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Environmental regulation and U.S. economic growth

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In this article we quantify the costs of pollution controls by reporting the results of simulations of the growth of the U.S. economy with and without regulation. For this purpose, we have constructed a detailed model of the economy that includes the determinants of long-term growth. We have also analyzed the interaction between industries in order to capture the full repercussions of environmental regulations. However, we have not attempted to assess the benefits resulting from a cleaner environment. We find that pollution abatement has emerged as a major claimant on the resources of the U.S. economy. The cost of emission controls is more than 10% of the total cost of government purchases of goods and services.

1. Introduction

■ The most striking economic development in the United States during the postwar period has been the sharp decline in the rate of economic growth during the 1970s and 1980s. Real output grew at an average annual rate of 3.7% during the period 1947–1973. By contrast the growth rate from 1973 to 1985 was only 2.5%, fully 1.2 percentage points lower. Two events coincided with the slowdown—the advent of environmental regulation and the increase of world petroleum prices. In this study we focus on the relationship between pollution abatement costs and economic growth.

We begin with the usual disclaimer in economic studies about the costs of environmental regulation. In this article we quantify the costs of environmental regulation and compare these costs with those of governmentally mandated activities that are financed directly through the government budget. We have not attempted to assess the benefits resulting from a cleaner environment.[1] We have not accounted for consumption benefits resulting from environmental cleanup or production benefits associated with pollution abatement. The

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[1] The evaluation of environmental benefits is discussed, for example, in Freeman (1985) and Maler (1985).

conclusions of this study cannot be taken to imply that pollution control is too burdensome or, for that matter, insufficiently restrictive.

Pollution control legislation began in earnest in the United States in 1965, when amendments to the Clean Air Act set national automobile emissions standards for the first time. The extent of regulation increased dramatically in 1970 with the passage of the National Environmental Policy Act and amendments to the Clean Air Act. In 1972 the Clean Water Act was passed and revisions to this Act and the Clean Air Act were adopted in 1977.[2] The consequence of this legislation was a large and abrupt shift of economic resources toward pollution abatement.

The possible responses of producers to new environmental regulations fall into three categories—substitution of less polluting inputs for more polluting ones, investment in pollution abatement devices to clean up waste, and changes in production processes to reduce emissions. Switching to cleaner inputs is the least disruptive of these responses, since it does not require a reorganization of the production process. A prime example is the substitution of low-sulfur coal for high-sulfur coal by electric utilities during the 1970s to comply with restrictions on sulfur dioxide emissions. Another important example is the shift from leaded to unleaded fuels for the purpose of cleaning up motor vehicle emissions.

The second response to emissions controls is the use of special devices to treat wastes after they have been generated. This is commonly known as end-of-pipe abatement and is frequently the method of choice for retrofitting existing facilities to meet newly imposed environmental standards. A typical example is the use of electrostatic precipitators to reduce the emission of particulates from combustion. Regulations promulgated in the United States by the Environmental Protection Agency effectively encourage the use of this approach by setting standards for emissions on the basis of the "best available technology."

Process changes involve redesigning production methods to reduce emissions. An example is the introduction of fluidized bed technology for combustion, which results in reduced emissions. Gollop and Roberts (1983) constructed a detailed econometric model of electric utility firms that is based on a cost function that incorporates the impact of environmental regulation on the cost of producing electricity and the rate of productivity growth. They concluded that the annual productivity growth of electric utilities impacted by more restrictive emissions controls declined by .59 percentage points over the period 1974–1979. This was the result of switching technologies to meet new standards for sulfur dioxide emissions.

We analyze the impact of environmental regulation by simulating the long-term growth of the U.S. economy with and without regulation. For this purpose, we have constructed a detailed model of the economy that includes the determinants of long-run growth. Before considering the impact of specific pollution controls, we present an overview of the model in Section 2. We focus attention on features that facilitate the incorporation of changes in environmental policy. We also discuss the dynamics of the response of the economy to new pollution abatement requirements.

In Section 3 we show that pollution abatement has emerged as a major claimant on the resources of the U.S. economy. The long-run cost of environmental regulation is a reduction of 2.59% in the level of the U.S. gross national product. This is more than 10% of the share of total government purchases of goods and services in the national product during the period 1973–1985. Over this period, the annual growth rate of the U.S. economy has been reduced by .191%. This is several times the reduction in growth estimated in previous studies.

Since the stringency of pollution control differs substantially among industries, our model also assesses the impact of environmental regulations on individual industries. We

[2] A detailed survey of U.S. environmental policy is presented in Christiansen and Tietenberg (1985).

have analyzed the interactions between industries in order to quantify the full repercussions of these regulations. We find that pollution controls have had their most pronounced effects on the chemicals, coal mining, motor vehicles, and primary processing industries—such as petroleum refining, primary metals, and pulp and paper. For example, we find that the long-run output of the automobile industry has been reduced by 15%, mainly as a consequence of motor vehicle emissions controls.

2. An overview of the model

■ The purpose of our model of the U.S. economy is to analyze the impact of changes in environmental policy by simulating the long-term growth of the economy with and without regulation. We began by dividing the U.S. economy into business, household, government, and rest-of-the-world sectors. Since environmental regulations differ substantially among industries, we subdivided the business sector into the thirty-five industries listed in Table 1. Each industry produces a primary product, and many industries also produce one or more secondary products. Thirty-five commodity groups are represented in our model, each corresponding to the primary product of one of the industries listed in Table 1.

TABLE 1 **The Definitions of Industries**

Number	Description
1	Agriculture, forestry, and fisheries
2	Metal mining
3	Coal mining
4	Crude petroleum and natural gas
5	Nonmetallic mineral mining
6	Construction
7	Food and kindred products
8	Tobacco manufacturers
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

The total supply of each commodity group is provided by domestic production and imports from the rest of the world. This supply is divided between intermediate and final demands. The intermediate demands are the inputs of the commodity into all thirty-five industries. Final demands include expenditures by the household and government sectors for consumption, purchases by the business and household sectors for investment, and exports to the rest of the world. Each industry utilizes inputs of capital and labor services, and these services are also allocated to final demands. Noncompeting imports, commodities that are not produced domestically, are allocated in the same way as capital and labor services.

To implement our model, we have constructed a consistent annual time series of interindustry transactions tables for the U.S. economy for the period 1947–1985.[3] These tables provide detailed information on production by each of the thirty-five industries in current and constant prices. The quantities of each commodity, including primary factors of production and noncompeting imports, have been allocated to intermediate and final demands using a "use" table. The quantities of all commodities made by each industry are presented in a "make" table. The "use" and "make" tables are presented diagrammatically in Figure 1. Figure 2 provides definitions of the variables that occur in both tables.

□ **Producer behavior.** The first problem in modelling producer behavior is to represent substitution between inputs. For this purpose, we have constructed econometric models of the demands of each industry for all inputs. We have identified inputs of capital and energy separately, since environmental regulations often require the use of specific types of equipment or restrict the combustion of certain types of fuels. For example, a restriction on sulfur dioxide emissions may require the substitution of low-sulfur for high-sulfur fuel. Similarly, regulations on particulate emissions may necessitate the use of an electrostatic precipitator, which requires additional capital inputs.

The econometric approach to modelling producer behavior is very demanding in terms of data requirements. An alternative approach is to characterize substitution between inputs by calibration from a single data point.[4] For example, almost all applied general equilibrium models employ the assumption of fixed input-output coefficients for intermediate goods, following the specification originated by Johansen (1960).[5] The ratio of the input of each commodity to the output of an industry is calculated from a single use table, like the one presented in Figure 1. However, the possibility of substitution between intermediate goods, such as energy and materials, is ruled out by assumption.

A high degree of substitutability between inputs implies that the cost of environmental regulation is low, while a low degree of substitutability implies high costs of environmental regulation. Although a calibration approach avoids the burden of estimation, it also specifies the nature of substitutability among inputs by assumption rather than relying on empirical

