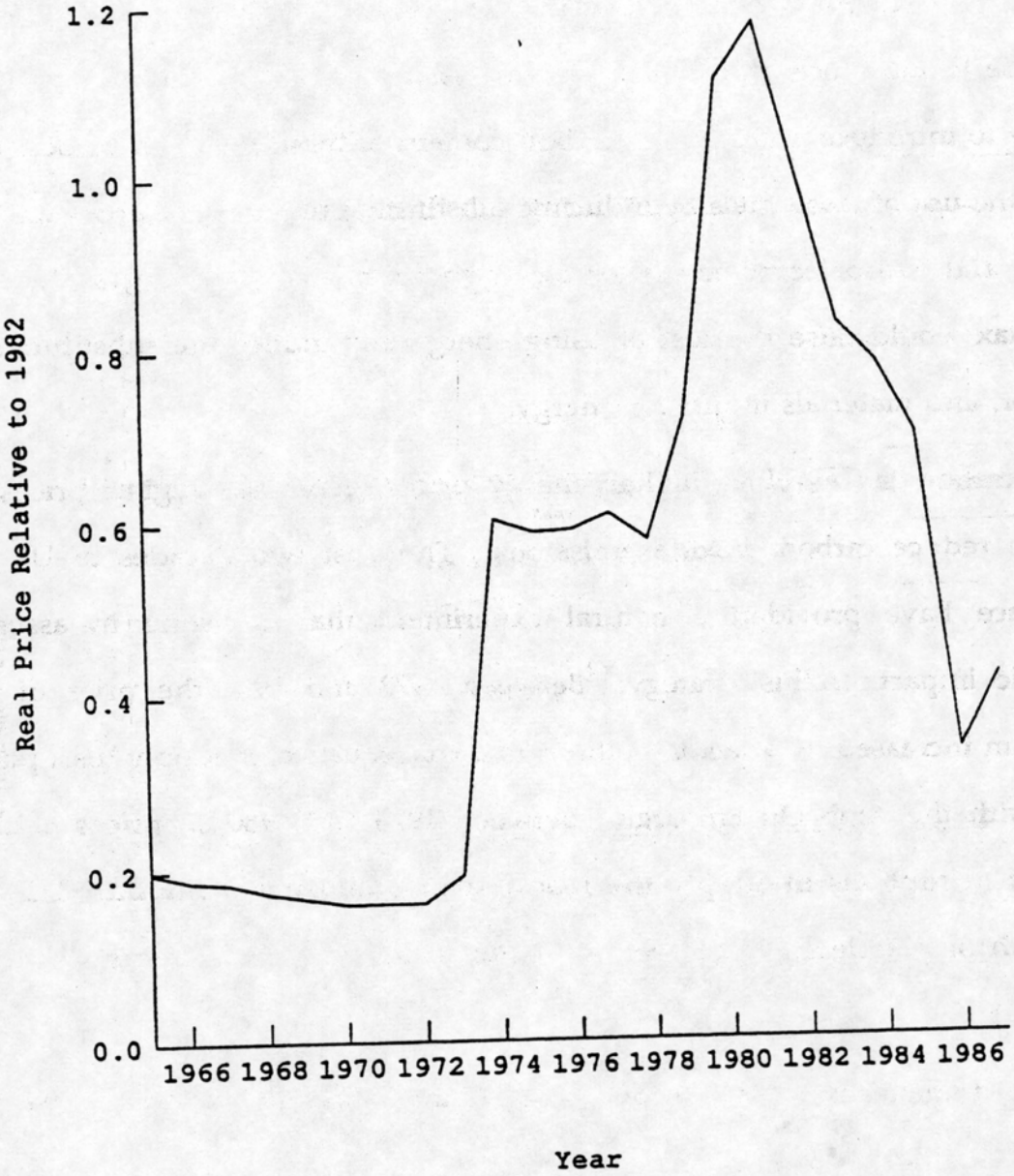
4. THE IMPACT OF HIGHER ENERGY PRICES

The possibility that carbon dioxide emissions from fossil fuel use might lead to global warming has become a leading environmental concern. Many scientific and environmental organizations have called for immediate action to limit these emissions. To the extent that the emissions are a global externality, one possible policy would be to introduce a Pigouvian tax on fossil fuel use. In particular, it would be possible to introduce a tax on the carbon content of fossil fuels. A carbon tax would reduce the use of fossil fuels by inducing substitution of energy sources such as solar, nuclear, and hydroelectric power for coal, petroleum, and natural gas. In addition, a carbon tax would raise the cost of using energy and induce the substitution of capital, labor, and materials inputs for energy.

A carbon tax employs higher energy prices, especially higher prices of fossil fuels, to reduce carbon dioxide emissions. The past two decades of US historical experience have provided a natural experiment that is useful in assessing the economic impact of this strategy. Between 1973 and 1975 the price of imported petroleum increased by a factor of three as a consequence of supply disruptions associated with the Arab Oil Embargo. Between 1978 and 1980 oil prices doubled as a result of disruptions in supply the followed the Iranian Revolution. The historical time path of petroleum prices between 1965 and 1990 in real terms is presented in Figure 4.1.

The dramatic increases in world petroleum prices during the 1970's were followed by a gradual decline in prices between 1980 and 1985 that gave way to a precipitous drop in 1986. By 1987 real petroleum prices had stabilized at levels that were more than double those prevailing in 1972. The increase in world petroleum prices raised the real cost of energy in the United States for all forms of energy. This increase in energy prices resulted in substantial energy conservation and stabilized

Figure 4.1: Real Price of Oil



carbon dioxide emissions for a period of fifteen years between 1972 and 1987. In Figure 4.2 we present historical data on carbon dioxide emissions for the period 1965 to 1987. In 1972, carbon dioxide emissions released 1224 million tons of carbon into the atmosphere.[48] Fifteen years later, in 1987, the emissions were identical.

In order to analyze the natural experiment that resulted from higher world petroleum prices since 1973, we have simulated the growth of the US economy with and without these price increases. We take the actual path of world petroleum prices over the period 1973 to 1987 as our base case and extrapolate real petroleum prices forward from 1987 at the level of prices prevailing in 1987. As alternatives to the base case we have considered the following scenarios:

OIL72: The real price of imported petroleum is held constant at its 1972 level. Thus, this scenario omits both the long-term increase in the level of world petroleum prices between 1972 and 1987 and the price shocks associated with supply disruptions in 1973-1975 and 1978-1980.

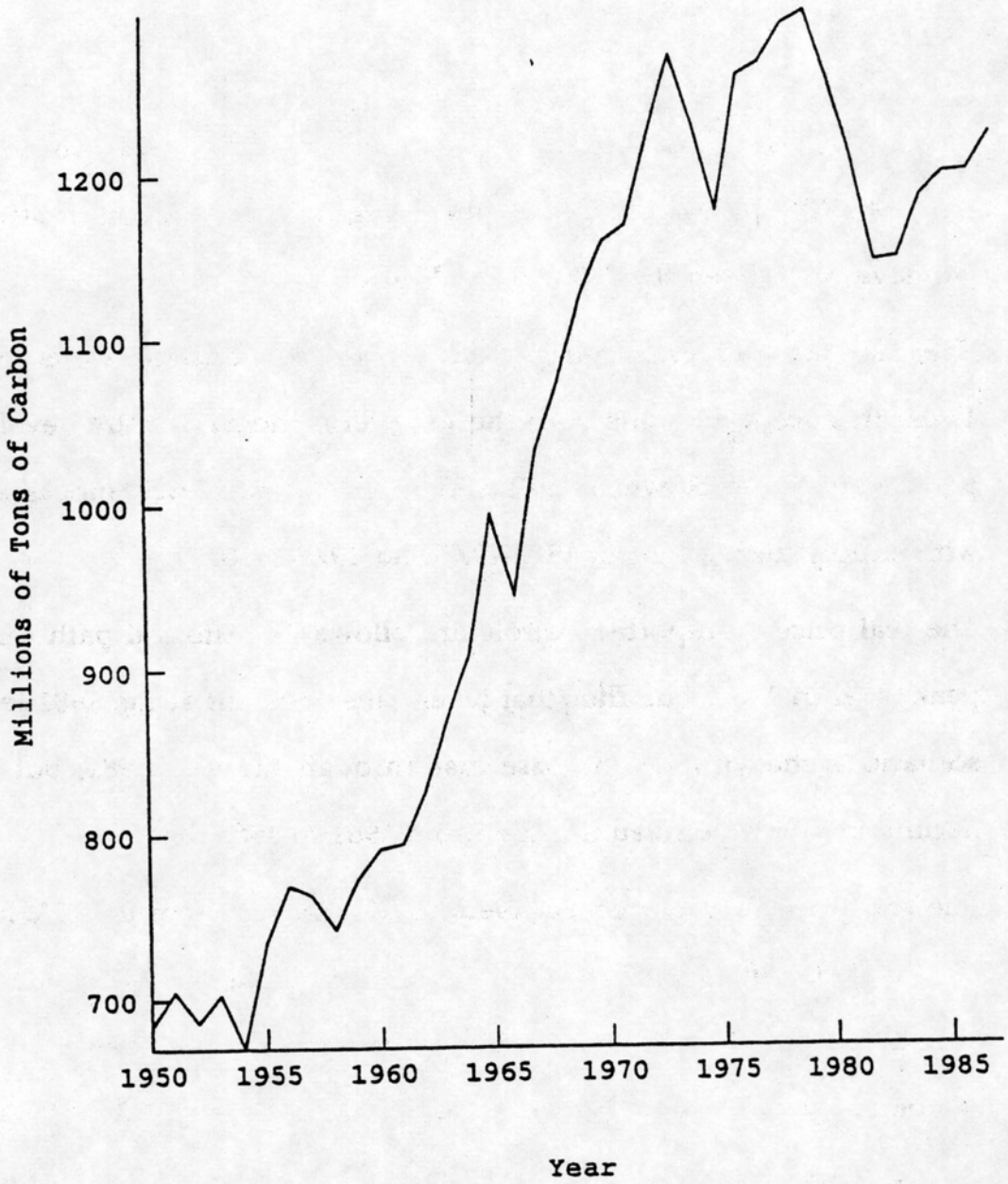
OIL81: The real price of imported petroleum follows its historical path through the peak level in 1981, but after that it remains constant at the 1981 level. This scenario is the same as the base case through the year 1981, but omits the decline in world petroleum prices from 1981 to 1987.

OIL87: The real price of imported petroleum rises linearly from its 1972 level to its level in 1987, after which it remains constant. This scenario omits the price shocks of 1973-1975 and 1978-1980, but captures the long-term rise in world petroleum prices over the fifteen-year period between 1972 and 1987.

By comparing the results for each of these simulations to our base case (in which world oil prices follow their historical course) we can assess the cost of stabilizing carbon dioxide emissions through high oil prices. Moreover, by analyzing all

48. Carbon dioxide emissions are conventionally measured by amount of carbon they contain.

Figure 4.2: Total Carbon Emissions



three of the alternative scenarios we can decompose the impact of the increase in world petroleum prices into separate components associated with the sharp price increases of the 1970's and the overall rise in the price level between 1972 and 1987.

4.1. Effects on the Steady State

Since the long run price of petroleum is the same in the base case and the OIL87 scenario, there are only three distinct long run equilibrium paths for our four scenarios. The base case associated with the historical path of oil prices and the revised OIL87 scenario result in the same long run behavior of the economy. However, the OIL81 scenario is associated with higher oil prices while the OIL72 scenario captures the effects of lower oil prices. The aggregate impacts of these scenarios are presented in Table 4.2. Under OIL72, the price of imported oil is 61 percent lower than the base case while under OIL81 it is 183 percent higher. Apart from important differences in the magnitudes, the long run impacts of OIL72 and OILS1 are dose to mirror images of each other. With lower oil prices real gross national product is 1.186 percent higher in the long run, while higher prices result in a 1.339 percent decrease in real GNP. Also, it is dear that the level of world oil prices has an important long run impact on the US economy. Lower prices increase GNP while higher prices decrease it. The real exchange rate, defined as the price of US imports relative to the price of US exports, is 1.098 percent lower under OIL72 than in the base case, and it is 1.254 percent higher under OIL81.

More rapid economic growth under the OIL72 petroleum price scenario leads to a capital stock that is 0.790 percent above the base case level and a capital rental price that is 0.713 percent lower. This is brought about in part by a 0.886 percent fall in the price of investment goods. In the long run the rate of return in the US economy is the same under all three scenarios-the base case, OIL72, and OIL81. As before,

Table 4.2: Long Run Oil Simulation Results

Variable	Scenario	
	OIL72	OIL81
Price of Imported Oil	-61.419	183.128
Capital Stock	0.790	-.912
Price of Investment Goods	-0.886	1.059
Real GNP	1.186	-1.339
Full Consumption	0.432	-0.494
Rental Price of Capital	-0.713	0.857
Exchange Rate	-1.098	1.254

OIL81 is close to a mirror image of OIL72, having a higher price of investment goods, a lower capital stock and a higher rental price of capital.

