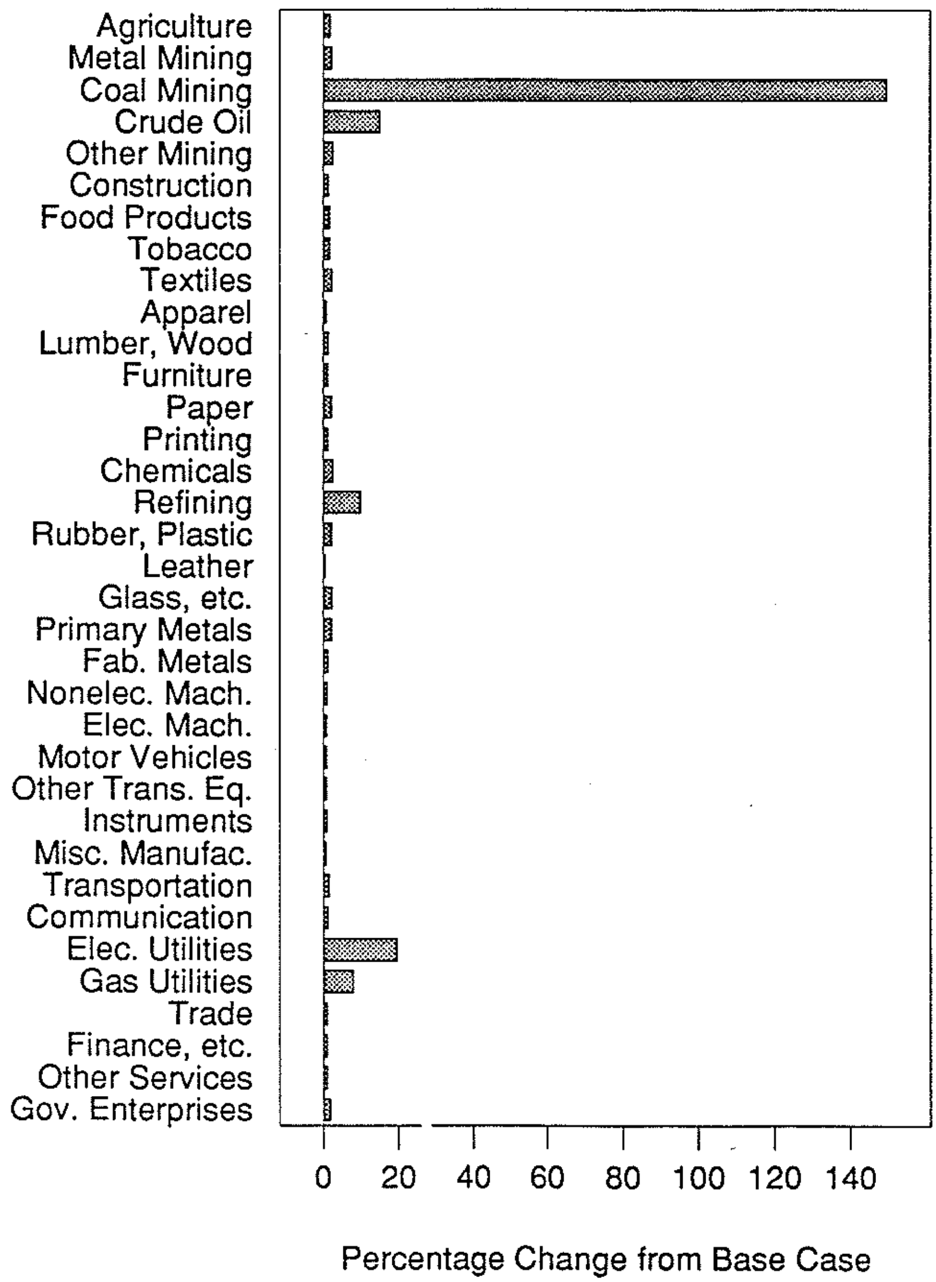