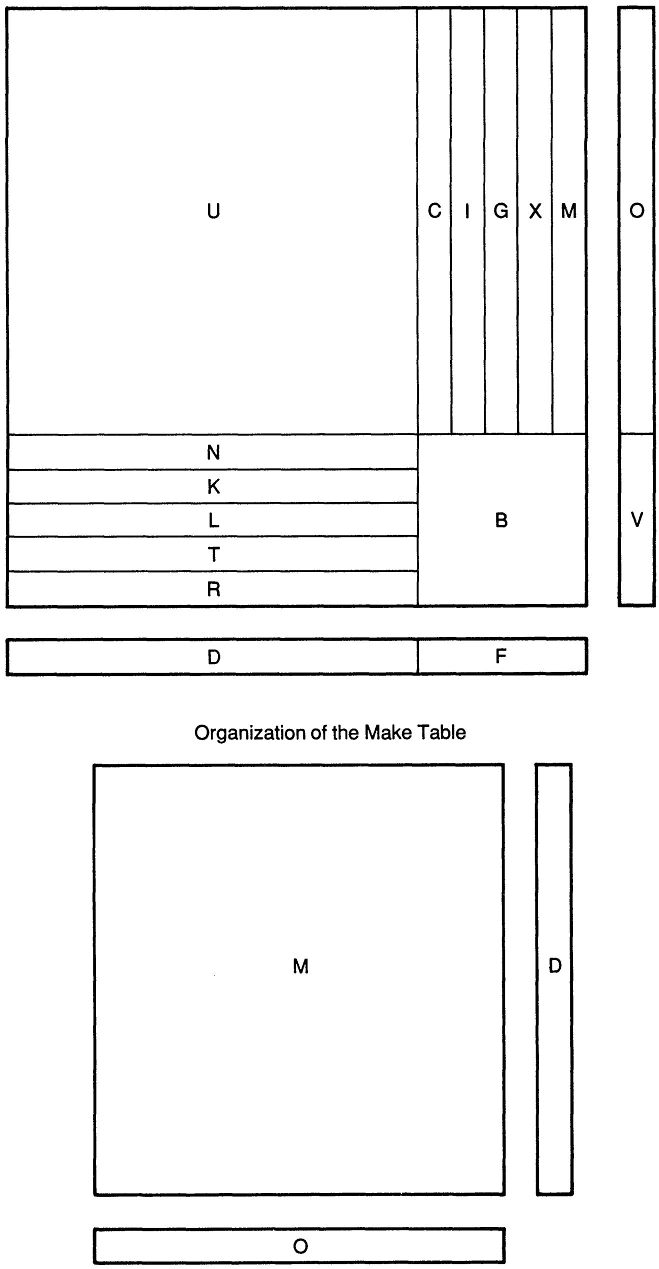
[3] The data on interindustry transactions are based on input-output tables for the U.S. constructed by the Bureau of Economic Analysis (1984). The income data came from the U.S. national income and product accounts, also developed by the Bureau of Economic Analysis (1986). The data on capital and labor services are based on those of Jorgenson, Gollop, and Fraumeni (1987). Our data are organized according to an accounting system based on the United Nations (1968) system of national accounts. The details are given in Appendix C in Wilcoxen (1988).

[4] The calibration approach is discussed in Mansur and Whalley (1984). This approach was employed by Borges and Goulder (1984) in a model analyzing the impact of energy prices on U.S. economic growth. The model is based on data for the year 1973. The econometric approach to this problem is reviewed in Jorgenson (1982). Further details on the econometric methodology are presented in Jorgenson (1984).

[5] Forsund and Strom (1976) employed the specification of substitution between commodities introduced by Johansen (1960). The materials balance approach introduced by Kneese, Ayres, and d'Arge (1970) is considered in a general equilibrium setting in Maler (1974). A detailed survey of fixed coefficient input-output models employed in environmental economics is given in Forsund (1985).

FIGURE 1

ORGANIZATION OF THE USE TABLE



evidence. This defeats the main purpose of modelling the impact of environmental policy. We conclude that empirical evidence on the substitutability of inputs is essential in analyzing the impact of environmental regulations.

The most important mechanisms to control environmental pollution are to induce substitution away from polluting inputs and require pollution abatement. These measures can affect the rate of productivity growth in an industry. If the level of productivity in an industry increases, the price of the output of the industry will fall relative to the prices of its inputs, while a decrease in the industry's productivity level will result in a rise in the

FIGURE 2

MAKE AND USE TABLE VARIABLES

Category	Variable	Description
Industry-commodity flows:		
	U	Commodities *used* by industries (use table)
	M	Commodities *made* by industries (make table)
Final demand columns:		
	C	Personal consumption
	I	Gross private domestic investment
	G	Government spending
	X	Exports
	M	Imports
Value added rows:		
	N	Noncompeting imports
	K	Capital
	L	Labor
	T	Net taxes
	R	Rest of the world
Commodity and Industry output:		
	O	Commodity output
	D	Industry output
Other variables:		
	B	Value added sold directly to final demand
	V	Total value added
	F	Total final demand

price of its output relative to its input prices. Our models of producer behavior endogenize productivity growth by representing the rate of productivity growth in each industry as a function of the prices of all its inputs.[6]

Our econometric models of producer behavior allocate the value of the output of each industry among the inputs of the thirty-five commodity groups, capital services, labor services, and noncompeting imports. Inputs of the thirty-five commodities into each industry are given in the columns labelled U in the use table presented in Figure 1. Inputs of capital services, labor services and noncompeting imports into all industries are given in the rows labelled K, L, and N, respectively. The remaining rows of this table give indirect taxes paid by all industries and inputs of factor services from the rest of the world into these industries.

The sum of all of the entries in each column of the use table is the value of the output of the corresponding industry. This output includes a primary product and, possibly, one or more secondary products. We have modelled the shares of all industries that produce a given commodity in the value of the total domestic production of that commodity as functions of the output prices of these industries. The model uses these value shares to allocate the domestic supply of each commodity among the industries that produce it. This allocation is given in the columns of the make table in Figure 1. Similarly, we have modelled the value shares of imports and domestic production of each commodity and employed these shares in generating the imports of each commodity in the column labelled M in the use table in Figure 1.[7]

[6] Our approach to endogenous productivity growth was originated by Jorgenson and Fraumeni (1981). The implementation of a general equilibrium model of production that incorporates both substitution among inputs and endogenous productivity growth is discussed by Jorgenson (1984, 1986). This model has been analyzed in detail by Hogan and Jorgenson (1990).

[7] This approach was originated by Armington (1969).

In our model of the U.S. economy, there is a single stock of capital that is allocated among all sectors, including the household sector. The supply of capital available in each period is the result of past investment. This relationship is represented by an accumulation equation that gives capital at the end of each period as a function of investment during the period and capital at the beginning of the period. This equation is backward-looking and captures the impact of investments in all past periods on the capital available in the current period. We have assumed that capital is perfectly malleable and mobile among sectors, so the price of capital services in each sector is proportional to a single capital service price for the economy as a whole. The value of capital services is equal to capital income.

Our model of producer behavior includes an equation giving the price of capital services in terms of the price of investment goods at the beginning and end of each period, the rate of return to capital for the economy as a whole, the rate of depreciation, and variables describing the tax structure for income from capital. The current price of investment goods incorporates expectations about all future prices of capital services and all future discount rates.[8] Our model of the U.S. economy includes this forward-looking relationship for the price of investment goods in each time period. The price of capital services determined by the model enters into the price of investment goods through the assumption of perfect foresight or rational expectations. Under this assumption, the price of investment goods in every period is based on the expectations of future capital services' prices and discount rates that are fulfilled by the solution of the model.

The final demands for the commodity groups in our model include purchases by the business and household sectors for investment purposes. The final set of behavioral equations in our model of producer behavior is a system of demand functions for investment goods. We have modelled the value shares of all commodities accumulated by the business and household sectors—including producers' and consumers' durables, residential and nonresidential structures, and inventories—as functions of the prices of these commodities. The shares are used to allocate the value of investment goods among commodity groups, as in column I in the use table in Figure 1.

□ **Consumer behavior.** An important objective of environmental regulation is to induce the substitution of nonpolluting products for polluting ones. This substitution can take place within the household sector as well as the business sector. For example, regulations on the exhaust emissions of motor vehicles affect household demands for vehicles and motor fuel. The first problem in modelling consumer behavior is to represent substitution between commodities that are purchased by households. For this purpose, we have constructed an econometric model of the demands for individual commodities by the household sector. As in our models of producer behavior, we have identified purchases of energy and capital services separately, since these commodity groups are directly affected by environmental regulation.[9]

Our model of consumer behavior allocates personal consumption expenditures among the thirty-five commodity groups included in our model of the U.S. economy, capital and labor services, and noncompeting imports. The allocation to individual commodities is given in the column labelled C in the use table in Figure 1. Our model of personal consumption expenditures can be used to represent the behavior of individual households, as in the studies of regulatory policy by Jorgenson and Slesnick (1985). Here, we employ the model to represent aggregate consumer behavior in simulations of the U.S. economy under alternative policies for environmental regulation. For this purpose, we have embeded this

[8] Further details are given in Jorgenson (1989).

[9] The econometric methodology employed in our study was originated by Jorgenson, Lau, and Stoker (1982). The econometric model we have employed was constructed by Jorgenson and Slesnick (1987). Further details on the econometric methodology are given in Jorgenson (1984, forthcoming).

model of personal consumption expenditures into a higher-level model that determines consumer choices between labor and leisure and between consumption and saving.

The second stage of our model of the household sector is based on the concept of full consumption, which is composed of goods and services and leisure time. We have simplified the representation of household preferences between goods and leisure by introducing the notion of a representative consumer. In each time period, the representative consumer allocates the value of full consumption between personal consumption expenditures and leisure time.[10] This produces an allocation of the exogenously given time endowment between leisure time and the labor market. Labor market time is allocated between the thirty-five industries represented in the model and final demands for personal consumption expenditures and government consumption. We have assumed that labor is perfectly mobile between sectors, so the price of labor services in each sector is proportional to a single wage rate for the economy as a whole. The value of the time allocated to the labor market equals labor income.

The third and final stage of our model of the household sector is a model of intertemporal consumer behavior. We have described intertemporal preferences by means of a utility function for a representative consumer that depends on levels of full consumption in current and future time periods. The representative consumer maximizes this utility function subject to an intertemporal budget constraint. The budget constraint gives full wealth as the discounted value of current and future full consumption. The necessary conditions for a maximum of the utility function subject to the budget constraint can be expressed in the form of an Euler equation, giving the rate of growth of full consumption as a function of the discount rate and the rate of growth of the price of full consumption.[11]

The Euler equation for full consumption is forward-looking, so the current level of full consumption incorporates expectations about future prices of full consumption and future discount rates. The solution of our model includes this forward-looking relationship for full consumption in each time period. The price of full consumption determined by the model enters full consumption through the assumption of perfect foresight or rational expectations. Under this assumption, full consumption in every period is based on expectations about future prices of full consumption and discount rates that are fulfilled by the solution of the model.