The final indicator of aggregate US economic activity given in Table 4.2 is full consumption. This is an important indicator of the change in consumer welfare associated with variations in the world oil price. Since leisure time is closely tied to the exogenous time endowment of the US economy, we find that full consumption is only 0.432 percent higher with lower oil prices in the OIL72 scenario and 0.494 percent lower with higher oil prices in the OIL81 scenario.

Finally, we present changes in industry output levels from the base case for OIL81 and OIL72 in Figure 4.3. Higher oil prices result in a drastic fall in the output of the petroleum refining sector illustrated graphically in Figure 4.3. The output of electric utilities is also substantially lower. The output of chemical manufacturing and gas utilities are also reduced by higher oil prices, while food and tobacco experience a modest increase in output as a consequence of substitution away from energy-intensive commodities by businesses and households. As before, the OIL72 scenario, corresponding to lower oil prices, is almost a mirror image of the high oil price scenario.

4.2. Dynamic Effects

In Section 2 we showed that the dynamics of our model are determined by the backward-looking capital accumulation equation and the forward-looking asset pricing and Euler equations. We can illustrate these mechanisms by first considering the OIL87 scenario, which has the same long run world petroleum price as the base case, but omits the price shocks of the 1970's. Figure 4.4 gives a comparison between this scenario and the base case.

In Figure 4.4 we see that the long run behavior of the US economy is identical in the base case and the OIL87 scenario. However, the transition path toward long

Figure 4.3(a): Effect of OIL81 on Output

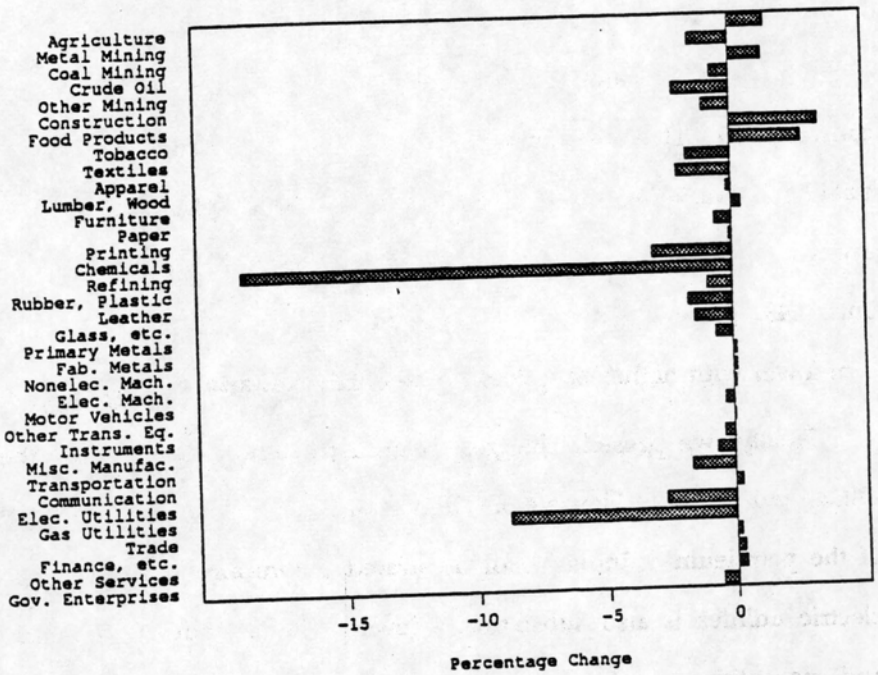
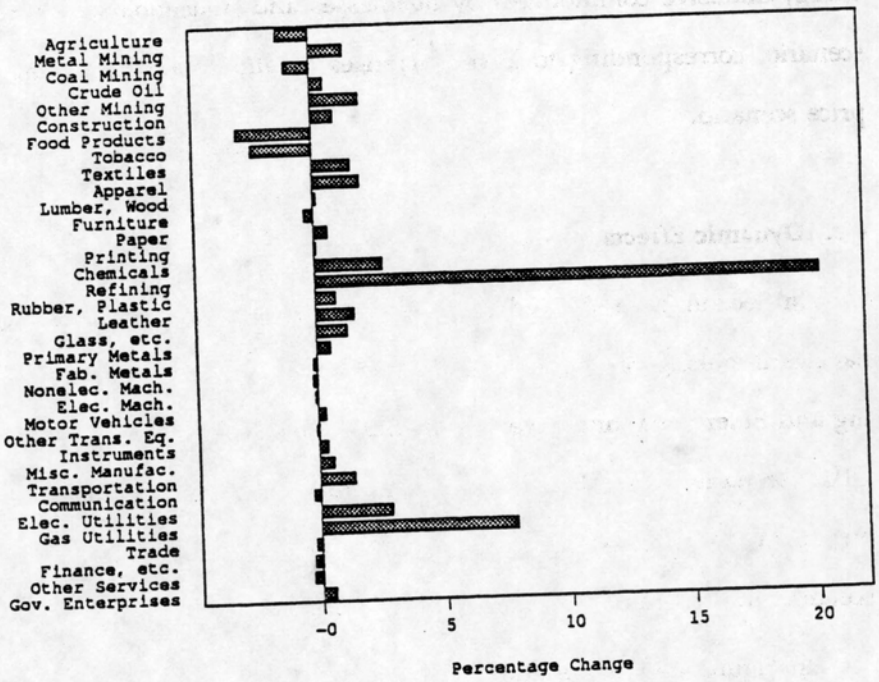


Figure 4.3(b): Effect of OIL72 on Output



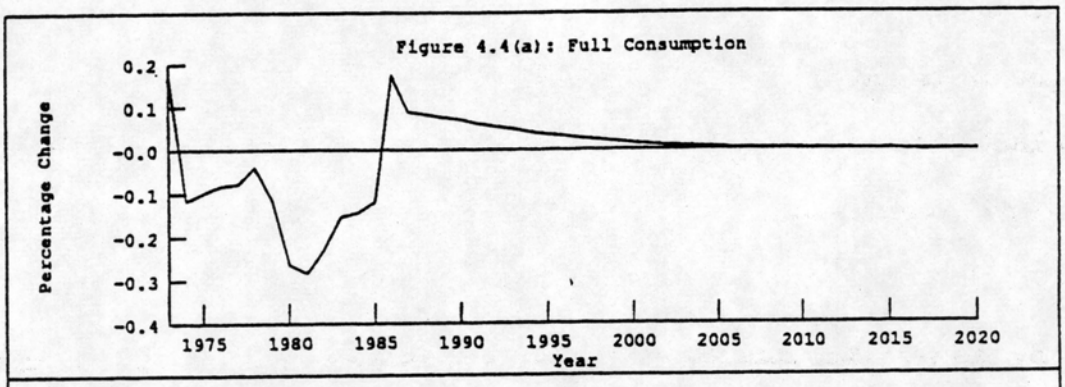


Figure 4.4(a): Full Consumption
Percentage Change
0.2
0.1
-0.0
-0.1
-0.2
-0.3
-0.4
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

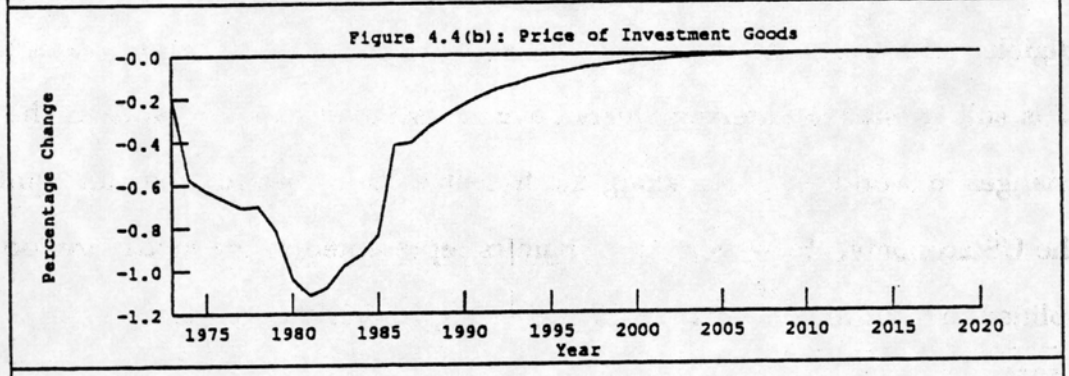


Figure 4.4(b): Price of Investment Goods
Percentage Change
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

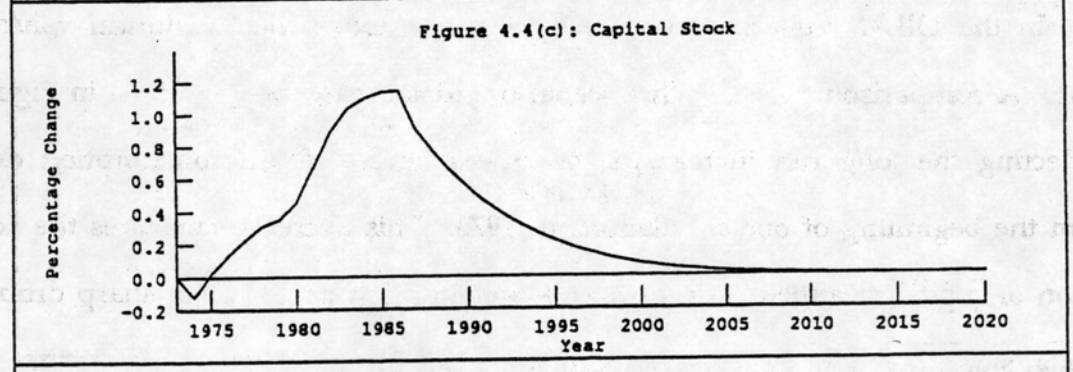


Figure 4.4(c): Capital Stock
Percentage Change
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

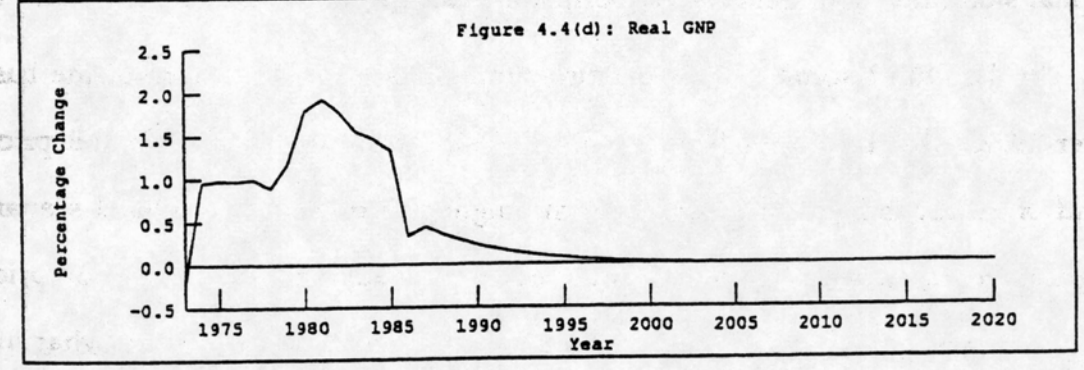


Figure 4.4(d): Real GNP
Percentage Change
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

run equilibrium is very different in the two scenarios. Between 1973 and 1987, oil prices are higher in the base case than in O1L87. Thus, during that period real income is higher under OIL87. However, this increase in income is only temporary because prices become the same after 1987. Since households have perfect foresight, they know the change is temporary, so consumption increases very little and most of the extra income is saved. This leads to pattern of capital accumulation shown in 4.4(c).

By the year 2005 differences between the base case and the OIL87 scenario are negligible. However, the impact of differences in world petroleum prices through 1987 is still substantial after ten years have elapsed. The model captures the effects of changes in world oil prices along the transition path toward long run equilibrium of the US economy. However, the dynamics represented in the model are too highly simplified to capture the short run impact of higher world oil prices.

In the OIL81 scenario, world oil prices are above their historical values after 1981. A comparison between this scenario and the base case is given in Figure 4.5. Reflecting the long run increase in oil prices, levels of full *consumption* decrease from the beginning of our simulations in 1973. This decrease facilitates the accumulation o£ capital in anticipation of future consumption needs. The sharp drop in the capital stock after 1987 reflects the permanent decline in real income after that time.

In the OIL72 scenario, world petroleum prices are below those of the base case after 1972. We have already seen that the long run impact of lower oil prices is a kind of mirror image of the effects of the higher oil prices in the OIL81 scenario. In Figure 4.6 we present the dynamics the economy's adjustment to lower oil prices. In this case, the path of full consumption shown in Figure 4.6(a) is somewhat misleading. Figure 4.6(a) shows the value of full *consumption* falling during the early years of the simulation. During that period, however, the price of consumption falls by more than enough to compensate, so the quantity of full consumption actually rises.