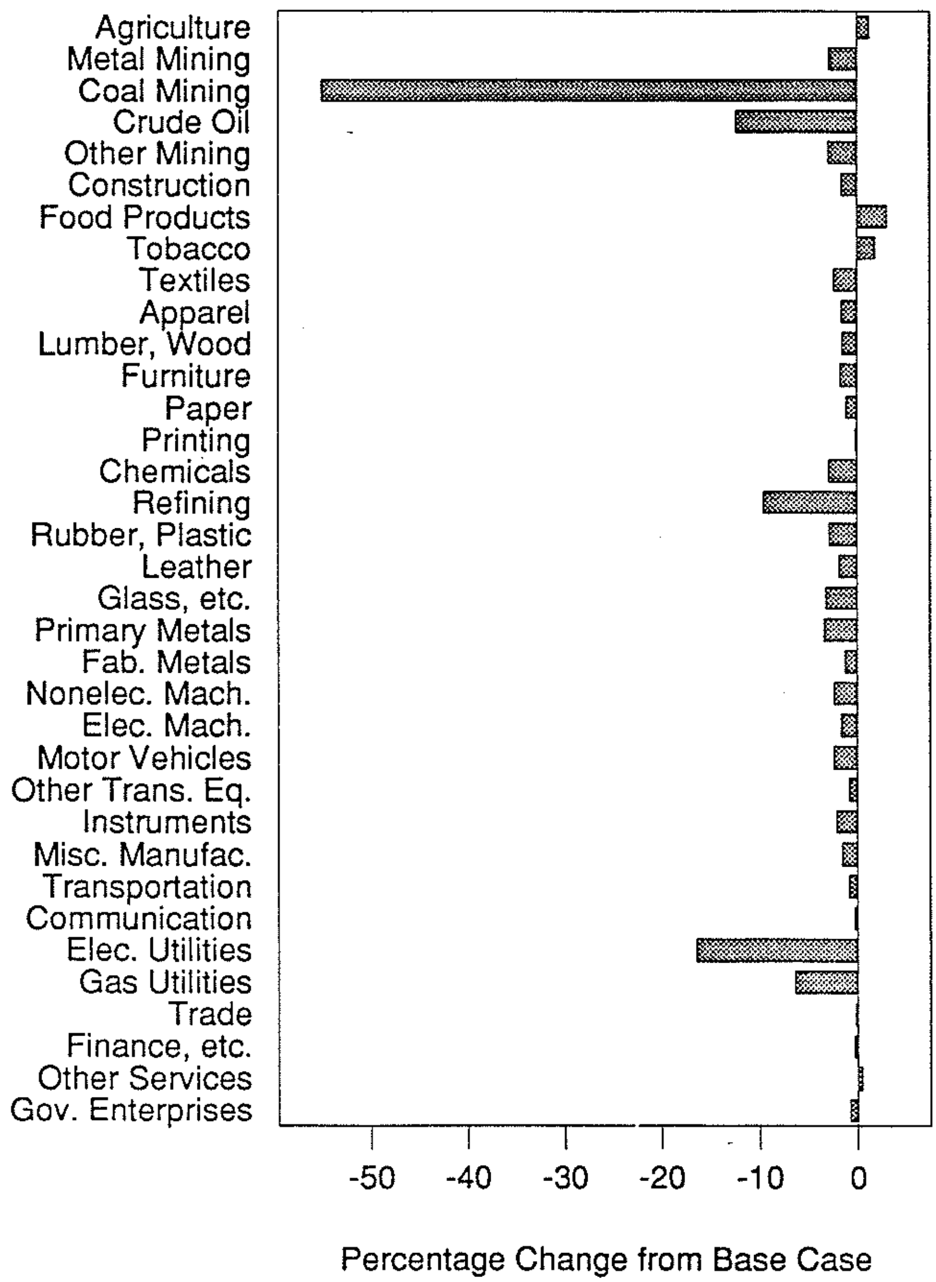