□ **The solution of the model.** We conclude this overview by outlining the solution of our model of the U.S. economy. An intertemporal submodel incorporates backward-looking and forward-looking equations that determine the time paths of the capital stock and full consumption. Given the values of these variables, an intratemporal submodel determines the prices that balance demand and supply in each time period for the thirty-five commodity groups included in the model, capital services, and labor services. These two submodels must be solved simultaneously to obtain a complete solution of the model.

The dynamics of adjustment to changes in evironmental policy are determined by the intertemporal features of our model. For example, investment in equipment for pollution abatement was a very substantial proportion of investment in producers' durable equipment during parts of our sample period, 1947–1985. This type of mandated investment increased the price of investment goods, requiring adjustments of capital service prices and discount

[10] The price of leisure time is equal to the market wage rate reduced by the marginal tax rate on labor income, which is the opportunity cost of foregone labor income. The price of personal consumption expenditures is a cost of living index generated from the first stage of our model of consumer behavior. This cost of living index is discussed in Jorgenson and Slesnick (1983).

[11] The Euler equation approach to modelling intertemporal consumer behavior was originated by Hall (1978). Our application of this approach to full consumption follows Jorgenson and Yun (1986).

rates over the whole future time path of the economy. Reductions in investment in capital accumulation reduced the capital available for production in subsequent time periods.

Given the prices of capital and labor services and noncompeting imports, the first step in the solution of the intratemporal model is to determine prices for the outputs of the thirty-five industries represented in the model. Given these prices, the next step is to determine the domestic supply prices for the corresponding commodities. Finally, the domestic supply price for each commodity is combined with the price of imports to determine the total supply price. These commodity prices enter the determination of intermediate demands by industries and final demands by the household, business, government, and rest-of-the-world sectors.

We have described the determination of supply prices for the thirty-five commodity groups included in our model given the prices of capital and labor services and the prices of competing and noncompeting imports. The prices of imports are given exogenously in every time period. The prices of capital and labor services are determined by balancing demand and supply for these services. The supply of capital is determined by previous investments and is taken as given in every period. The exogenously given time endowment of the household sector is allocated between the labor market and leisure time by our model of consumer behavior.

The demand side of the intratemporal model is divided between intermediate and final demands for the thirty-five commodity groups, capital and labor services, and noncompeting imports as presented in the use table in Figure 1. Our models of producer behavior include value shares for inputs of commodities, primary factors of production, and noncompeting imports into each industry. These value shares incorporate income-expenditure identities for the industry, since the total value of output must be equal to the value of the inputs. The value shares determine inputs per unit of output for each industry as functions of the input and output prices. The endogenously determined input-output coefficients in each industry are multiplied by the output of the industry to obtain the input quantities. These quantities are then summed over the thirty-five industries to obtain total intermediate demands.

In our intratemporal model, final demands are divided among personal consumption expenditures, purchases by the business and household sectors for investment purposes, expenditures by the government for public consumption, and exports to the rest of the world. To determine the quantities of the thirty-five commodities for each of these final demand categories, our model of consumer behavior allocates the value of full consumption between the aggregate expenditure on goods and services that make up personal consumption expenditures and the value of leisure time. Given aggregate expenditure, its distribution among households, and commodity prices, this model also allocates personal consumption expenditures among commodity groups, including capital and labor services and noncompeting imports. This allocation determines the quantity of each commodity included in the final demand for personal consumption. These quantities are included in column C in the use table in Figure 1.

While the value of personal consumption expenditures is determined within our model of consumer behavior, the value of gross private domestic investment is driven by private savings. First, the income of the household sector is the sum of incomes from the supply of labor and capital services, interest payments from the government and rest-of-the-world sectors, all net of taxes, and transfers from the government. Savings are equal to income minus personal consumption expenditures minus personal transfers to foreigners and nontax payments to the government. This is the income-expenditure identity of the household sector.

The balance sheet identity of the household sector sets private wealth equal to the sum of the value of the capital stock in the private sector, claims on the government, and claims on the rest of the world. The change in the value of private wealth from period to period is the sum of private savings and the revaluation of wealth as a result of inflation. Private savings plus government savings equals the current account balance of the rest-of-the-world sector plus gross private domestic investment. Within our intratemporal model, the level of investment is determined by savings, since the government deficit and the current account balance are taken to be exogenous. Our model of producer behavior allocates gross private domestic investment among commodity groups. Given the commodity prices, this allocation determines the quantity of each group included in final demand for investment purposes. These quantities are included in column I in the use table in Figure 1.

In order to complete the determination of final demands in our model, we considered purchases by the government and rest-of-the-world sectors. Wherever possible, we have assigned government enterprises to the corresponding industry. For example, we have assigned the Tennessee Valley Authority to electric utilities and municipal transportation systems to transportation services. A separate industrial sector includes the remaining government enterprises, such as the U.S. Postal Service. Demands for commodities by government enterprises have been incorporated into intermediate demands. Purchases by the government sector for public consumption are part of final demands. Similarly, demands for competing and noncompeting imports are determined by our econometric models of producer behavior. Exports to the rest-of-the-world sector are part of final demands.

The final demands for public consumption are determined by the income-expenditure identity for the government sector. Government revenues are generated by exogenously given tax rates applied to appropriate transactions in the business and household sectors. For example, sales tax rates are applied to the values of the outputs of the thirty-five industries to generate sales tax revenues; tariff rates are applied to imports to generate tariff revenues, and income tax rates are applied to incomes from capital and labor services to generate income tax revenues. In addition, property and wealth tax rates are applied to property employed in the business and household sectors and to household sector wealth to generate revenues from property and wealth taxes.

The model of the government sector adds the capital income of government enterprises, determined endogenously, and nontax receipts, given exogenously, to tax revenues to obtain total revenues of the government sector. The model subtracts the government budget surplus (or adds the government budget deficit) from (to) these revenues to obtain government expenditures. The key assumption here is that the government budget surplus (or deficit) is given exogenously. To arrive at government purchases of goods and services, it subtracts interest paid to domestic and foreign holders of government bonds and government transfer payments to domestic and foreign recipients from these expenditures. The shares of individual commodity groups in government purchases are taken to be exogenous. The model determines the quantities of all commodities included in the final demand of the government sector by dividing the values of government purchases by the corresponding commodity price. The resulting quantities are given in column G in the use table in Figure 1.

Our intratemporal model incorporates the income-expenditure identity of the rest-of-the-world sector. The current account surplus of the rest of the world equals the value of exports minus the value of imports plus the interest received on domestic holdings of foreign bonds minus private and government transfers abroad minus the interest on government bonds paid to foreigners. The key assumption of our model of the rest-of-the-world sector is that the current account balance is exogenous, so the exchange rate is endogenous. Exports to the rest of the world are determined by demand equations that depend on world income and on ratios of commodity prices in U.S. currency to the exchange rate. The quantities of exports of all commodities are included in column X in the use table in Figure 1. Exogenously given prices of competing and noncompeting imports in foreign currency are expressed in U.S. currency by multiplying these prices by the exchange rate.

To construct a solution of our model of the U.S. economy, we first require values of all the exogenous variables. These variables have been set equal to their historical values for the sample period, 1947–1985. We have projected all the exogenous variables for the postsample period, 1986–2050, and taken these variables to be constant at their 2050 values through the year 2100. The exogenous variables have been held constant for the period 2050–2100 to allow sufficient time for the endogenous variables determined by the model to converge to their steady-state values.

We require projections of the exogenous components of the income-expenditure identities for government and rest-of-the-world sectors in order to project final demands for public consumption and exports. We have projected a gradual decline in the government deficit to the year 2025. For all later years, this deficit has been set to 4% of the nominal value of the government debt. This has the effect of maintaining a constant ratio of the value of the government debt to the value of the national product at a 4% inflation rate in a steady-state solution to our model.

We have set future prices of import and exports in foreign currency equal to the prices in 1985, the last year of our sample period. Projections of prices in U.S. domestic currency depend on the endogenously determined exchange rate. We have projected that the exogenous current account balance for the rest-of-the-world sector will fall gradually to zero by the year 2000. For later years, we have projected a current account surplus sufficient to produce a stock of net claims on foreigners by the year 2050 that equals the same proportion of national wealth as it did in 1982.

The most important exogenous variables in our model of the U.S. economy are those associated with the U.S. population and the corresponding time endowment. We have projected population by individual year of age, individual year of educational attainment, and sex to the year 2050, using demographic assumptions that result in a maximum population in that year.[12] In projecting future levels of educational attainment, we have assumed that future demographic cohorts will have the same level of attainment as the cohort that reached age 35 in the year 1985. We have transformed our population projection into a projection of the time endowment used in our model of the labor market by assuming that the relative wages have been constant at 1985 levels.