Figure 4.5(a): Full Consumption

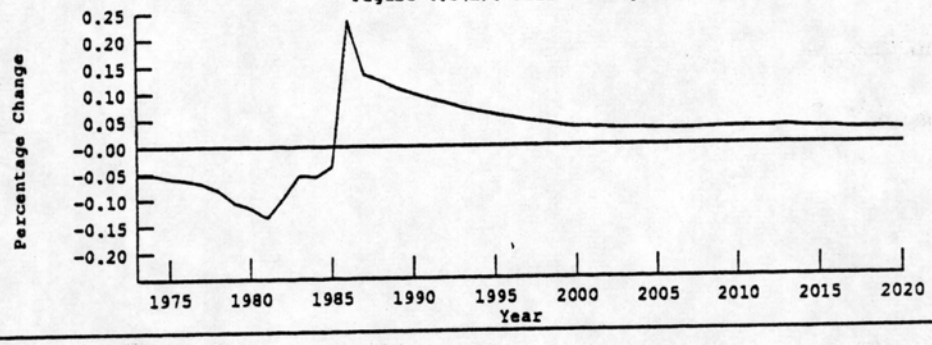


Figure 4.5(b): Price of Investment Goods

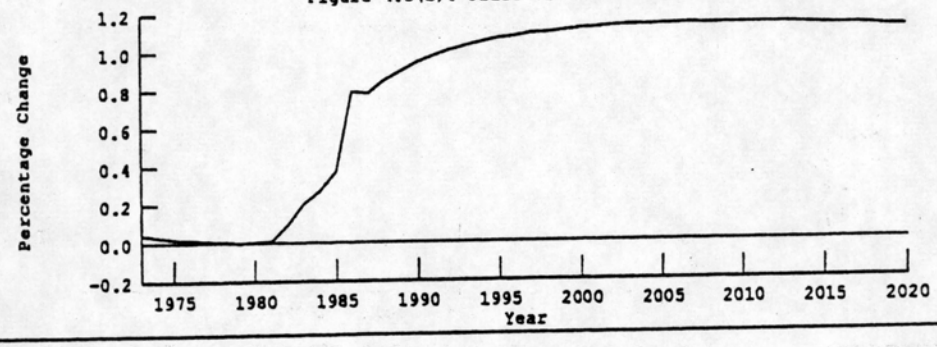


Figure 4.5(c): Capital Stock

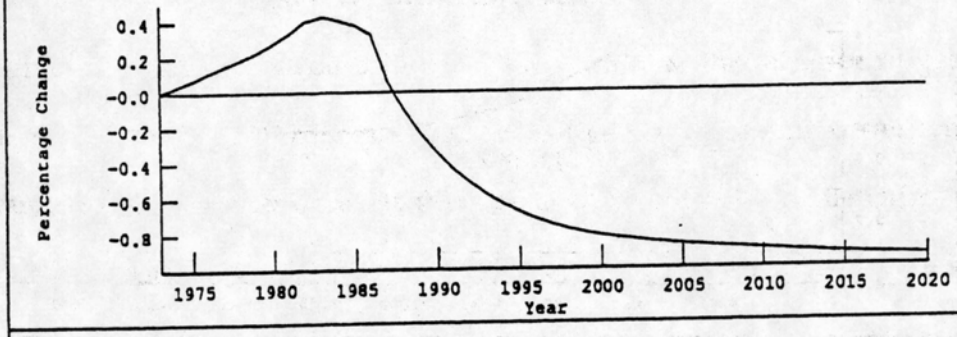
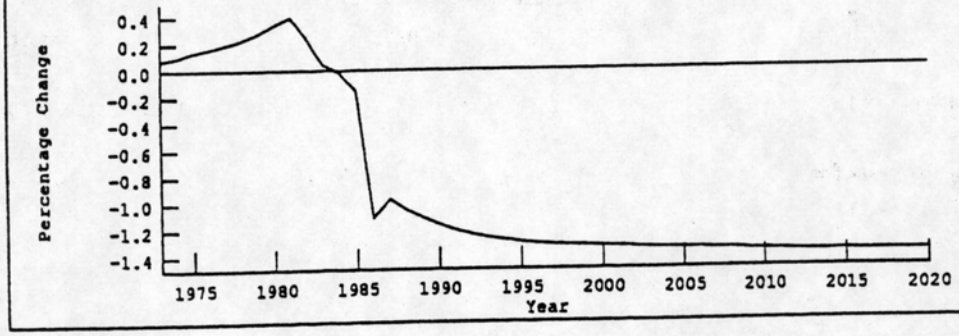


Figure 4.5(d): Real GNP



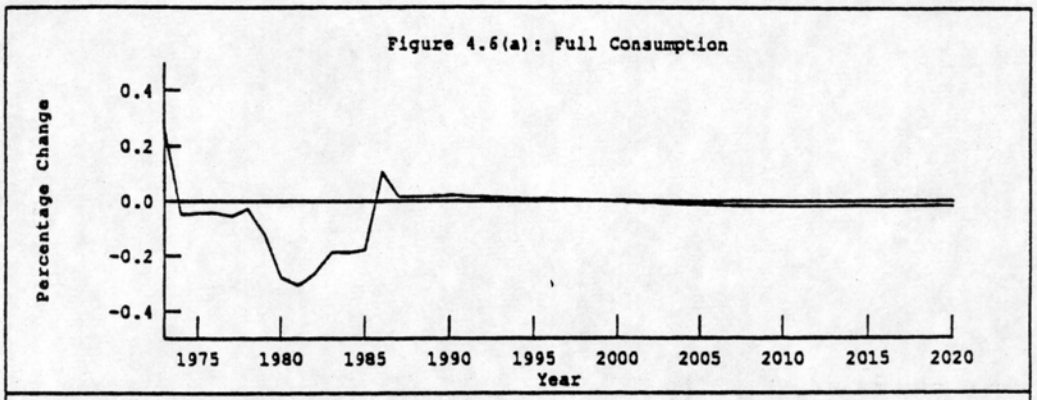


Figure 4.6(a): Full Consumption
Percentage Change
0.4
0.2
0.0
-0.2
-0.4
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

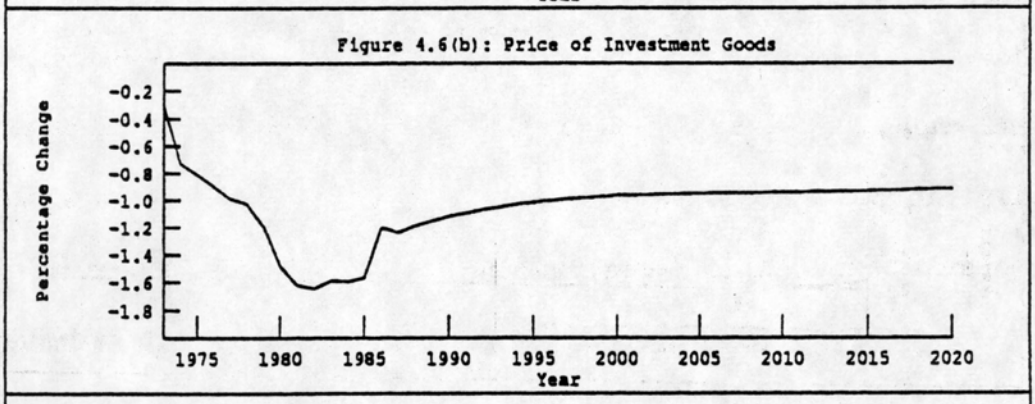


Figure 4.6(b): Price of Investment Goods
Percentage Change
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

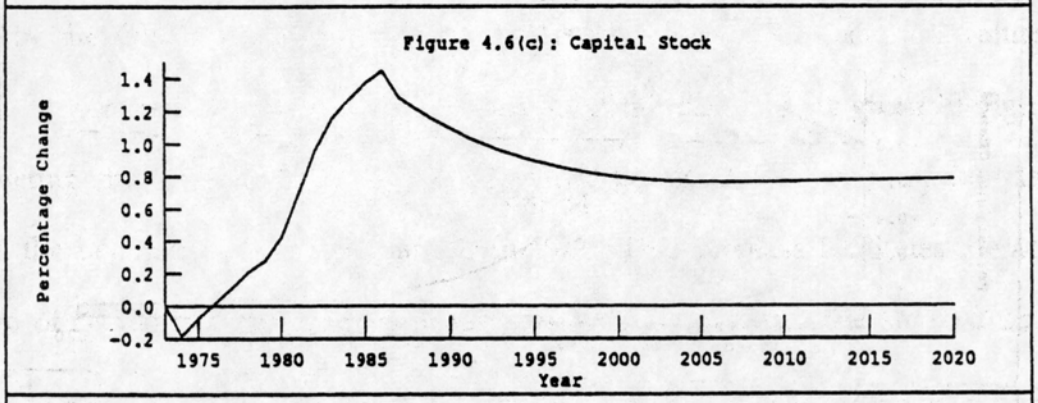


Figure 4.6(c): Capital Stock
Percentage Change
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

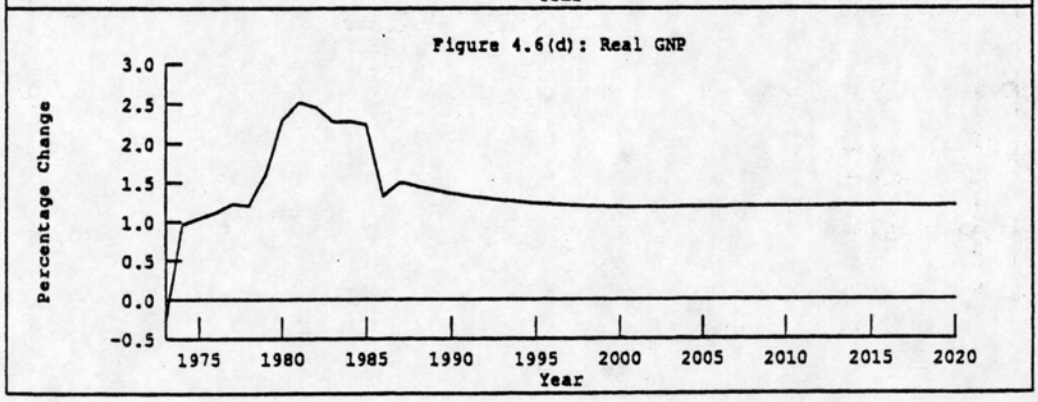


Figure 4.6(d): Real GNP
Percentage Change
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

This reaches a peak in 1987, when world petroleum prices reach their long run level under the base case. After that, it gradually subsides to a long run level that is substantially above the base case. While this long run level is the reverse of that in OIL81 (the high price scenario) the transition path followed by the economy is very different. Under OIL72, the economy undergoes a boom (relative to the base case) in both investment and consumption. Capital is accumulated very rapidly through 1987 and then declines slowly to a long-term equilibrium, which sustains higher consumption after 1987. The difference between real GNP in the OIL72 scenario and the base case peaks in 1981, when the difference in petroleum prices is most pronounced; the long run difference in real GNP is considerably lower.

4.3. Summary

By comparing the OIL72 and the OIL87 simulations we can separate the impact of higher long-term world oil prices from the effects of the oil. price surges that took place in 1973-1975 and 1978-1980. Recall that the OIL72 scenario corresponds to permanently lower oil prices at levels that prevailed before 1973, while OIL87 represents a gradual increase in world oil prices to the level of 1987. In Table 4.3 we summarize the impact of higher oil prices and decompose it into effects attributable to the long run increase and those attributable to the price shocks of the 1970's. As shown in the table, the growth rate of real GNP was 0.216 percent per year lower over the period 1974-1985 in the base case than the OIL72 scenario. Thus, the rise in oil prices accounts for a substantial portion of the slowdown in US economic growth after 1973.

The portion of the slowdown that can be attributed to the price shocks of the 1970's is captured by the OIL87 scenario. OIL87 has the same long run price trend as the base case, but it omits the sharp rise and fall of oil prices during the 1970's

Table 4.3: Decomposition of Effects on Average Growth Over 1974-1985

Description	Change in Growth Rate
Total change (OIL72)	.216
Change due to price surge (OIL87)	.136
Change due to price level (OIL72-OIL87)	.080

and early 1980's. Under this scenario the growth of real gross national product over the period 1974-1985 was 0.136 percent per year higher than in the base case. Thus, the price shocks account for almost two-thirds of the overall 0.216 percent drop in growth. The remainder, given by the difference between OIL72 and OIL87, shows the effect of a gradual increase in oil prices. This difference accounts for a slowdown of 0.080 percent per year in the average annual growth rate of real GNP over the period 1974-1985.

5. THE IMPACT OF CARBON TAXES

In the preceding section we have calculated the implicit cost of stabilizing carbon dioxide emissions through high world oil prices. Clearly, however, this is not a policy that the US government would choose voluntarily. A more likely policy would be a broad-based tax on the carbon content of all fossil fuels. Such a tax could be applied to primary production of coal, oil and natural gas, and would have the advantage of taxing emissions directly. In this section we examine the carbon taxes that would be needed to attain various carbon dioxide emission targets, and discuss how those taxes would affect the economy.