Figure 4: Change in Output at 2020 Under Scenario 4



energy) would become more expensive. To the extent that domestic saving does not rise enough to compensate, higher prices for capital goods mean a slower rate of capital accumulation and lower GNP in the future. Second, higher energy prices discourage technical change in industries in which technical change is energy-using. Together, these two effects cause the capital stock to drop by 0.7 percent and GNP to fall by 0.5 percent (both relative to the base case) by 2020. Average annual GNP growth over the period 1990-2020 is 0.02 percentage points lower than in the base case. About half of this is due to slower productivity growth and half due to reduced capital formation.

3.2 Larger Reductions

EMF-12 scenarios 2 and 3 specify more ambitious goals for carbon dioxide control. In scenario 2, emissions are required to decrease gradually until 2010, when they must be twenty percent below 1990 levels. In scenario 3, emissions must fall by twenty percent in 2010 and then by fifty percent by 2050. Figure 5 shows the paths of carbon taxes needed over time in scenarios 2, 3 and 4 while Figure 6 shows the paths of carbon emissions in each case. Table 4 compares key long-run results for these two simulations with results for scenario 4.

Comparing scenarios 2 and 3 with 4 shows that increasing the stringency of the policy rapidly increases its cost. Moving from scenario 4 to 2 doubles the effect of the policy: emissions fall by 32.90 percent instead of 16.12 percent. However, this comes at the cost of tripling the carbon tax and the loss of output. Moving from scenario 4 to scenario 3 raises costs even more sharply: the carbon tax and loss of GNP go up by more than a factor of four while the carbon reduction rises by only a factor of 2.4.