The size of the economy corresponding to the steady state of our model is effectively determined by the time endowment. The capital stock adjusts to this time endowment, while the rate of return depends only on the intertemporal preferences of the household sector. In this sense, the supply of capital is perfectly elastic in the long run. It is useful to contrast the behavior of our model with that of a neoclassical growth model of the Cass-Koopmans type.[13] For example, the rate of return in the stationary solution of our model is independent of environmental policy, just as in a one-sector neoclassical growth model. However, different policies result in different levels of capital intensity—all corresponding to the same rate of return. This is impossible in a one-sector model.

In the short run, the supply of capital in our model is perfectly inelastic, since it is completely determined by past investment. Under our assumption of perfect mobility of capital and labor, changes in environmental policy can affect the distribution of capital and labor supplies among sectors, even in the short run. The transition path for the economy depends on environmental policy. It also depends on the time path of variables that are exogenous to the model. If the initial wealth of the economy is low relative to the time endowment, the rate of return will exceed the stationary rate of return. This will induce the representative consumer to postpone the consumption of goods and leisure into the future,

[12] Our breakdown of the U.S. population by age, educational attainment, and sex is based on the system of demographic accounts compiled by Jorgenson and Fraumeni (1989). The population projections are discussed in detail in Appendix B in Wilcoxen (1988).

[13] This model was originated by Cass (1965) and Koopmans (1967). The Cass-Koopmans model has recently been discussed by Lucas (1988) and Romer (1989). Neoclassical growth models with pollution abatement have been presented by Maler (1975) and Uzawa (1975).

so the rate of capital accumulation will be positive. Conversely, if the initial wealth of the economy is sufficiently high relative to the time endowment, the rate of capital accumulation will be negative.

3. The impact of environmental regulation

■ Our next objective is to assess the impact of environmental regulation by projecting the growth of the U.S. economy with and without regulation. The base case for our simulations is a regime with pollution controls in effect. To determine the impact of environmental restrictions on economic activity, we simulate U.S. economic growth in the absence of regulation. We perform separate simulations to assess the impact of pollution control in industry and controls on motor vehicle emissions, which also affect the consumption behavior of households. We then estimate the overall impact of environmental regulation by eliminating both types of pollution control.

Simulations of the U.S. economy in which pollution controls are removed differ from the base case in the steady state, the initial equilibrium, and the transition path between the two. Since the capital stock is endogenous in our model, the new steady state corresponds to the long-run impact of environmental regulation on the U.S. economy. The initial equilibrium with a fixed capital stock gives the short-run impact of a change in environmental policy. Since agents in the model are endowed with perfect foresight, this initial equilibrium reflects changes along the entire time path of future regulatory policy. Finally, the transition path between the initial equilibrium and the steady state traces out the dynamics of the adjustment of the economy to a new policy for environmental regulation.

In presenting the results of our simulatons of U.S. economic growth, we begin by quantifying the impact of pollution controls on production costs. We then incorporate the changes in costs into our model of the U.S. economy. We first consider the impact of environmental regulations on the steady state of the economy. For this purpose, we focus attention on a few key variables. The capital stock determines the production capacity of the economy, since the time endowment is given exogenously. Full consumption is a measure of the goods and services and leisure time available to the household sector. The level of the gross national product is an overall measure of the output of the economy, including private and public consumption, investment, and net exports to the rest of the world. Finally, the exchange rate is an indicator of the international competitiveness of the U.S. economy.

The second step in our analysis of the impact of environmental regulation is to analyze the transition path of the U.S. economy from the initial equilibrium to the new steady state. The time path of the capital stock is the most important indicator of the process of economic adjustment to a change in environmental policy. The price of investment goods is an important determinant of the time path of capital stock, since it incorporates expectations about future prices of capital services and discount rates. The rental price of capital services also reflects the rate of return, which is critical to the allocation of national income between consumption and savings. We employ the time paths of capital stock, the price of investment goods, the price of capital services, and the level of GNP in describing the adjustment process.

□ **Operating costs.** We have used data collected by the Bureau of the Census (Bureau of the Census, various issues, 1973–1983) to estimate investment in pollution abatement equipment and operating costs of pollution control activities for manufacturing industries.[14] The investment data give capital expenditures on pollution abatement equipment in current prices, while the data on operating costs give current outlays attributable to pollution control.

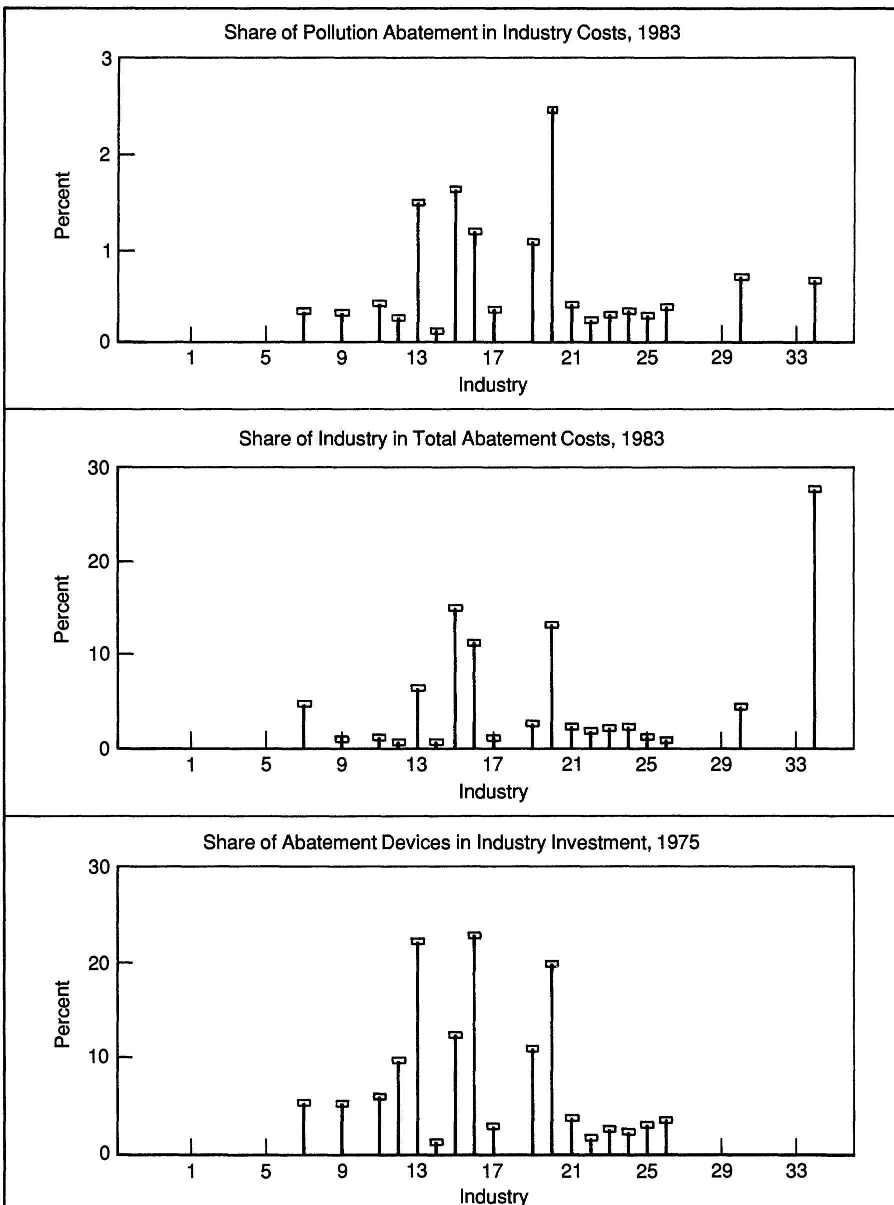
[14] A detailed description of the data is given in Appendix D in Wilcoxen (1988).

These are the actual costs reported by the business sector and do not include taxes levied as part of the Superfund program. Taxes amounting to more than a billion dollars a year were placed on the petroleum-refining and chemicals industries in 1981 and the primary metals industry in 1986. These may have had a substantial impact on U.S. economic growth, but we do not examine their consequences in this article.

Figure 3 summarizes the share of pollution abatement in industry costs, the share of individual industries in total abatement costs, and the share of abatement devices in industry investment for the manufacturing industries. Inspection of the first panel shows that pollution control expenses have formed only a small part of total costs for individual industries. The

FIGURE 3

THE IMPACT OF ENVIRONMENTAL REGULATION



largest share is for the primary metals industry, at slightly more than 2%. The second panel shows that the expenses for pollution abatement have been concentrated in a relatively small number of industries. Three sectors—chemicals, petroleum refining, and primary metals—account for 55% of total spending. The third panel shows that investment in pollution abatement equipment has consumed more than 20% of total investment for paper and pulp, petroleum refining, and primary metals industries.

The first step in eliminating the operating costs of pollution control is to estimate the share of pollution abatement in the total costs of each industry. The 1983 cost shares are a maximum for the period 1973–1983, since pollution controls have increased steadily over the period. We have assumed that shares for the later years have been constant at the 1983 values. Data for industries outside manufacturing were available only for electric utilities and wastewater treatment, which is part of the services industry. For both industries, data on operating costs and investment expenditures for pollution abatement have been compiled by the Bureau of Economic Analysis. We have estimated the proportion of operating costs devoted to pollution abatement for these industries.[15]

Additional information on the impact of environmental regulation on costs is available for electric utilities, namely, the extra costs of burning low-sulfur fuels. Switching from high-sulfur to low-sulfur coal changes the relative proportions of the two products in the output of the coal industry. Since low-sulfur coal is more expensive, this increases the price of coal. Eliminating regulations on sulfur emissions would lower the price of coal by permitting substitution to high-sulfur grades. We have modelled the impact of lifting these emissions controls by subtracting the differential between high-cost and low-cost coal from the costs of coal production.[16] Including the coal industry, twenty industries are subject to pollution abatement regulations.