5.1. Computing Carbon Emissions

The first step in simulating different carbon tax policies is to calculate carbon dioxide emissions. For tractability, we have assumed that these emissions are proportional to fossil fuel use. This implies the carbon dioxide produced by a given combustion process cannot be reduced. In practice this is largely the case.[49] We then calculate the carbon content of each fossil fuel in the following way. From the Department of Energy we obtain the average heat content of each fuel in millions of BTU per unit of quantity (Department of Energy, 1990). Next, we obtain data from the Environmental Protection Agency on the amount of carbon emitted per million BTU produced from each fuel.[50] Multiplying EPA's figures by the heating value of the different fuels gives the carbon content of each fuel. Carbon emissions can then be calculated from total fuel production. Table 5.1 gives the data for each fuel in 1987.

49. Unlike ordinary pollutants, carbon dioxide is one of the natural products of combustion. Little can be done to change the amount of it produced when burning any particular fuel. 50. Environmental Protection Agency (1990) internal memoranda.

Table 5.1: Carbon Emissions Data for 1987

Item	Fuel		
	Coal	Oil	Gas
Unit of Measure	ton	bbl	kcf
Heat Content (10^6 *BTU per unit*)	21.94	5.80	1.03
Emissions Rate (*kg per* 10^6 *BTU*)	26.9	21.4	14.5
(*kg per unit*)	590.2	124.1	14.9
Total Domestic Output (10^9 *units*)	0.9169	0.3033	17.8
Total Carbon Emissions (10^6 *tons*)	595.3	414.1	268.6

Our simulation model is normalized so that all prices are equal to one in 1982. The quantities do not correspond directly to physical units. Moreover, the model has a single aggregate sector for oil and gas. To convert the figures above into a form appropriate for the model's quantity units, we sum carbon production for oil and gas and divide by the model's base case output of oil and gas in 1987. This gives the carbon coefficient for the industry. Similarly, the coefficient for coal is computed by dividing total carbon production from coal by the model's 1987 value for coal output. These coefficients are then used to compute carbon emissions in each simulation.

5.2. Carbon Dioxide Emissions Policies

We now turn to the consequences of using a carbon tax to achieve different carbon dioxide emissions levels. We have run three simulations in addition to the base case, one for each of the following policies:

[1] Stabilizing carbon emissions at the 1990 base level beginning immediately.

[2] Decreasing carbon emissions gradually over 1990-2005 until they are 20% below the 1990 base level.

[3] Doing nothing until 2000, then gradually increasing the carbon tax over 2000 2010 to stabilize emissions at the year 2000 base level.

These policies vary considerably in stringency. In 1990, base case fossil fuel use produced 1576 million tons of carbon. Policy 1 would keep that level constant forever, even in the face of rapid GNP growth. Policy 2, however, is even more restrictive: it requires emissions to drop to 1261 million tons by 2005 and remain at that level forever. Policy 3, on the other hand, is the least restrictive: it allows emissions to rise to the base case year 2000 level of 1675 million tons.

In each simulation, we constrain total carbon emissions and allow the level of the carbon tax to be determined endogenously. The tax is applied to primary fuels in proportion to carbon content. Since even the least stringent policy produces substantial tax revenue, it is necessary to make an assumption about how the revenue would be used. In these simulations, we hold the real value of government spending constant at its base case level. We then allow the average tax on labor to adjust to keep the difference between government spending and government revenue equal to the exogenous budget deficit. At the same time, we hold the marginal tax on labor constant, so that adjustments in the average rate reflect changes in the implicit zero-tax threshold.

5.3. Long Run Effects

The principal direct consequence of all three carbon control strategies is to increase purchasers' prices of coal and crude oil. This can be seen most dearly by examining the model's results for each simulation at a particular point in time, so in

this section we present detailed results for the year 2020. We begin with results for the first experiment: holding emissions at 1990 levels. By the year 2020, maintaining 1990 emissions will require a tax of $16.96 per ton of carbon contained in primary fuels 5[1] Using the data in Table 5.1, it can be shown that this amounts to a tax of about $11.01 per ton of coal, $2.32 per barrel of oil or $0.28 per thousand cubic feet of gas. The tax would generate revenue of $26.7 billion annually.

The rising price of fossil fuels results in substitution toward other energy sources and away from energy in general. Total BTU consumption falls by 12 percent to about 68 quadrillion BTU (quads). This substitution away from energy, and hence toward more expensive production techniques, results in a drop of 0.7 percent in the capital stock and 0.5 percent in real GNP. These figures are fairly small because they measure, in a loose sense, the welfare losses from introducing a small distortionary tax. Since revenue from the tax is returned to households through lump-sum adjustments in the income tax, social welfare falls due to the inefficiency of the tax.

At the commodity level the impact of the tax varies considerably. Figure 5.1(a) shows changes in the supply price of the 35 commodities measured as percentage changes relative to the base case. The largest change occurs in the price of coal, which rises by 40 percent. This, in turn, increases the price of electricity by about 5 percent. Electricity prices rise considerably less than coal prices because coal accounts for only about 13 percent of total utility costs. Other prices showing significant effects are those for crude and refined petroleum and gas utilities. These rise, directly or indirectly, because of the tax on oil.

These changes in prices affect demands for the commodities, which in turn determine how industry outputs are affected. Figure 5.1(b) shows percentage

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51. All dollar amounts are in 1989 prices.

Figure 5.1(a): Effect of CONST on Prices

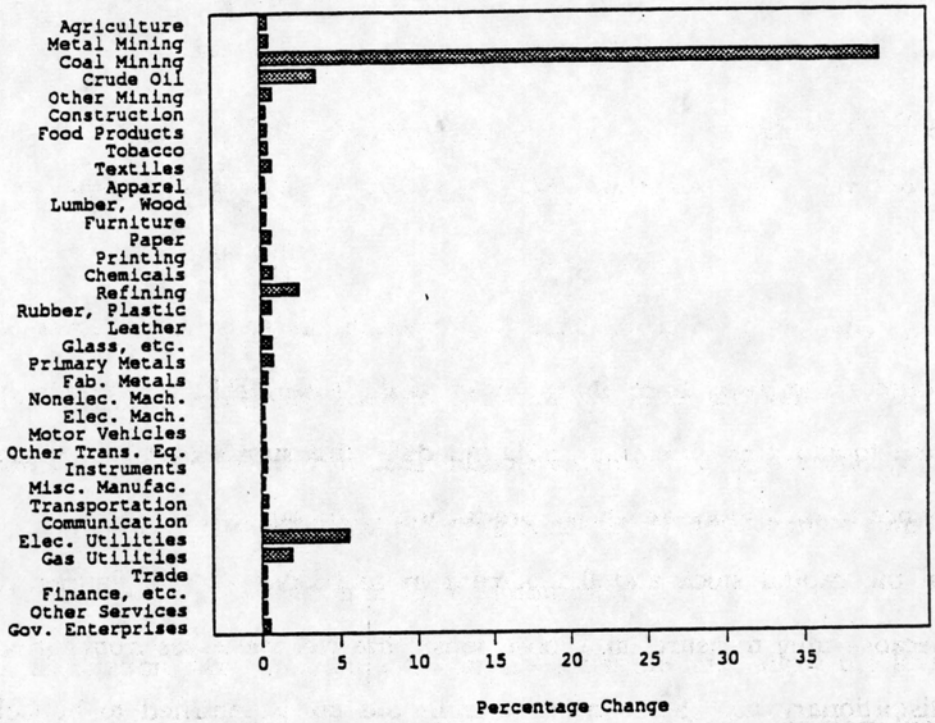
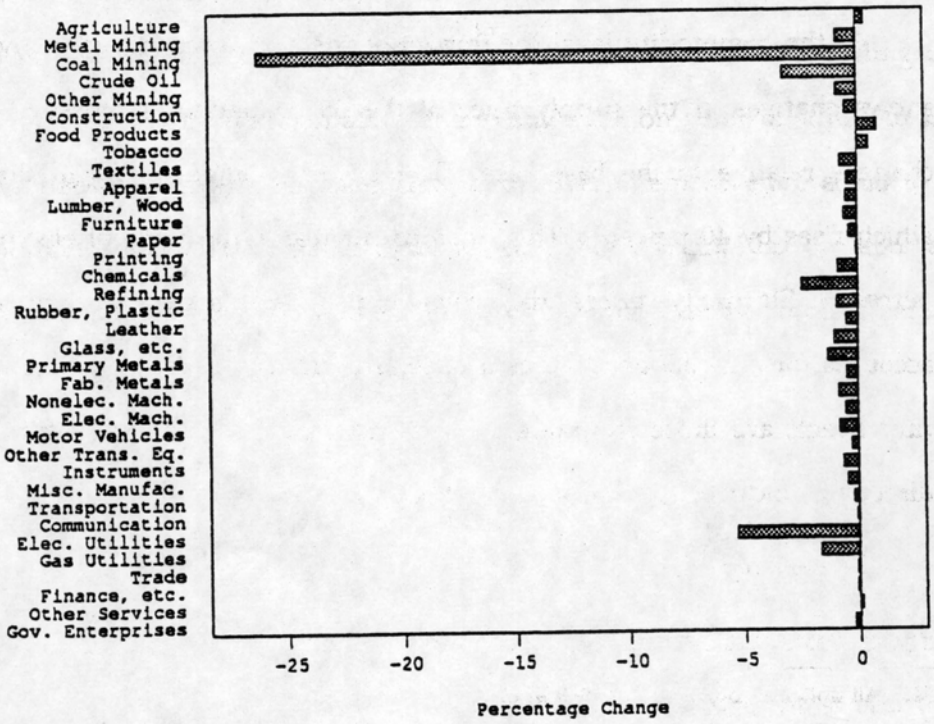


Figure 5.1(b): Effect of CONST on Output



changes in quantities produced by the 35 industries. Most of the sectors show only small changes in output. Coal mining is the exception; its output falls by 26 percent. Coal is affected strongly because the demand for it is somewhat elastic. Most coal is purchased by electric utilities, which in our model can substitute toward other fuels when the price of coal rises. Moreover, the utilities also have some ability to substitute other inputs, such as labor and capital, for energy, further reducing the demand for coal. Since electric utilities play such an important role in determining how a carbon tax affects coal mining, we now digress briefly to discuss how the utilities are represented in the model.

Electric utilities, like all other sectors, are represented by a nested translog unit cost function. The top tier of the function gives cost in terms of the prices of four inputs: capital, labor, an energy aggregate, and a materials aggregate. Substitution between energy and other inputs takes place at this level. The price of the energy aggregate itself is formed at a lower tier by translog aggregation of the prices of five inputs: coal, crude petroleum, refined petroleum, electricity, and natural gas from gas utilities. Substitution among fuels takes place at that level.

Estimated parameters govern the ease of substitution at both the top tier and the energy tier of - the cost function. At the top level, substitution between energy and capital is very inelastic (an elasticity of -0.15), substitution between energy and labor is moderately inelastic (-0.64), and substitution between energy and materials is slightly elastic (-1.16). Thus, increases in the relative price of energy will, for the most part, induce substitution toward materials. In addition, substitution possibilities exist at the energy tier. The elasticity of substitution between coal and refined petroleum is -0.7, although between coal and natural gas it is only -0.1. Thus, an increase in the relative price of coal will produce some substitution toward other fuels. Overall, the parameters appearing in the cost function for electric utilities imply that an increase in the relative price of coal will lead to substitution toward

other fuels and toward non-energy inputs.

The second policy we consider is a 20 percent reduction below 1990 emission rates, to be phased in gradually over 15 years. By 2020, this would amount to a drop of 32 percent below base case emissions, and would require a tax of $60.09 per ton of carbon. Using the data in Table 5.1, this is equivalent to a tax of $39.01 per ton of coal, $8.20 per barrel of oil, or $0.98 per thousand cubic feet of gas. The tax would produce $75.8 billion in revenues. Comparing these results to those for maintaining 1990 emissions shows that the tax would more than triple, from $17 to $60. At equilibrium, the tax gives the marginal cost of reducing emissions by an additional ton of carbon, so that further reductions are becoming significantly more difficult.

Tighter carbon regulations also lead to a reduction in total fossil fuel BTU production to 57 quads, a drop of 27 percent from the base case. This, in turn, reduces the capital stock by 2.2 percent and real GNP by 1.6 percent. These figures are about triple the values obtained for holding emissions at 1990 levels. Although the changes in capital and GNP appear small, recall that they are measures of deadweight loss associated with fairly large marginal changes in the energy sector.

At the commodity and industry level, results for this experiment are qualitatively similar to those for maintaining 1990 emissions, although they are numerically somewhat different. Figure 5.2(a) shows percentage changes in commodity prices relative to the base case. The price of coal more than doubles, rising by 137 percent from its base case value. The price of oil rises by 13 percent, while that of electricity rises by about 18 percent. The prices of refined petroleum and natural gas also rise, but by somewhat less. Comparing Figures 5.2(a) and 5.1(a) shows how this simulation compares with the previous one. In particular, commodity prices rise roughly in proportion to the increase in the carbon tax. The tax rises by a factor of 3.5, and so do most of the percentage changes in commodity prices.