Figure 5: Carbon Taxes Under Scenarios 2-4

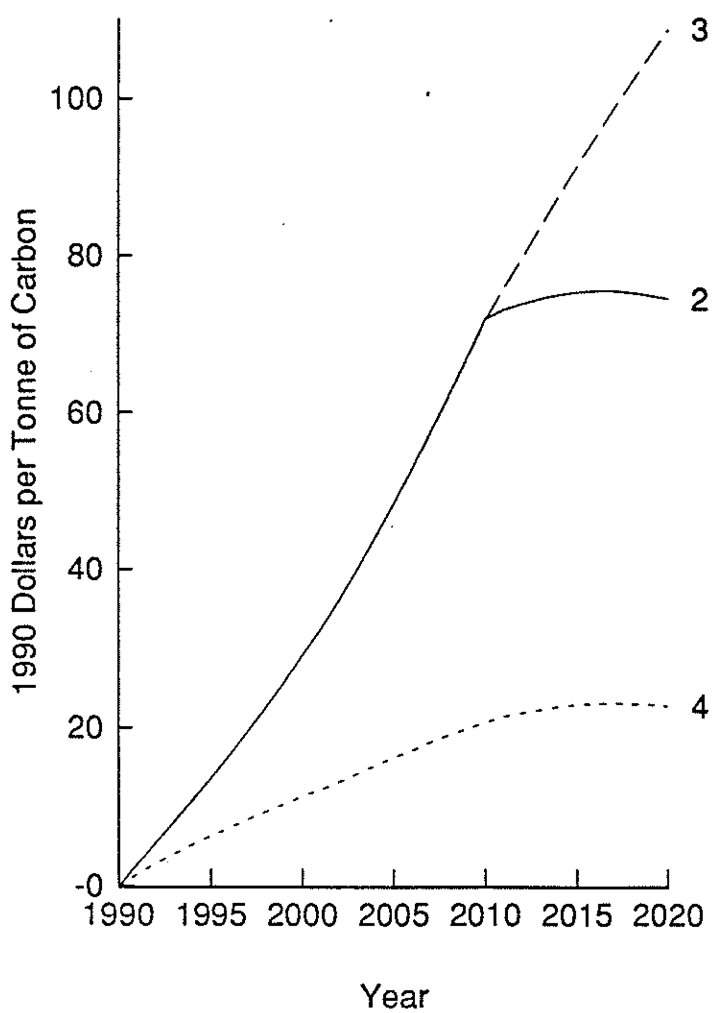


Figure 6: Reduction in Emissions Under Scenario 4

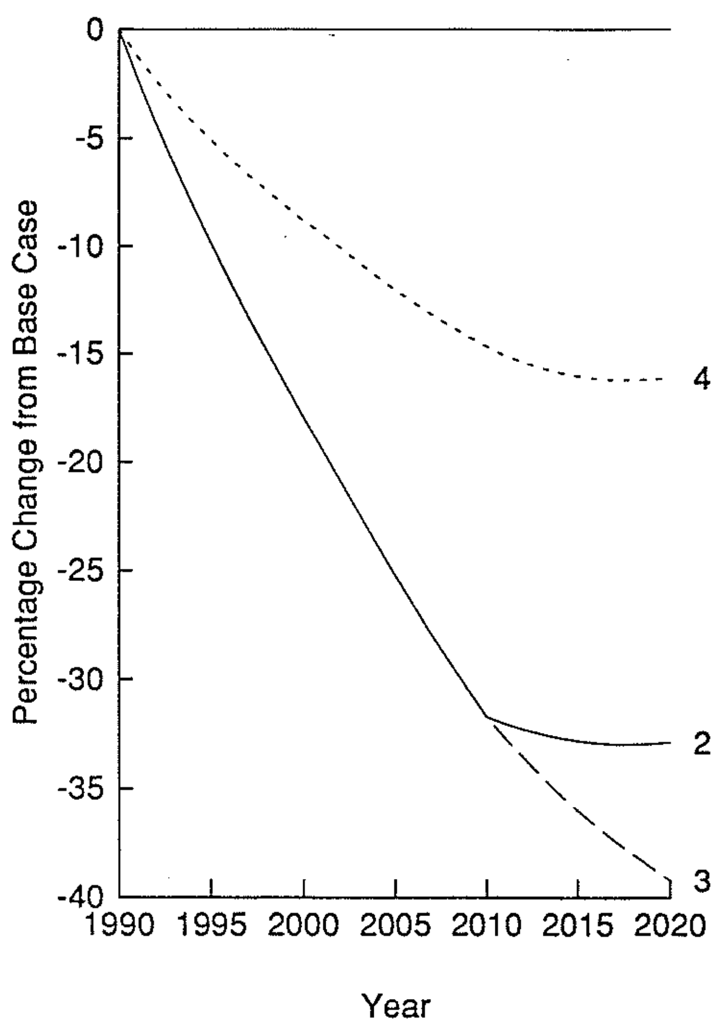


Table 4: Selected Results for Scenarios 2-4 in 2020

Variable	Unit	Scenario		
		2	3	4
Carbon Emissions	%Δ	-32.90	-39.19	-16.12
Carbon Tax	$/t	74.49	108.78	22.71
Price of Capital	%Δ	1.10	1.40	0.40
Capital Stock	%Δ	-2.35	-2.95	-0.83
Tax Revenue	$B	82.52	109.16	31.41
Real GNP	%Δ	-1.71	-2.36	-0.55
Coal Price	%Δ	149.86	216.09	46.99
Coal Output	%Δ	-55.03	-62.47	-29.28
Electricity Price	%Δ	19.46	26.90	6.60
Electricity Output	%Δ	-16.43	-21.74	-6.17
Oil Price	%Δ	15.06	22.37	4.45
Oil Output	%Δ	-12.35	-17.63	-3.90

Comparing industry results across each of the scenarios shows that the more stringent policies have progressively larger effects on sectors other than coal mining. Doubling the emissions reduction by moving from scenario 4 to scenario 2 does not cause the reduction in coal output to double. Coal users, particularly electric utilities, find it increasingly difficulty to substitute away from coal. Thus, larger reductions in carbon emissions require progressively larger reductions in oil use. From scenario 4 to scenario 2, for example, the drop in oil use more than triples.