The long-run impact of eliminating the operating costs of pollution abatement is summarized in the column labelled ENV in Table 2. The output of the economy, as measured by the real gross national product, is raised by .728%. The capital stock rises by .544%. Since our model has a perfectly elastic supply of savings in the long run, the rate of return is unaffected by regulation. However, the price of investment goods, which also reflects capital service prices, falls by .897%. The price of capital services declines by .907%, almost the same as the price of investment goods. The resulting decrease in the prices of goods and services produces a rise in full consumption of .278%. This increase is less than that of the gross national product, since full consumption includes leisure time as well as personal consumption expenditures. Finally, the exchange rate, which gives the domestic cost of

TABLE 2 The Effects of Removing Environmental Regulation

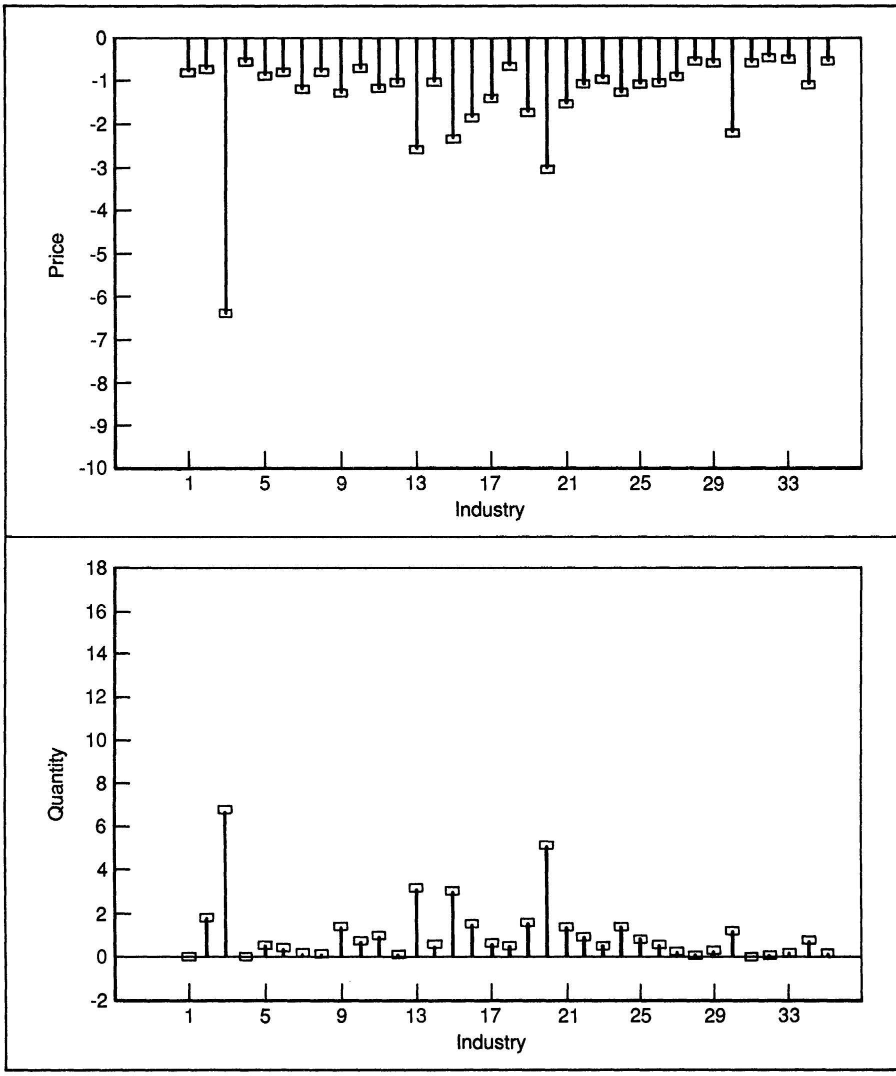
Variable	Percentage Change in the Steady State ENV	INV	MV	ALL
Capital Stock	.544	2.266	1.118	3.792
Price of Investment Goods	−.897	−2.652	−1.323	−4.520
Full Consumption	.278	.489	.282	.975
Real GNP	.728	1.290	.752	2.592
Rental Price of Capital	−.907	−2.730	−1.358	−4.635
Exchange Rate	−.703	−.462	−.392	−1.298

[15] The details are given in Appendix D in Wilcoxen (1988).

[16] The details of our methodology for estimating cost differentials between high-sulfur and low-sulfur coal are given in Appendix D in Wilcoxen (1988).

FIGURE 4

THE EFFECTS OF REMOVING ABATEMENT COSTS ON INDUSTRIES



foreign goods, falls slightly, indicating an increase in the international competitiveness of the U.S. economy.[17]

The long-run effects of eliminating operating costs associated with pollution abatement on the prices and outputs of individual industries are shown in Figure 4. The bars in the first panel indicate the percentage change in the steady-state output price of the corresponding industry. The bars in the second panel give the percentage changes in industry output levels. Not surprisingly, the principal beneficiaries of the elimination of operating costs are the most heavily regulated industries. The greatest expansion of output occurs in coal production, since the fuel cost differential between low-sulfur and high-sulfur coal is large relative to the total costs of the coal industry. Turning to manufacturing industries, the primary metals, paper, and chemicals industries have the largest gains in output from the elimination of

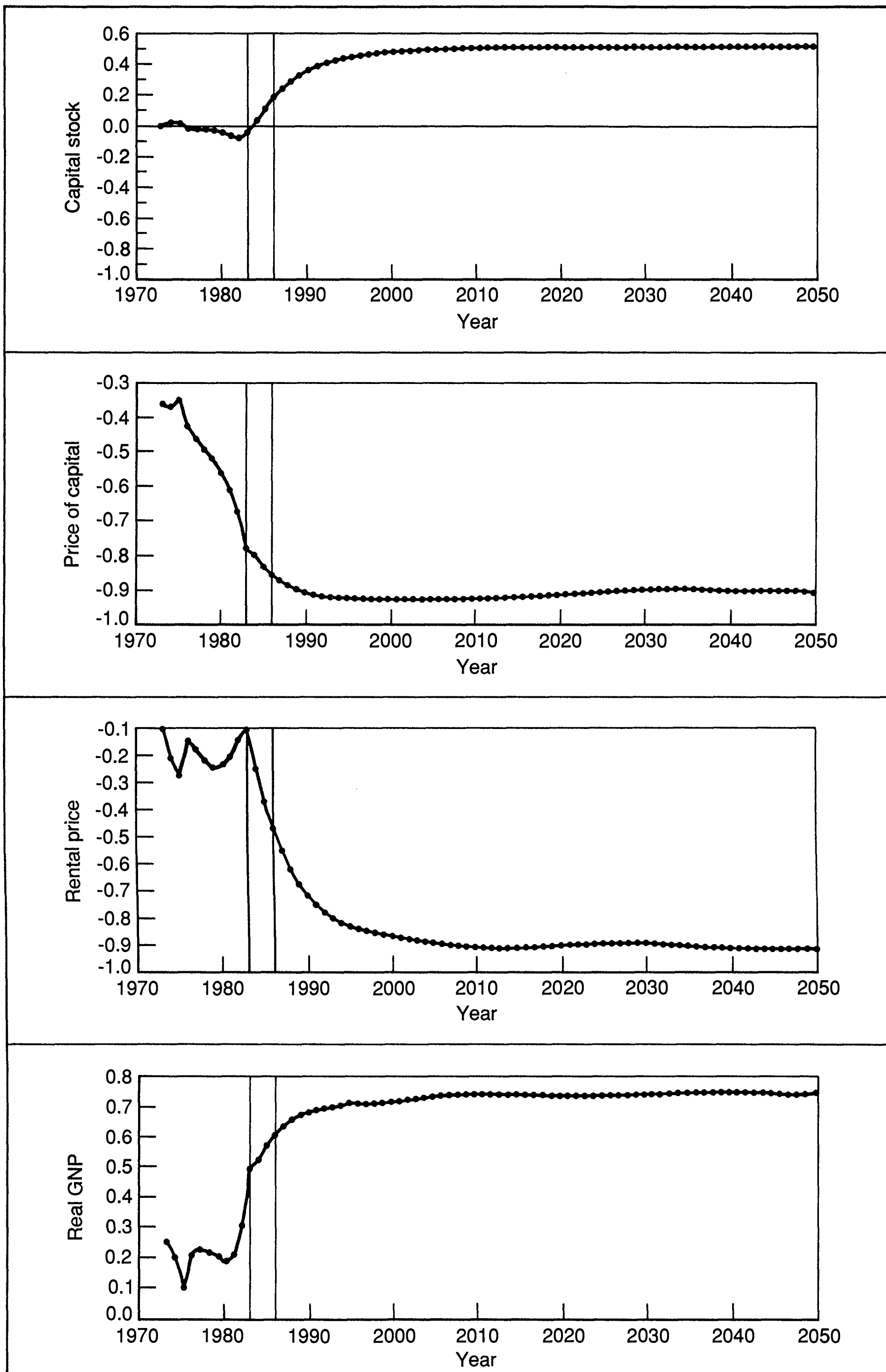
[17] An alternative analysis of the impact of environmental regulation on U.S. international competitiveness is given in Kalt (1988).

operating costs for pollution abatement. Several other sectors benefit from the removal of operating costs of pollution abatement, but the impact is fairly modest.