Figure 5.2(a): Effect of CUT20 on Prices

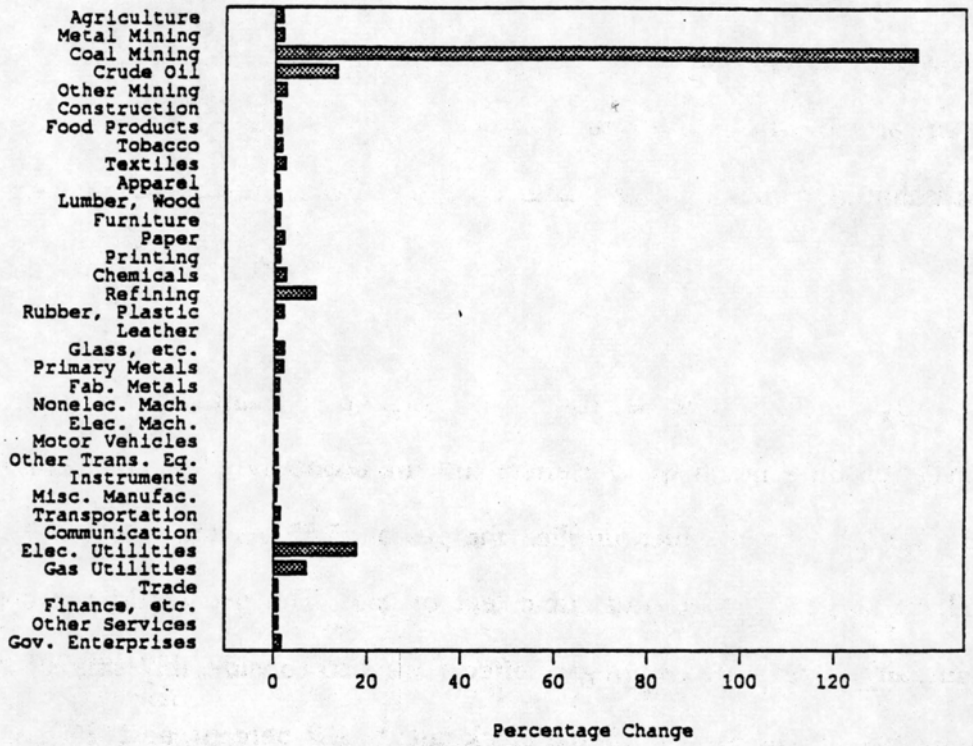
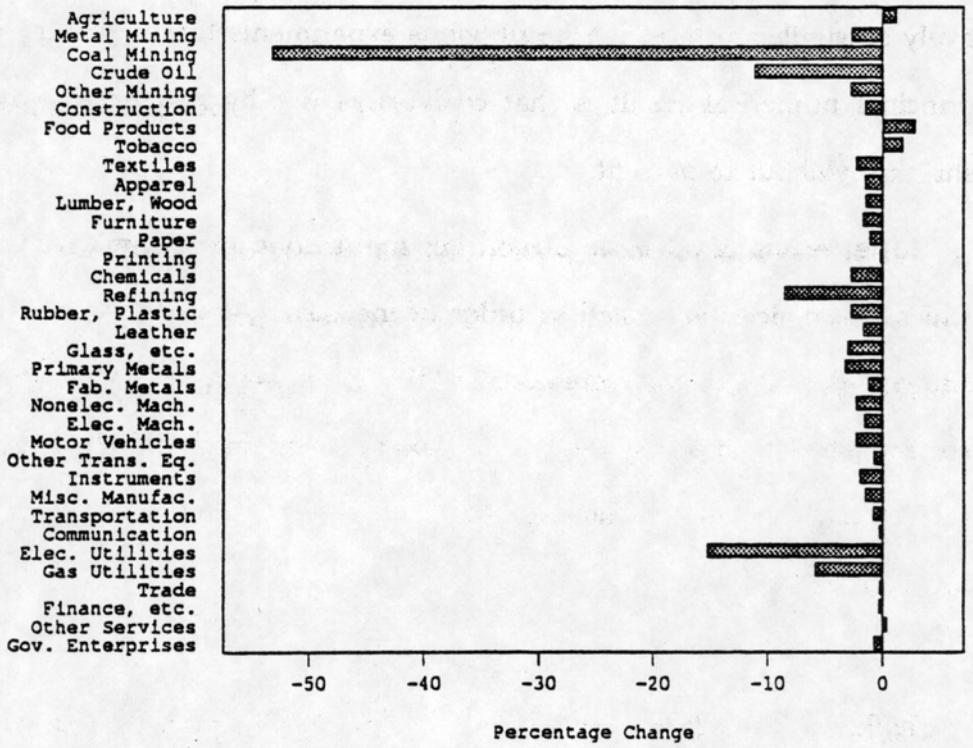


Figure 5.2(b): Effect of CUT20 on Output



The quantity results, shown in Figure 5.2(b), display a similar pattern except that they scale up in proportion to the change in carbon reductions rather than the change in taxes. That is, reducing emissions to 20 percent below 1990 levels requires a cut of about twice the size needed to reach 1990 levels. Thus, percentage changes in quantities from the base case are about twice those of the previous experiment. The most important results are the 53 percent drop in coal production and the 15 percent drop in electricity produced.

By contrast the looser restrictions implied by maintaining emissions at year 2000 levels produce much smaller effects on the economy. The tax required is only $8.55 per ton of carbon, which implies charges of $5.55 per ton of coal, $1.17 per barrel of oil, or $0.14 per thousand cubic feet of gas. The tax would produce $14.4 billion annually in revenue. Aggregate effects are also considerably smaller than in the two previous scenarios. The capital stock falls by 0.4 percent, and GNP drops by 0.3 percent, about half the value obtained in the 1990 simulation. This is quite reasonable since the cut in emissions is about half as deep. The industry results look qualitatively so similar to those of the previous experiments that we omit the graphs. The principal numerical result is that coal prices rise by 20 percent while coal output shrinks by about 16 percent.

The results of all three carbon tax simulations are summarized in Table 5.2, in which the policies are listed in order of increasing stringency. From these results it appears that stabilizing emissions at the, base-case level in the year 2000 can be accomplished with a very low carbon tax and a minimal disturbance of the economy. The strongest effect would be felt by the coal mining industry, which sees its demand fall as electric utilities substitute toward other fuels. More stringent regulations would lead to markedly higher energy prices and greater disruption of the economy. Coal mining would bear the brunt of the changes brought about by the tax under any scenario. Of the remaining sectors, electric utilities would be affected most strongly.

Table 5.2: Summary of Long Run Carbon Tax Simulations

Variable	Unit	Emissions Target		
		2000 Level	1990 Level	80% of 1990
Carbon Emissions	%Δ	-8.4	-14.4	-31.6
Carbon Tax	$/ton	8.55	16.96	60.09
Tax on Coal	$/ton	5.55	11.01	39.01
Tax on Oil	$/bbl	1.17	2.32	8.20
Tax on Gas	$/kcf	0.14	0.28	0.98
Labor Tax Rate	Δ	-0.25	-0.45	-1.22
Tax Revenue	Bil.$	14.4	26.7	75.8
BTU Production	%Δ	-7.1	-12.2	-27.4
Capital Stock	%Δ	-0.4	-0.7	-2.2
Real GNP	%Δ	-0.3	-0.5	-1.6
Price of Coal	%Δ	20.3	40.0	137.4
Quantity of Coal	%Δ	-15.6	-26.3	-53.2
Price of Electricity	%Δ	2.9	5.6	17.9
Quantity of Electricity	%Δ	-2.9	-5.3	-15.3
Price of Oil	%Δ	1.8	3.6	13.3

5.4. Intertemporal Results

Carbon restrictions adopted today will have effects far into the future. At the same time, anticipated future restrictions will have effects today. To assess the intertemporal consequences of carbon taxes, we now turn to the model's dynamic results. As with the long run results, we begin by discussing a carbon tax designed to maintain emissions at 1990 levels. Following that, we examine the dynamic behavior of other experiments.

The path of the carbon tax needed to maintain 1990 emissions is shown in Figure 5.3(a). Base case emissions increase over time, so the tax grows gradually, about $0.70 per year, over the next few decades. It reaches a peak around the year 2020

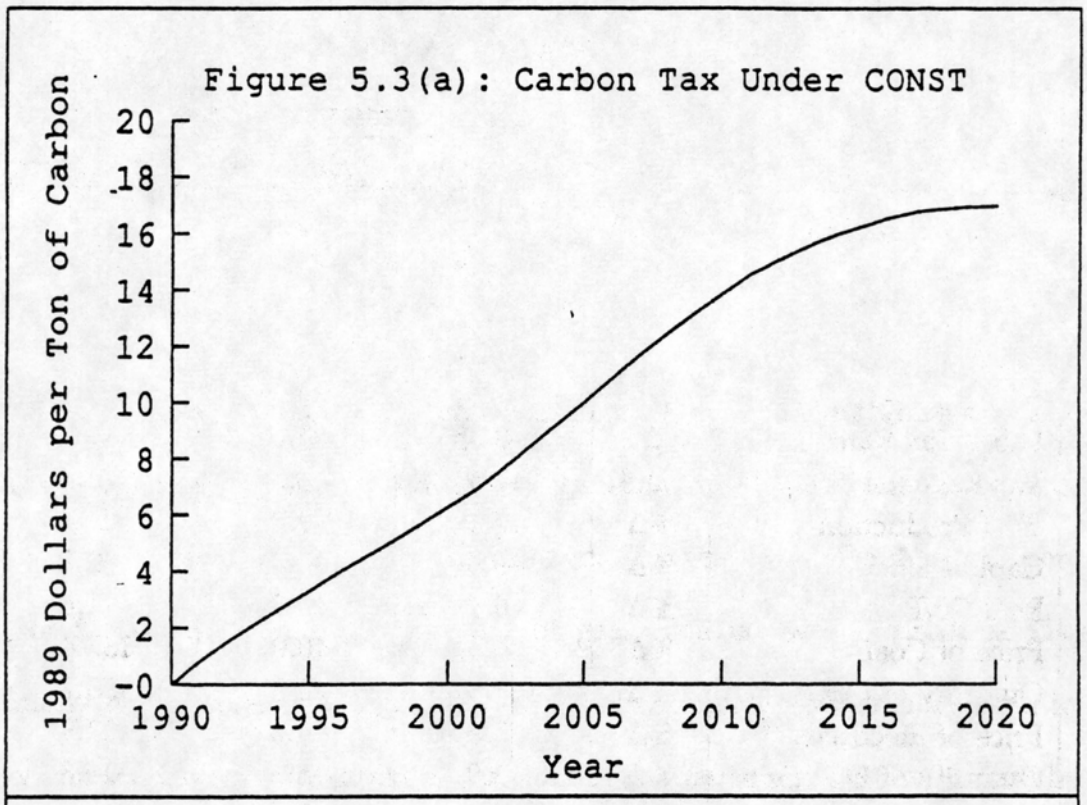


Figure 5.3(a): Carbon Tax Under CONST
1989 Dollars per Ton of Carbon
20
18
16
14
12
10
8
6
4
2
-0
1990
1995
2000
2005
2010
2015
2020
Year

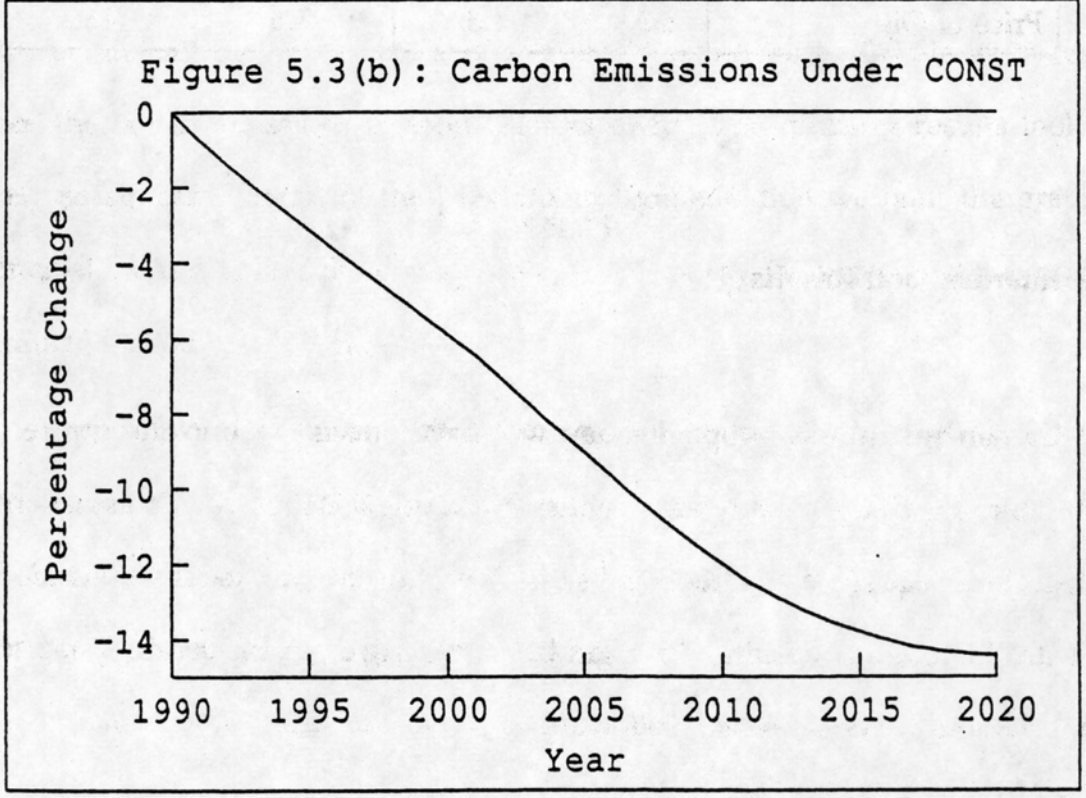


Figure 5.3(b): Carbon Emissions Under CONST
Percentage Change
0
-2
-4
-6
-8
-10
-12
-14
1990
1995
2000
2005
2010
2015
2020
Year

when our forecast of the US population crests.[52] The tax produces significant reductions in carbon emissions which are shown in Figure 5.3(b) as percentage changes from the base case. Emissions begin dropping immediately and by 2020 are about 14 percent below their unconstrained level.