3.3 Use of Carbon Tax Revenues

Even a modest carbon tax would raise substantial revenue. In the simulations above we assumed the proceeds were returned to households by a lump-sum rebate. This is probably not the most likely use of the revenue, nor is likely to be the best use given that the federal budget deficit is large and that other government revenue is raised by distortionary taxes. Using the revenue to reduce a distortionary tax would lower the net cost of the carbon tax by removing inefficiency elsewhere in the economy.

To determine how large this efficiency improvement might be we constructed three simulations based on EMF-12 scenario 7. In each simulation we impose a carbon tax of $15 per ton in 1990 with the rate rising by 5% annually in subsequent years. The simulations differ in how the revenue was used. In the first simulation the revenue was returned to households by a lump-sum rebate; in the second it was used to lower taxes on labor; and in the third it was used to lower taxes on capital. Table 5 reports results from the three simulations.

The GNP results in Table 5 show that the disposition of revenue from a carbon tax has a very significant effect on its overall impact. In the lump-sum case, output in 2020 drops by 1.70 percent relative to the base case. When the revenue is returned by lowering the tax on labor the loss of GNP is less than half as much: only 0.69 percent. The improvement is due to an increase in employment brought about by the drop in the wedge between before- and after-tax wages. If the revenue were returned as a reduction in taxes on capital, GNP would actually increase above its base case level by 1.10 percent. In this case, the gain is due to accelerated capital formation generated by an increase in the after-tax rate of return on investment. These results suggest that a carbon tax would provide an opportunity for significant tax reform.

Table 5: Selected Results Revenue Experiments in 2020

Variable	Unit	Revenue Policy		
		Lump	Labor	Capital
Carbon Emissions	%Δ	-32.24	-32.09	-31.65
Carbon Tax	$/t	64.83	64.83	64.83
Price of Capital	%Δ	0.97	-1.86	0.23
Capital Stock	%Δ	-2.13	-1.36	1.89
Tax Revenue	$B	79.65	79.82	80.35
Real GNP	%Δ	-1.70	-0.69	1.10
Coal Price	%Δ	143.49	140.57	142.06
Coal Output	%Δ	-54.14	-54.19	-53.45
Electricity Price	%Δ	18.57	15.97	16.99
Electricity Output	%Δ	-15.93	-15.37	-14.66
Oil Price	%Δ	14.20	12.28	14.55
Oil Output	%Δ	-11.92	-11.54	-11.39

3.4 Sensitivity to Base Case Assumptions

Most EMF-12 scenarios required carbon dioxide emissions to be held indefinitely at a specified absolute level, such as that prevailing in 1990. In general, uncontrolled emissions will rise at the overall rate of economic growth less adjustments for increasing fossil fuel prices and energy-saving technical change. Achieving a fixed target in the face of continuously rising baseline emissions will require a growing carbon tax. At each point in time, the magnitude of the tax will depend on the size of the gap between uncontrolled emissions and the target. The more rapid the growth of uncontrolled emissions, the larger will be the gap and hence the larger will be the tax needed to keep emissions constant.

The growth of carbon emissions is determined by productivity growth, the rate of capital accumulation, the rate of labor supply growth, any energy-saving biases in technical change, and the path of world oil prices. For most models participating in EMF-12, many of these factors were exogenous. In fact, the EMF-12 study design includes a specified, exogenous GNP growth rate for each region. In our model, however, productivity growth, capital accumulation and biases in the rate of technical change are all endogenous. Moreover, productivity growth and biased technical change occurs at the level of individual industries rather than at the level of the economy as a whole. Thus, GNP growth is fundamentally endogenous in our model.

This difference in the treatment growth makes direct comparisons of our results with those of the other EMF-12 participants difficult. Our base case estimate of U.S. growth is substantially below the rate specified in the EMF-12 study design. As a result, our base case path of carbon emissions rises more slowly than it would if growth were faster. Thus, the carbon taxes needed to hold emissions at a fixed absolute level will tend to be lower in our model. To allow our results to be compared more easily with those of the other participants, and to explore the importance of GNP growth in general, EMF-12 scenario 12 was designed. Scenario 12 was identical to scenario 2 (a twenty percent reduction of emissions below 1990 levels), except that the growth rate of U.S. GNP was set to the value predicted by our base case simulation. Thus, the results of other participants could be directly compared with ours.