We have now summarized the long-run impact of eliminating operating costs associated with pollution controls in industry. Figure 5 presents the dynamics of the process of ad-

FIGURE 5

THE DYNAMIC EFFECTS OF REMOVING ABATEMENT COSTS



justment to lower costs. After 1973, the price of investment goods falls slowly, reflecting the gradual price decline brought about by the elimination of operating costs associated with increasingly stringent regulations. Lower costs of investment goods tend to increase the rate of return, stimulate savings, and produce more rapid capital accumulation. Additional capital eventually brings down the rental price of capital, lowering costs still further. Finally, the quantity of full consumption rises rapidly to the new steady-state level and remains there.

The transition from the short run to the steady state is relatively slow, requiring almost three decades for the capital stock and the price of capital services to fully adjust to the change in environmental policy. The graph of the capital stock shows that the process of adjustment is not complete until the year 2000. This reflects the nature of our simulation experiment. The regulations are imposed gradually, so their removal is also gradual. On the other hand, full consumption attains its final value more quickly as a consequence of intertemporal optimization by households under perfect foresight. Since income is permanently higher in the future, current consumption rises in anticipation. However, the rise of consumption is dampened by an increase in the rate of return that produces greater investment.

□ **Investment in pollution control equipment.** The most important impact of environmental regulation for some industries is the imposition of requirements for investment in costly new equipment for pollution abatement. Investment in pollution control devices crowds out investment for capital accumulation, further reducing the rate of economic growth. Our second simulation of U.S. economic growth is designed to assess the impact of investment for pollution control. An examination of the data on investment presented in Figure 3 reveals several striking features. First, the paper, petroleum-refining, and primary metals industries each spent more than 20% of the their total investment on pollution control devices in 1975. Some other sectors were not far behind, and the overall share of this investment in total gross private domestic investment was substantial.

The share of investment for pollution abatement rose to a peak in the early 1970s and then declined substantially. This can be attributed to the fact that much of the early effort in pollution control was directed at reducing emissions from existing sources by retrofitting equipment already in place. The appropriate method for modelling mandatory investment in pollution control requires a distinction between achieving environmental standards for existing sources of emissions and meeting restrictions on new sources of emissions. Environmental regulations increase the cost of new investments, since producers are required to purchase pollution abatement equipment whenever they acquire new investment goods.

We assumed that investment in pollution control equipment provides no benefits to the producer other than satisfying environmental regulations. Accordingly, we simulate mandated investment as an increase in the price of investment goods. Unfortunately, the existing data do not provide a separation between investments required for new and existing facilities. We have assumed that the backlog of investment for retrofitting old sources of emissions had been eliminated by 1983. We simulate the impact of removing environmental regulations on investment by reducing the price of investment goods by the proportion of total investment attributable to pollution control for 1983. This captures the effect of requirements for pollution abatement on investment in new capital goods but does not include the effect of windfall losses to owners of the capital associated with old sources of emissions.

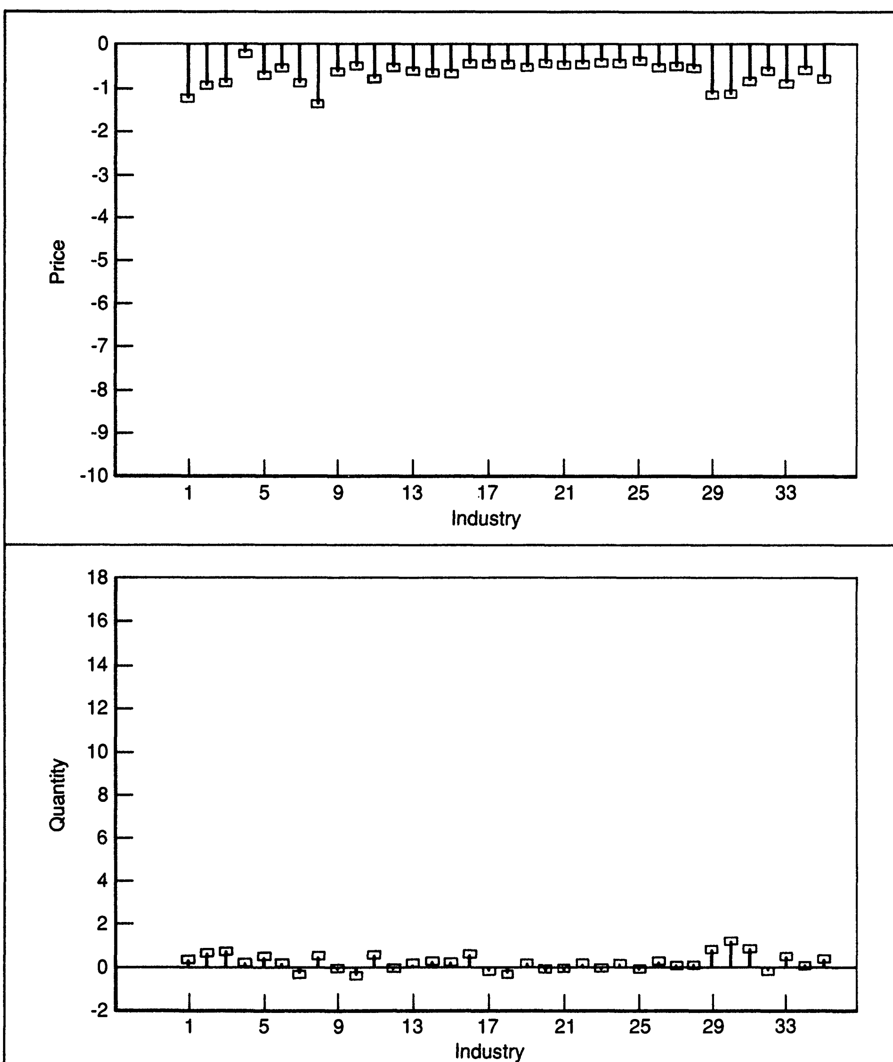
Our method for simulating the impact of investment requirements for pollution control has certain limitations that should be pointed out. First, it relies on the assumption that capital is completely malleable and mobile between sectors. An alternative approach would be to incorporate costs of adjustment into our models of producer behavior. However, this approach would lead to considerable additional complexity in modelling and simulating producer behavior. The long-run impact of environmental regulations would be unaffected by costs of adjustment, since these costs would be zero in the steady state of our model.

The steady-state effects of mandated investment in pollution control devices are given in the column labelled INV in Table 2. The largest change is in the capital stock, which rises by 2.266% as a direct result of the drop in the price of investment goods. In the short run, this price decline pushes up the rate of return, which raises the level of investment. Higher capital accumulation leads to a fall in the rental price of capital services, decreasing the overall price level. The long-run level of full consumption rises by .489%, almost double the increase resulting from eliminating operating costs of pollution abatement. The 1.290% rise in GNP is also nearly twice as large as this increase. The exchange rate appreciates by .462%, indicating an increase in international competitiveness of the U.S. economy.

The effects of eliminating pollution abatement investment on industry output and price levels are shown in Figure 6. These effects stem from the drop in the rental price of capital services. The largest gains in output are for communications, electric utilities, and gas utilities, since these are the most capital intensive industries. While most sectors gain from eliminating investment for pollution control, a few sectors are hurt by this change in

FIGURE 6

THE EFFECTS OF REMOVING ABATEMENT INVESTMENT ON INDUSTRIES



environmental policy. Outputs of food, apparel, rubber and plastic, and leather all decline noticeably. These sectors are among the least capital intensive, so the fall in the rental price of capital services has little effect on the prices of outputs. Buyers of the commodities produced by these industries face higher prices and substitute other commodities in both intermediate and final demand.

The transition path of the U.S. economy after investment requirements for pollution control have been eliminated is summarized in Figure 7. The process of adjustment is markedly different from that of the previous simulation. The capital stock grows immediately and rapidly to its new equilibrium value. This comes about as a consequence of the fall in the price of investment goods. As new capital goods become cheaper, beginning in 1973, the rate of return rises, driving up investment and producing a sharp increase in the capital stock. This explanation is further substantiated by the behavior of full consumption. Initially, consumption drops, and a larger share of income is diverted to investment. Then, as the capital stock rises, so does consumption. The path of the rental price reflects the behavior of the capital stock and drives output prices downward as more capital is accumulated.

□ **Motor vehicle emissions control.** Environmental regulation is not limited to controlling emissions by industries within the business sector. Regulations on motor vehicle emissions affect users of motor vehicles, including households as well as businesses. Motor vehicle regulation is set apart from other forms of environmental control by the fact that the pollution abatement equipment is installed by the manufacturer. Like pollution control in industry, the reduction of motor vehicle exhaust emissions adds to both capital expenditures and operating costs. The catalytic converter is a typical piece of pollution abatement equipment requiring capital expenditures. The premium paid for unleaded gasoline represents an increase in operating costs.