As suggested by the long run results, the principal effect of the tax is to reduce coal mining. This is shown dearly in Figure 5.4(a), which gives percentage changes in coal output from the base case. Production gradually slows as the tax is introduced. It does not, however, fall all the way back to its 1990 level-some of the reduction in emissions comes about through reductions in oil consumption. This can be seen in Figure 5.4(b), which gives percentages changes in crude petroleum and natural gas extraction over time.

The increasing price of energy raises costs and reduces household income. This, in turn, changes the rate of capital accumulation. The outcome is shown in Figure 5.5(a), which gives percentage changes in the capital stock from the base case. Unlike variables in the preceding graphs, the capital stock does not start declining immediately; instead, it tends to remain near its base case level for the first few years. This is the consequence of intertemporal optimization by households. From a household's point of view, the effect of the tax is to decrease its real income by an amount related to the tax's deadweight loss.[53] Thus, the household regards carbon taxes as reductions in future earnings, so it reacts by lowering consumption in all periods. In the early years, however, the carbon tax is minimal and household income is largely unaffected. During that period, therefore, the drop in consumption leads to an increase in saving. This helps maintain investment-and thus the capital

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52. As noted in Section 2, our population projections are based on those of the Bureau of the Census (1989).
53. Since revenue earned by the tax is given back to households through a horizontal shift in the labor tax schedule, the simulation is essentially the replacement of a lump sum tax (the labor tax) by a distorting one (the carbon tax).

Figure 5.4(a): Coal Production Under CONST

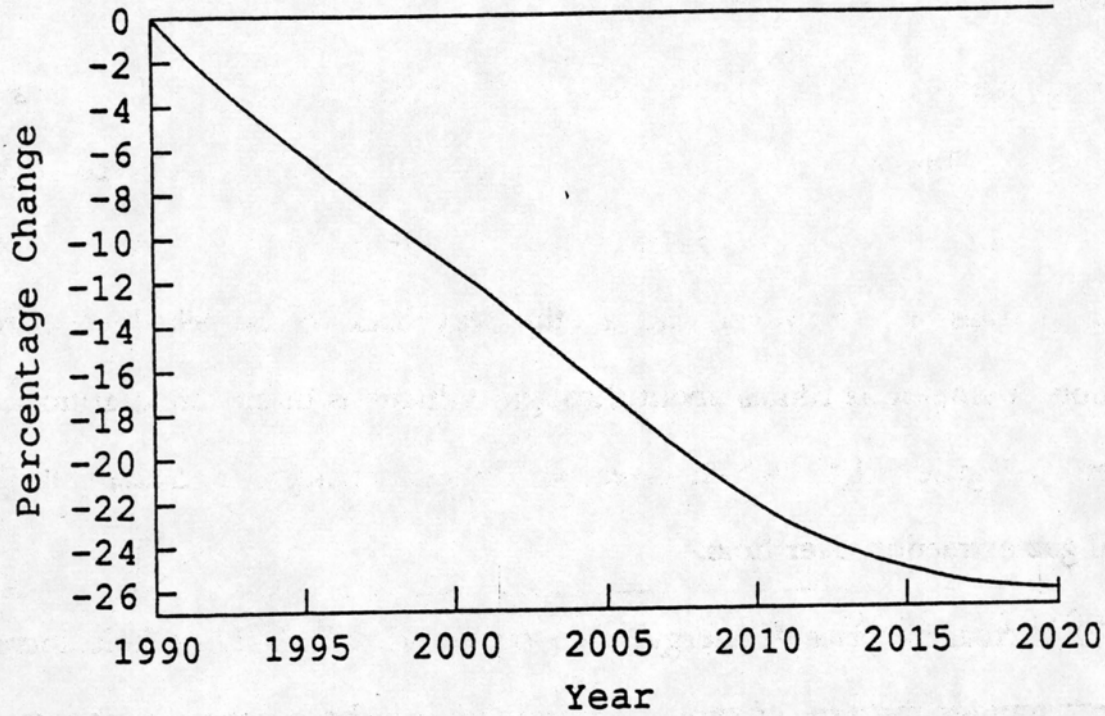


Figure 5.4(b): Oil and Gas Extraction Under CONST

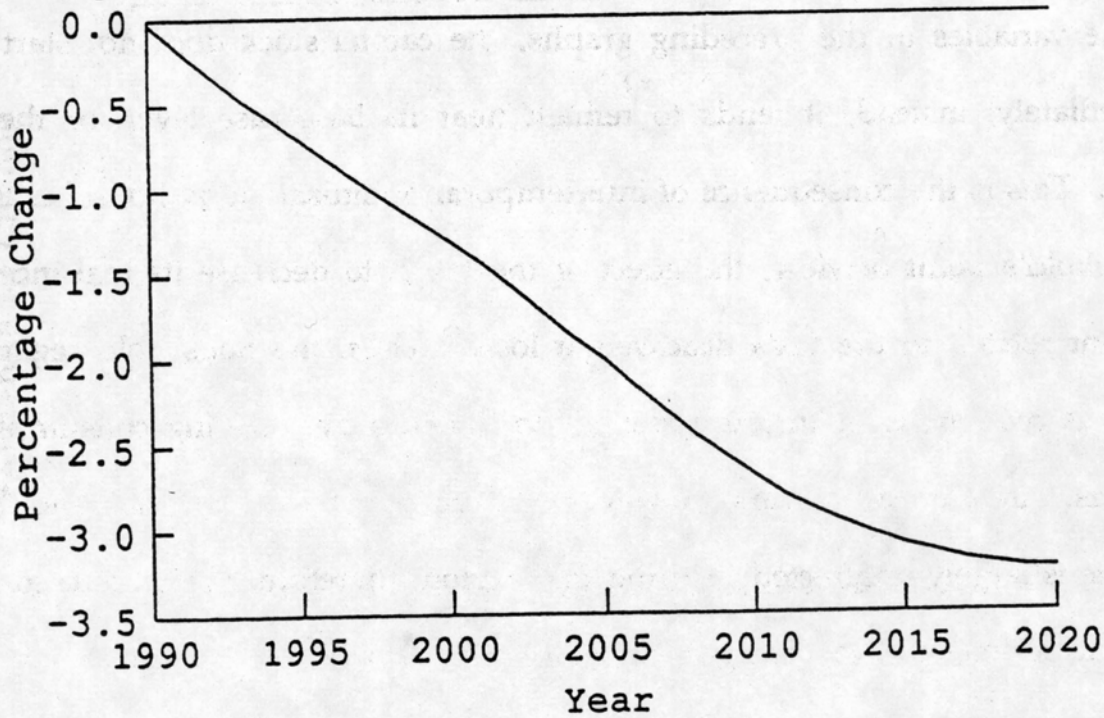


Figure 5.5(a): Capital Stock Under CONST

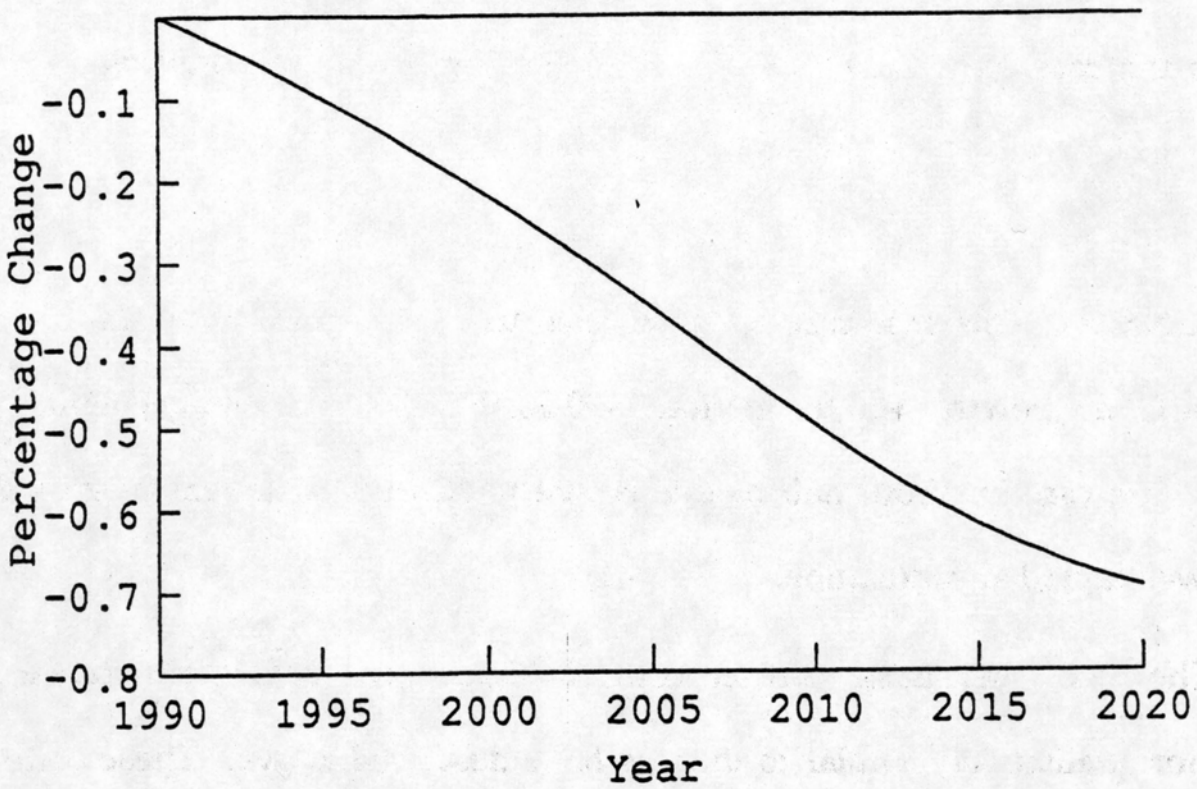
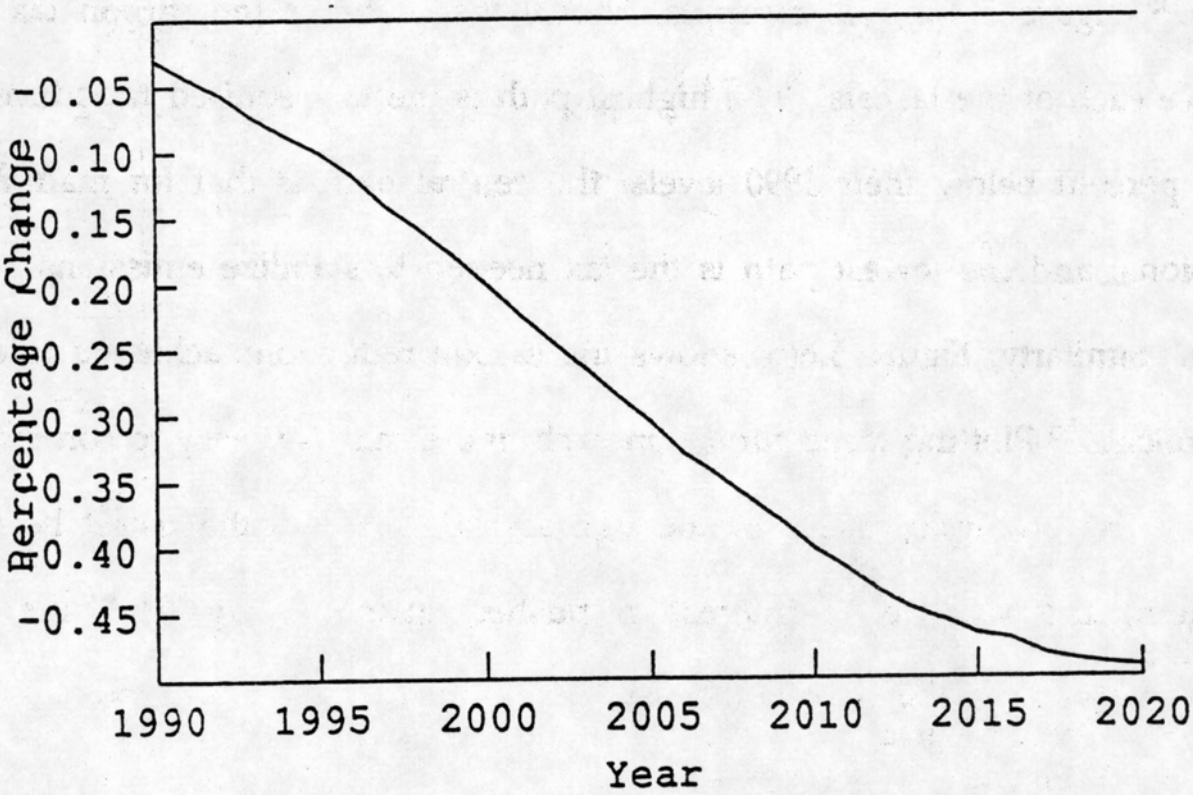


Figure 5.5(b): Real GNP Under CONST



stock-in the early years of the simulation. Eventually, the income effect of the tax begins to be felt and the capital stock finally starts to decline relative to the base case.