The principle finding of scenario 12 was that the carbon taxes and GNP loss predicted by other participants dropped sharply. Comparing our results for scenario 2 to the scenario 12 results of others, our carbon tax moves from being particularly low to being near the middle of the group. Our prediction for loss of GNP due to the tax moves from the middle of the group to among the highest. This is precisely what might be expected given that our initial growth rate was relatively low. Our model incorporates stronger intertemporal links between current carbon taxes, capital accumulation and productivity growth than most of the other models. Thus, our model should generate higher GNP losses than the others. Scenario 12 shows that after adjusting for base case emissions growth, this is in fact the case. More generally scenario 12 emphasizes that overall economic growth will have a profound effect on the cost of controlling carbon dioxide emissions.

4. CONCLUSION

In summary, our approach to EMF-12 has three features that distinguish it from others: our model is disaggregated to the level of individual industries, our behavioral parameters are obtained by econometric estimation, and productivity growth and biased technical change are endogenous in our model. These features allow us to investigate several aspects of carbon taxes that other EMF-12 participants were unable to examine. In particular, we find that a carbon tax will have sharply differing effects in different industries. The tax will fall most heavily on coal mining, leading to a substantial drop in coal use by electric utilities and other industries. Outside the coal industry, the main effect of the tax will be to increase the price of electricity. This will reduce productivity growth and slow the rate of capital formation, leading to slower growth of U.S. output.

The tax needed to attain any particular emissions target will depend heavily on how fast carbon dioxide emissions would have grown in the absence of the tax. Higher rates of GNP growth will lead to higher baseline emissions and will thus require higher carbon taxes. In addition, to achieve larger reductions in carbon emissions will require sharply increasing carbon taxes and will produce markedly higher losses of output.

Finally, a carbon tax large enough to have much effect on carbon emissions will raise considerable revenue. How this revenue is used will affect the overall economic burden of the tax. If the revenue were used to reduce distortionary taxes elsewhere in the economy, the impact of the tax on GNP would be reduced. In fact, it is possible that GNP would actually increase if the revenue were used to reduce taxes on capital.

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ENDNOTES

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2. In other words consumers and firms will conserve energy as it becomes more expensive.

3. For more detail on the specification of the model or the base case simulation, see Jorgenson and Wilcoxen (1990b)

4. Data on inter-industry transactions are based on input-output tables for the U.S. constructed by the Bureau of Economic Analysis (1984). Income data are from the U.S. national income and product accounts, also developed by the Bureau of Economic Analysis (1986). The data on capital and labor services are described by Jorgenson (1990). Additional details are given by Wilcoxen (1988), Appendix C, and Ho (1989).

5. A detailed discussion of our econometric methodology is presented by Jorgenson (1984, 1986).

6. Our approach to endogenous productivity growth was originated by Jorgenson and Fraumeni (1981).

7. Full wealth is defined to be the sum of financial wealth, the present value of future labor earnings, and the imputed value of leisure time.

8. Details on the econometric methodology are given by Jorgenson (1984). Additional details are provided by Wilcoxen (1988) and Ho (1989).

9. The capital income of government enterprises is endogenous while non-tax receipts are exogenous.

10. This is the Armington (1969) approach. See Wilcoxen (1988) and Ho (1989) for further details on our implementation of this approach.

11. We take foreign income to be exogenous.

12. The data is taken from Department of Energy (1990).

13. Environmental Protection Agency (1990) internal memorandum.

14. To convert to tons of carbon dioxide, multiply by 3.67.

15. A more detailed discussion of the base case is given by Jorgenson and Wilcoxen (1992).

16. Our breakdown of the U.S. population by age, sex, and educational attainment is based on the system of demographic accounts compiled by Jorgenson and Fraumeni (1989).

17. As noted above, our population projection is based on forecasts made by the Social Security Administration in which population growth approaches zero early in the next century.

18. All dollar amounts are in 1990 prices.