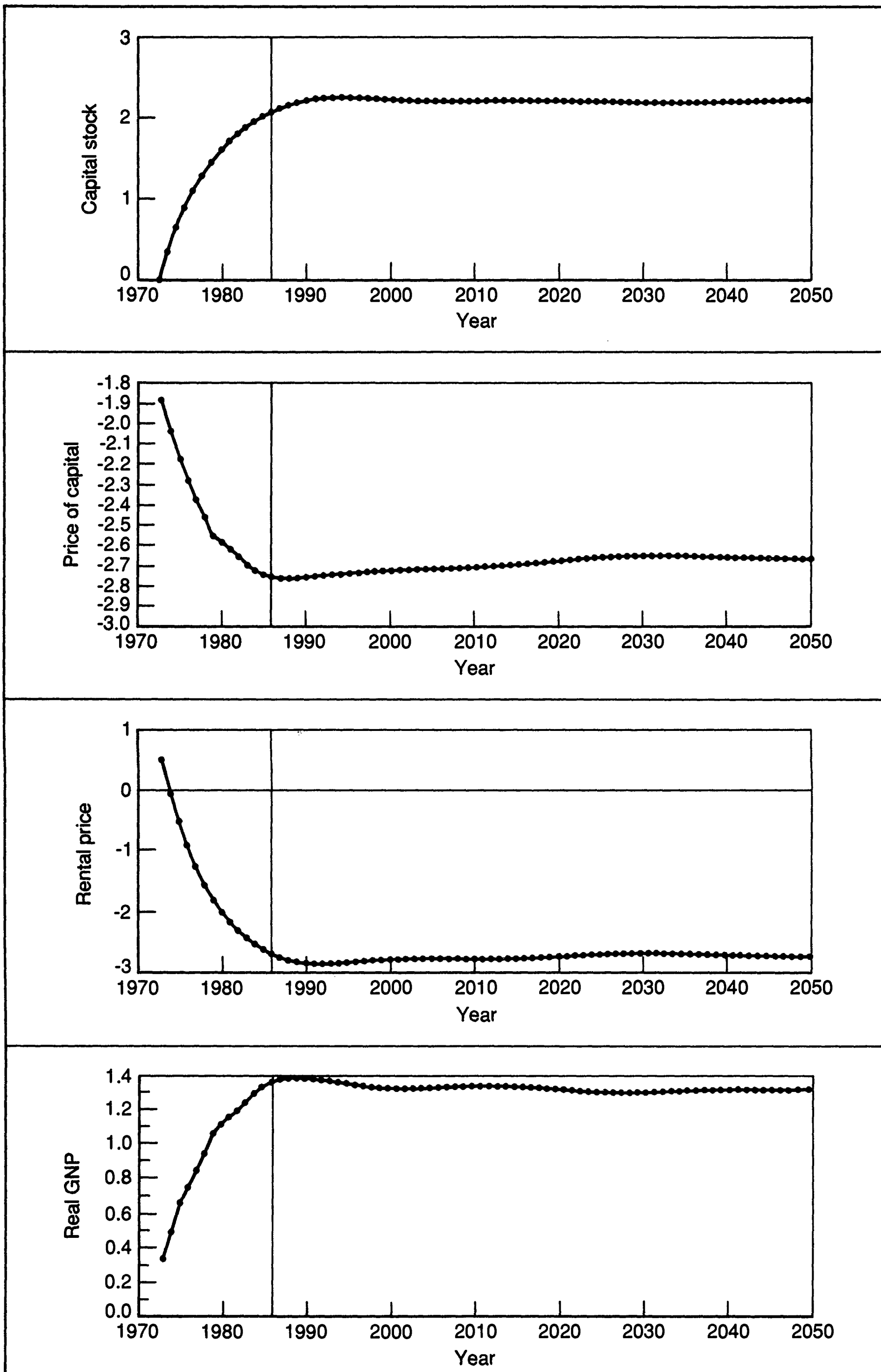
Using data obtained from Kappler and Rutledge (1985), we have estimated the change in motor vehicle prices resulting from emission control regulations. Pollution abatement also imposes additional operating costs on users of motor vehicles. Kappler and Rutledge separated these additional expenses into three components—increased fuel consumption, increased fuel prices, and increased motor vehicle maintenance. We first divided the total cost of pollution abatement equipment between imported and domestic vehicles in proportion to their shares in total supply. We excluded the cost of this equipment from the total cost of domestic production of motor vehicles. Now, we reduce the price of motor vehicles in proportion to the cost of pollution control devices to simulate the impact of eliminating controls on motor vehicle emissions.

The price premium for unleaded motor fuels can be modelled as a change in the cost of the output of the petroleum-refining sector. This is similar to the treatment of the fuel cost differential between high-sulfur and low-sulfur coal used in our simulations of the impact of pollution abatement in industry. Only the costs associated with higher fuel prices are removed in our simulation of U.S. economic growth without motor vehicle emissions controls. Consequently, our results will understate the impact of these controls. To complete the inputs to our simulation of U.S. economic growth in the absence of controls on motor vehicles emissions, we reduce the price of imported motor vehicles in the same proportion as the price of domestic vehicles.

The economic impact of imposing emissions controls on motor vehicles is similar in magnitude to the impact of pollution controls in industry. These results are summarized in the column labelled MV in Table 2. The long-run capital stock rises by 1.118% after the elimination of controls on emissions, while full consumption increases by .282%. Real GNP increases by .752% in the absence of controls. Finally, the exchange rate appreciates by .392%. Almost all of the economic impact is due to decreased motor vehicle prices as a consequence of the absence of emissions controls. Changes in the price of investment goods

FIGURE 7

THE DYNAMIC EFFECTS OF REMOVING ABATEMENT INVESTMENTS

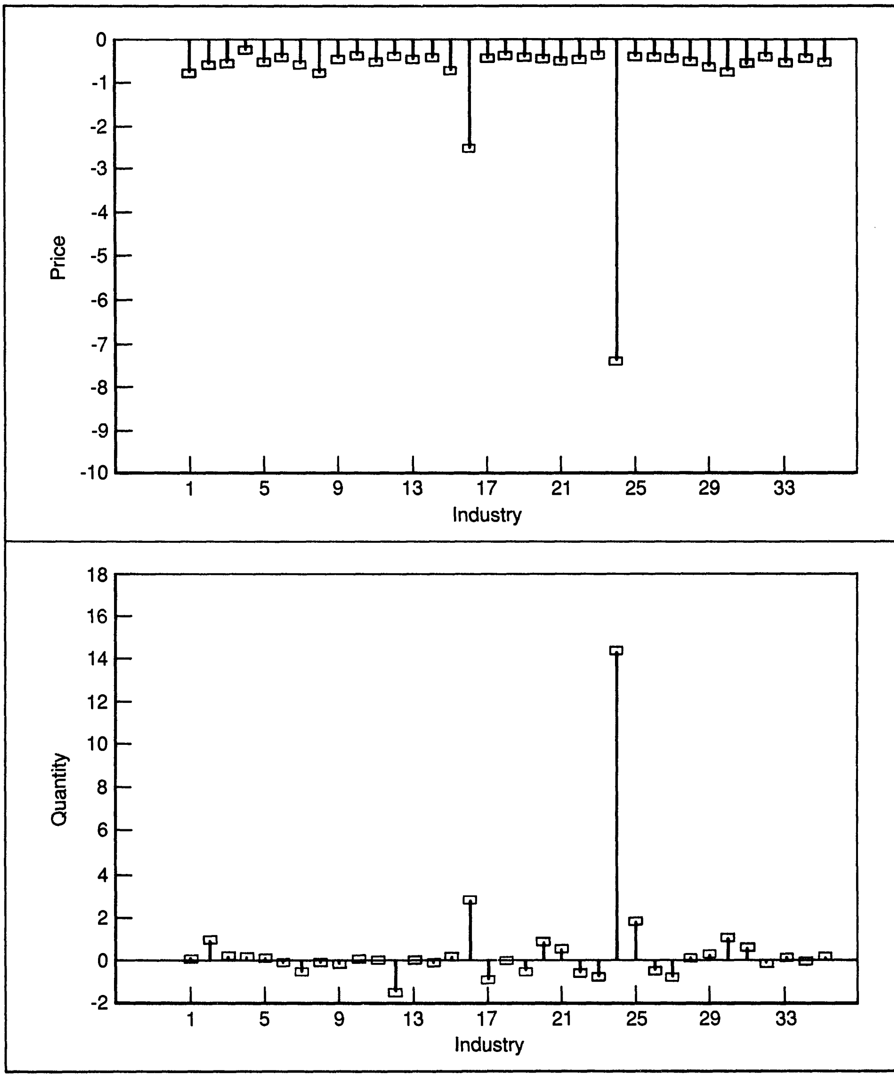


raise the rate of return, leading to large changes in the capital stock. The price of investment goods changes substantially, since motor vehicles make up nearly 15% of new capital goods.