The decline in growth of the capital stock leads to a drop in GNP growth, as shown in Figure 5.5(b). Over time GNP gradually falls by about half a percent relative to the base case. The capital stock, however, is not the only factor contributing to the decline. In addition, higher energy prices reduce the rate of technical change in industries which are energy-using. This leads to slower income growth and helps keep GNP below its base case level. In fact, under the carbon tax simulation average annual GNP growth over the period 1990-2020 is 0.02 percentage points lower than in the base case.-[v4] About half of this is due to slowing productivity growth and half to slower capital accumulation.

The two alternative carbon control targets we examined showed dynamic behavior qualitatively similar to that we have described above. These results can best be displayed by plotting each variable's values for all three simulations on a single graph. Figure 5.6(a), for example, shows the paths of the carbon tax needed to achieve each of the targets. The highest path is the tax required to reduce emissions to 20 percent below their 1990 levels; the central path is that for maintaining 1990 emissions; and the lowest path is the tax needed to stabilize emissions at year 2000 levels. Similarly, Figure 5.6(b) shows the carbon reductions achieved under each of the policies.[96] Plotting three curves on each figure makes it easy to compare different targets. For example, many of the figures show that as the target becomes more stringent, the variable of interest is pushed further away from the base case.

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54. The difference in two variables growing at rates differing by 0.02 percentage points is about 2 percent after a hundred years.
55. Recall that the targets were (1) maintaining 1990 emissions, (2) reducing emissions by 20 percent below 1990 levels, and (3) gradually introducing taxes to stabilize at year 2000 emissions.
56. Notice that target policies are drawn using the same line type in each graph. Maintaining 1990 emissions is always a solid line, reducing emissions to 20 percent below 1990 is always dashed, and maintaining emissions at 2000 levels is alternating dots and dashes. Also, variables are plotted on the same scale across different tax instruments for easier comparison.

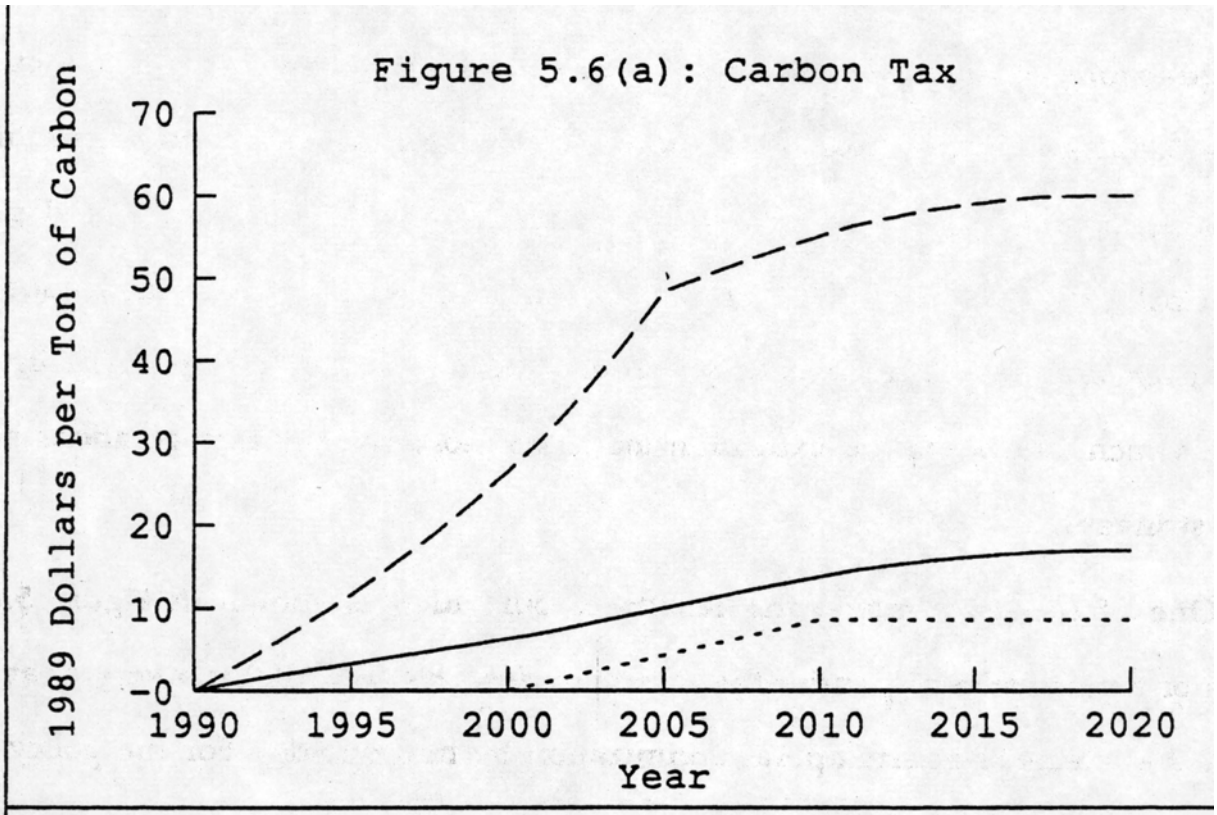


Figure 5.6(a): Carbon Tax
1989 Dollars per Ton of Carbon
70
60
50
40
30
20
10
-0
1990
1995
2000
2005
2010
2015
2020
Year

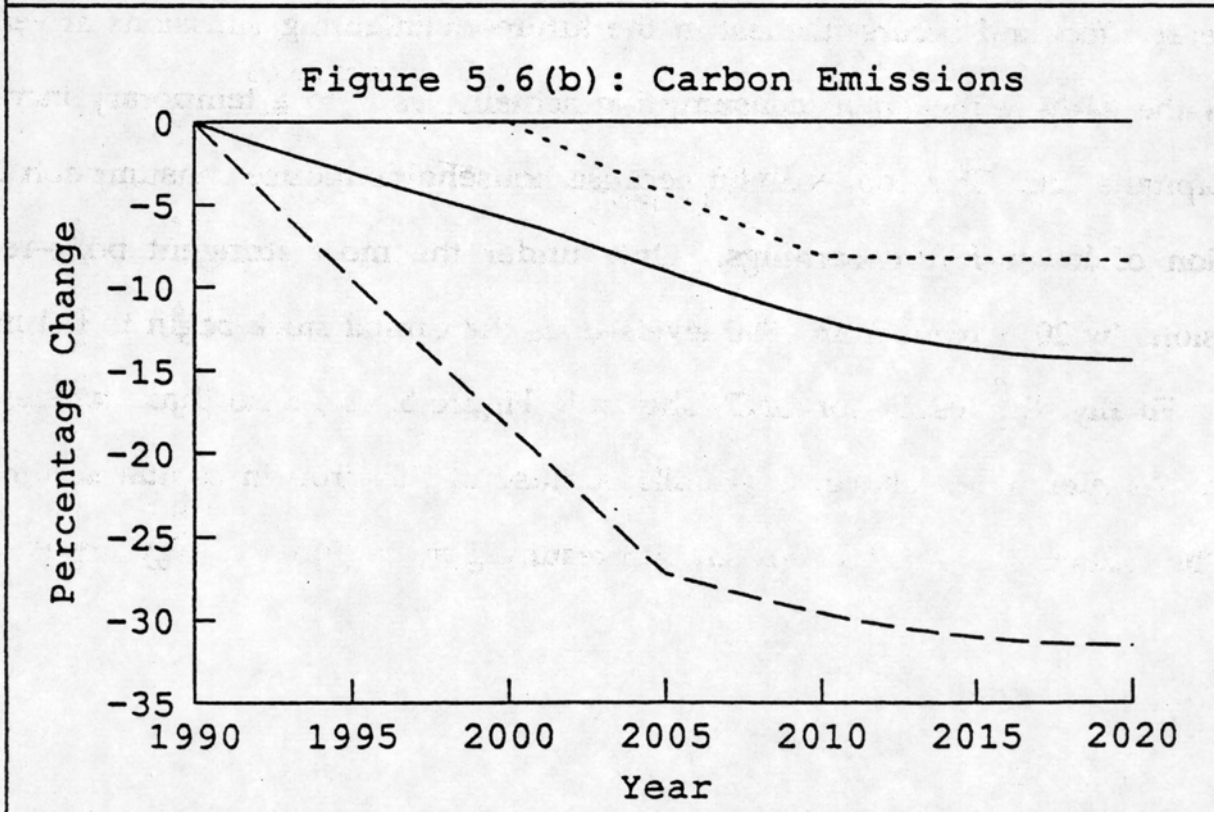


Figure 5.6(b): Carbon Emissions
Percentage Change
0
-5
-10
-15
-20
-25
-30
-35
1990
1995
2000
2005
2010
2015
2020
Year

However, some of the figures show much more interesting behavior, and we will focus on these for the remainder of this section.

The first feature apparent from Figure 5.6(b) is that the three targets require carbon reductions of roughly 8, 14 and 32 percent. Keeping these reductions in mind, Figure 5.7(a) shows that coal production does not fall in proportion to the drop in emissions. This occurs because it becomes increasingly costly to drive coal production. Coal users, notably electric utilities, find it increasingly difficult to substitute away from coal as the amount they use of it decreases. This is reflected in Figure 5.7(b), which shows that oil extraction increases more sharply as regulations become more stringent.

One of the most interesting results of our study is shown in Figure 5.8(a), a graph of the capital stock under the three policies. Figure 5.8(a) is a very dear example of the effects of intertemporal optimization by households. For the policy which has least effect and occurs furthest in the future-maintaining emissions at year 2000 levels-the early reduction in consumption actually leads to a temporary increase in the capital stock. This comes about because households reduce consumption in anticipation of lower future earnings. Only under the most stringent policy-reducing emissions by 20 percent from 1990 levels-does the capital stock begin to fall immediately. Finally, the results for GNP, shown in Figure 5.8(b), echo those for the capital stock. As mentioned above, GNP falls because of the drop in capital accumulation and the reduction in productivity growth resulting from higher energy prices.

Figure 5.7(a): Coal Production

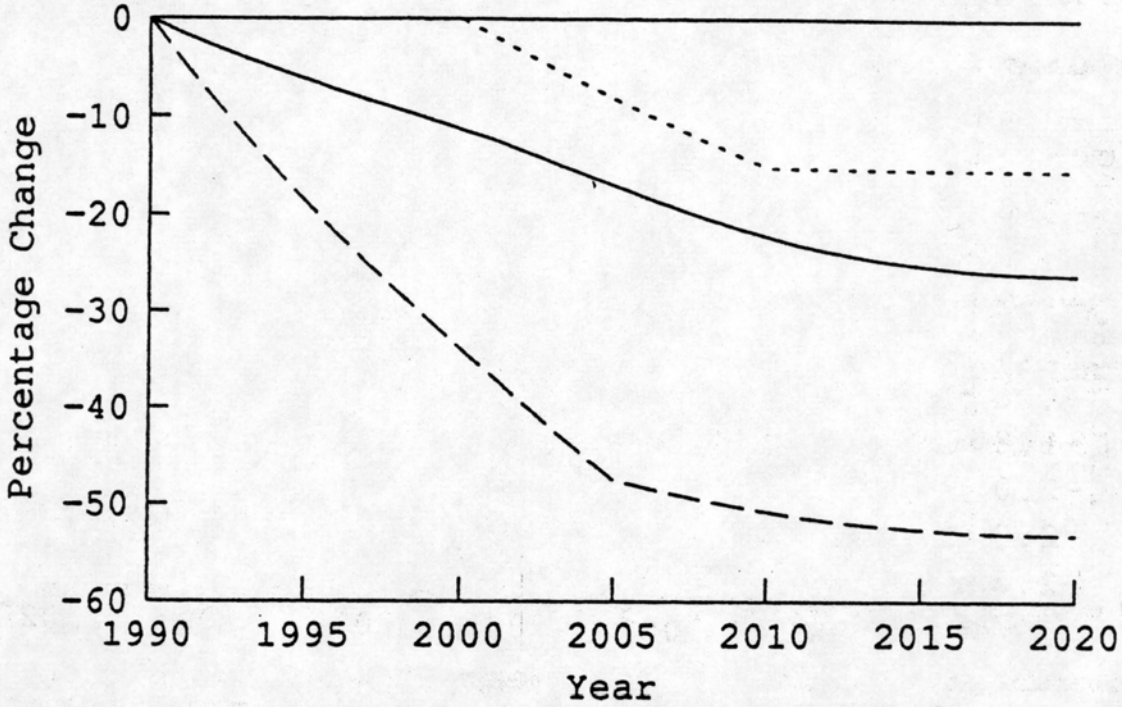


Figure 5.7(b): Oil and Gas Extraction

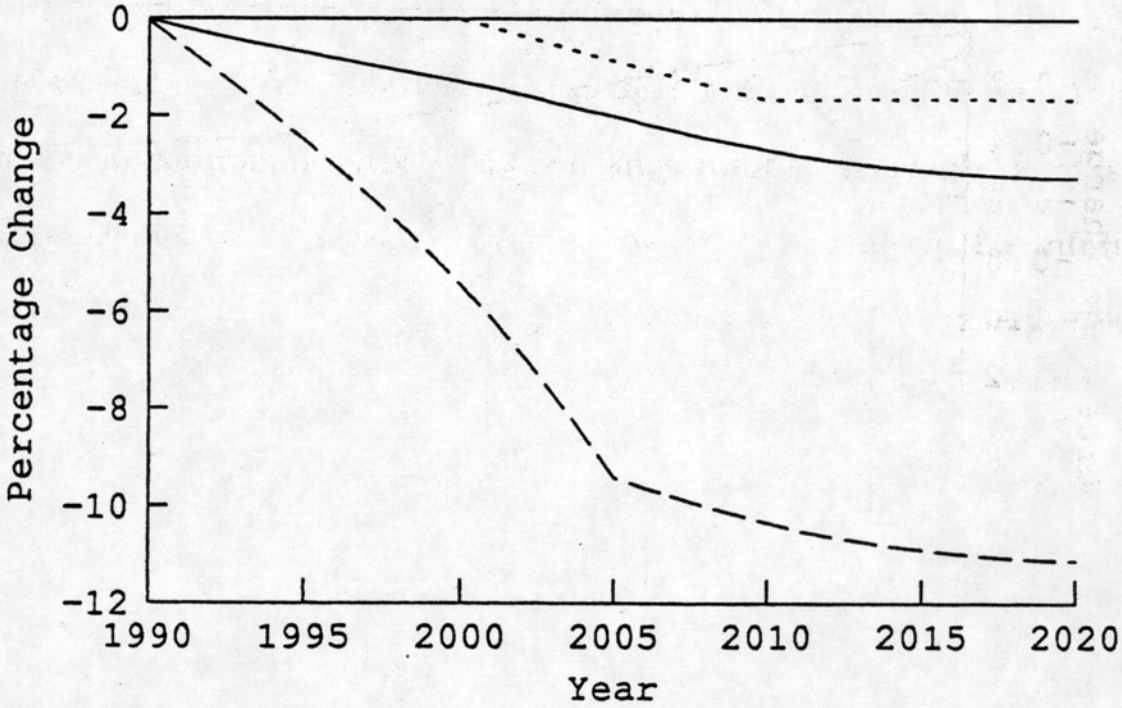


Figure 5.8(a): Capital Stock

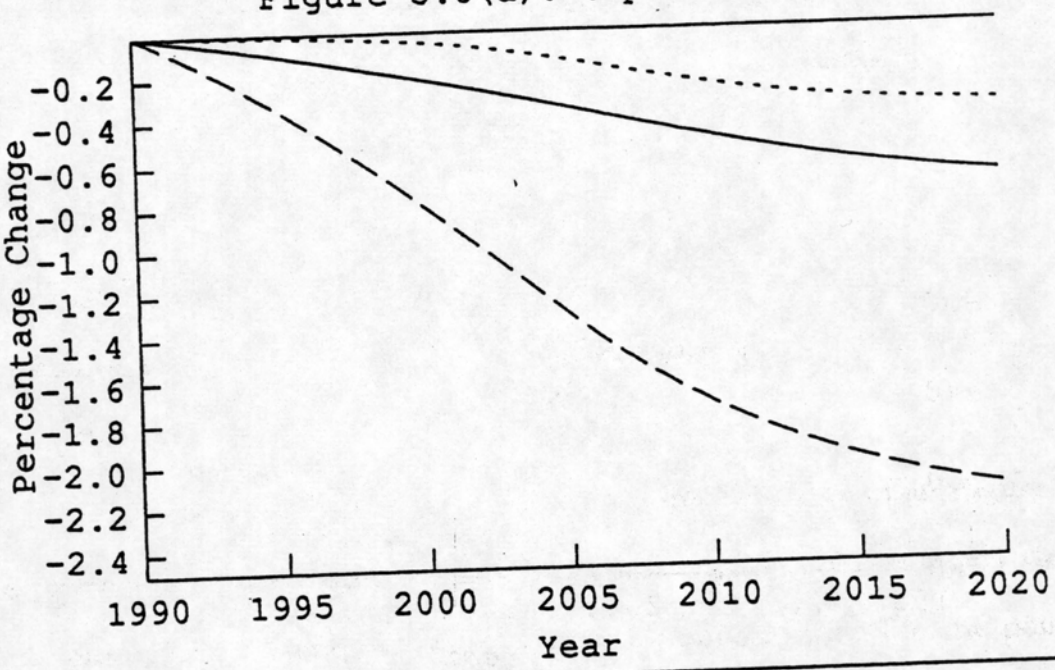
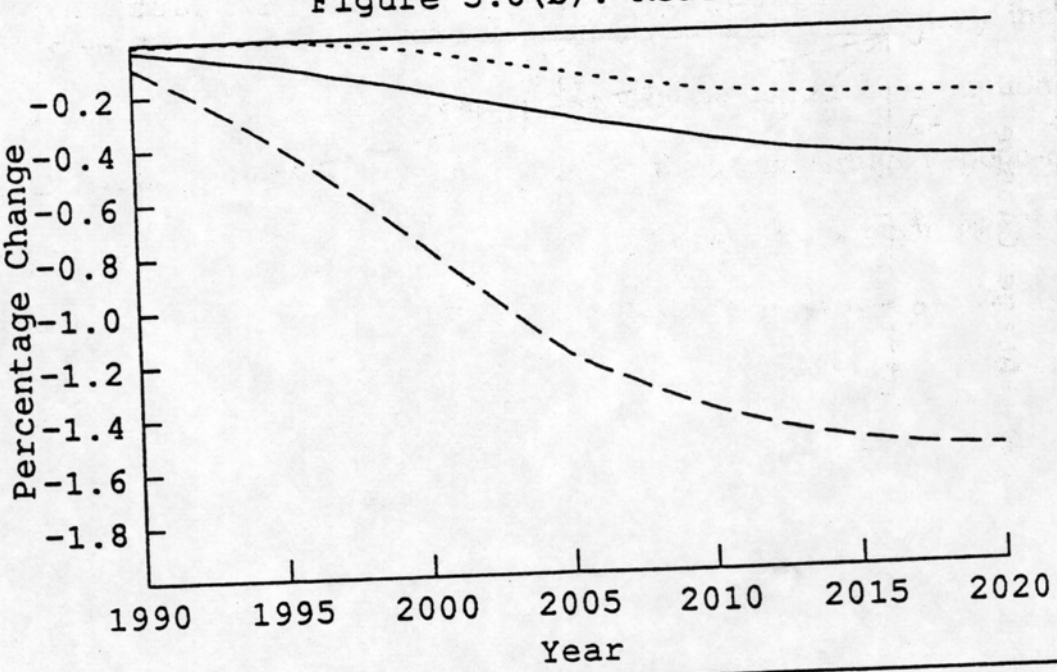


Figure 5.8(b): Real GNP



6. CONCLUSION

The purpose of this section is to evaluate the usefulness of intertemporal general equilibrium modeling as a practical guide to assessment of the impacts of energy and environmental policies. The neo-classical theory of economic growth has been applied to the evaluation of policies to control global climate change by Nordhaus (1992), Manne and Richels (1992), and Jorgenson and Wilcoxen (1992a). Nordhaus's model of the world economy includes a physical model of climate change. This provides the basis for designing an optimal environmental policy that can be implemented by means of a carbon tax. The policy results from a sophisticated application of cost benefit analysis.

The GLOBAL 2100 model of Manne and Richels (1992) disaggregates the world economy into five regions-each represented by a one-sector neo-classical growth model. Environmental policy affects the output of each region through restrictions on carbon dioxide emissions resulting from fossil fuel combustion. This approach is useful in assessing the costs of these restrictions and the benefits from international co-operation in controlling global climate change through tradeable permits. Finally, the energy technology assessment (ETA) submodel provides valuable information on the payoff from accelerated research and development on new energy sources and alternative energy technologies.

The framework for the econometric approach to modeling the impact of energy and environmental policies is also provided by intertemporal general equilibrium theory. This makes it possible to preserve the features of the aggregate growth models employed by Nordhaus (1992) and Manne and Richels (1992), while disaggregating the impacts of these policies. We have distinguished among thirty-five industrial sectors of the US economy and have also identified thirty-five commodity groups, each one the primary product of one of the industries. In modeling

consumer behavior we have distinguished among 672 different household types, broken down by demographic characteristics. Aggregate demand functions for components of consumer expenditure are constructed by summing over individual demand functions.

The econometric method for parametrization used in modeling technology and preferences can be contrasted with the calibration approach employed in earlier general equilibrium models. The main advantage of the econometric approach is that the responses of production and consumption patterns to changes in energy prices and environmental controls can be derived from historical experience. The implementation of the econometric approach requires a system of national accounts that successfully integrates capital with the income and production. The new accounting system incorporates an accumulation equation relating capital to past investments and an asset pricing equation linking the price of assets to future prices and rates of return.

Jorgenson and Wilcoxen (1990b) have provided a highly disaggregated model of the impact of environmental regulations on US economic growth. This model incorporates detailed data on costs of compliance with environmental regulations by individual industries. An important mechanism for adjusting to changes in environmental policy is altering rates of capital formation. A second mechanism is the pricing of capital assets through forward-looking expectations of future prices and discount rates. This illustrates the significance of intertemporal general equilibrium modeling for obtaining insights into dynamic effects of energy and environmental policies on US economic growth.

Jorgenson and Wilcoxen (1992a) have analyzed a "natural experiment" in stabilization of carbon dioxide emissions for the US during the period 1972-1987. This is the result of price-induced energy conservation that has important feedbacks to the rate of economic growth through capital asset pricing and capital formation. By

combining forward-looking features of the model with the backward-looking capital accumulation equation, the decline in economic growth can be separated into two components. The first is the impact of the rise in energy prices from 1972 to 1987. The second is the effect of the energy price shocks of 1973-1975 and 1978-1980. The slowdown in economic growth during the period is largely attributable to the price shocks.

Finally, Jorgenson and Wilcoxen (1992b) have modeled the impact on US economic growth of a carbon tax that would stabilize emissions of carbon dioxide at 1990 levels. Since the tax would be phased in gradually, this has a relatively modest impact on growth. Both consumers and producers anticipate the steady increase in carbon tax rates and plan accordingly. This brings about a gradual re-orientation of the economy to reduce dependence on coal, the most carbon intensive fuel, and conserve energy more generally. An important qualification is that the cost of controlling carbon dioxide emissions rises at an increasing rate as restrictions on these emissions become more stringent.

Although the intertemporal general equilibrium approach has proved to be useful in modeling the impact of energy and environmental policies, much remains to be done to exploit the full potential of this approach. As an illustration, the model of consumer behavior employed by Jorgenson and Wilcoxen (1990b) successfully dispenses with the notion of a representative consumer. An important feature of this model is that systems of individual demand functions can be recovered from the *sys*tem of aggregate demand functions. The consumer preferences underlying these individual demand systems can be used to generate measures of individual welfare that are useful in evaluating the distributional consequences of energy and environmental policies.

For example, Jorgenson and Slesnick (1985) have separated the impacts of changes in US petroleum taxes into equity and efficiency components. Similarly,

Jorgenson and Slesnick (1987b) have considered the equity and efficiency impacts of natural gas price deregulation in the US. Finally, Jorgenson, Slesnick, and Wilcoxen (1992) have analyzed the progressiveness or regressiveness of carbon taxes that would stabilize emissions of carbon dioxide at 1990 levels. Although the size of the equity impact depends on normative considerations, the efficiency impact greatly dominates in all three applications.

Our conclusion is that intertemporal general equilibrium modeling provides a very worthwhile addition to methodologies for modeling the economic impact of energy and environmental policies. The neo-classical theory of economic growth is essential for understanding the dynamic mechanisms that underly long run and intermediate run growth trends. The econometric implementation of this theory is critical for capitalizing on the drastic changes in energy prices and substantial alterations in environmental policies of the past two decades. This wealth of historical experience, interpreted within an intertemporal framework, can provide valuable guidance in future policy formulation.

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