The long-run impact of eliminating motor vehicle emissions controls on the outputs and prices of individual industries is shown in Figure 8. The principal beneficiary of the

FIGURE 8

THE EFFECTS OF REMOVING VEHICLE REGULATION ON INDUSTRIES



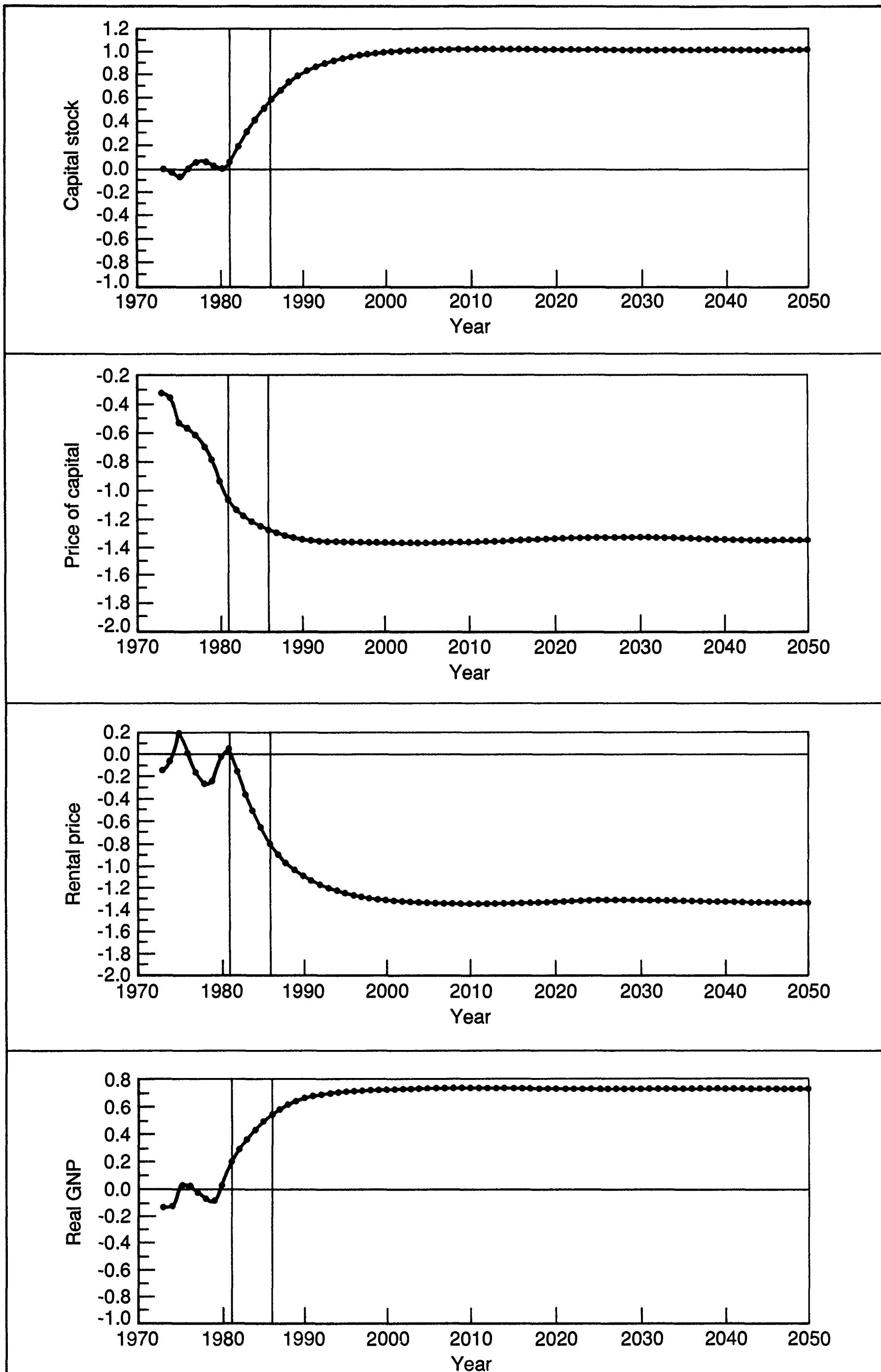
elimination of these regulations is the motor vehicles industry. This is partly due to the fact that the demand for motor vehicles is price elastic. A price change of 7% produces an output change of 14%. Two other industries also benefit significantly from the elimination of environmental controls—petroleum refining and electric utilities. Both gain from the reduction in fuel prices associated with elimination of the fuel price premium.

The process of adjustment to a change in controls on motor vehicle emissions is shown for key variables of the model in Figure 9. The important features of this path are similar to those for the removal of pollution abatement investment in industry. Vehicles are a large part of investment, so lowering their price brings down the cost of new capital goods substantially. This increases the rate of return, stimulates saving, and leads to a surge in investment. Since the change in vehicle prices is largest in later years, however, the effect is more gradual, and the capital stock does not climb as rapidly.

□ **The impact of environmental regulation.** To measure the total impact of eliminating all three costs of environmental regulation—operating costs resulting from pollution abatement

FIGURE 9

THE DYNAMIC EFFECTS OF MOTOR VEHICLE REGULATION



in industry, costs of investments required by industry to meet environmental standards, and costs of emissions controls on motor vehicles—we perform a final simulation. This simulation is not a simple combination of its three components. Operating costs include capital costs, so combining the reductions in operating costs with the elimination of investment requirements would count the cost reductions associated with capital twice. To solve this problem, the capital component is removed from operating costs in the combined simulation. The results of removing all forms of environmental regulation are summarized in the column labelled ALL in Table 2.

The long-run consequences of pollution control for different industries are presented in Figure 10. The sectors hit hardest by environmental regulations are the motor vehicles and coal-mining industries. Primary metals and petroleum refining follow close behind. About half of the remaining industries have increases in output of 1% to 5% after pollution controls are removed. The rest are largely unaffected by environmental regulations. The economy follows the transition path to the new steady state shown in Figure 11. Driven by large changes in the price of investment goods, the capital stock rises sharply. The quantity of full consumption rises at a similar rate, as does real GNP. The adjustment process is dominated by the rapid accumulation of capital and is largely complete within two decades.

FIGURE 10

THE EFFECTS OF REMOVING ALL ENVIRONMENTAL REGULATION ON INDUSTRIES

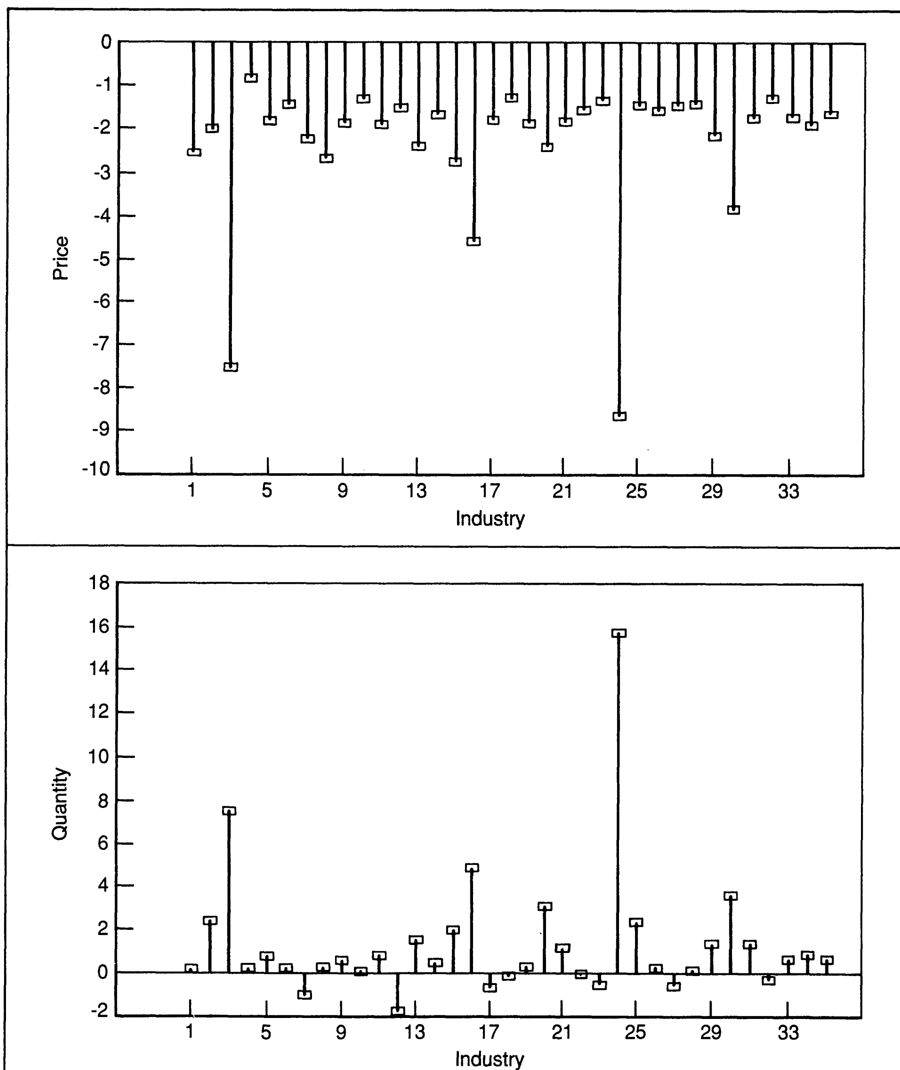
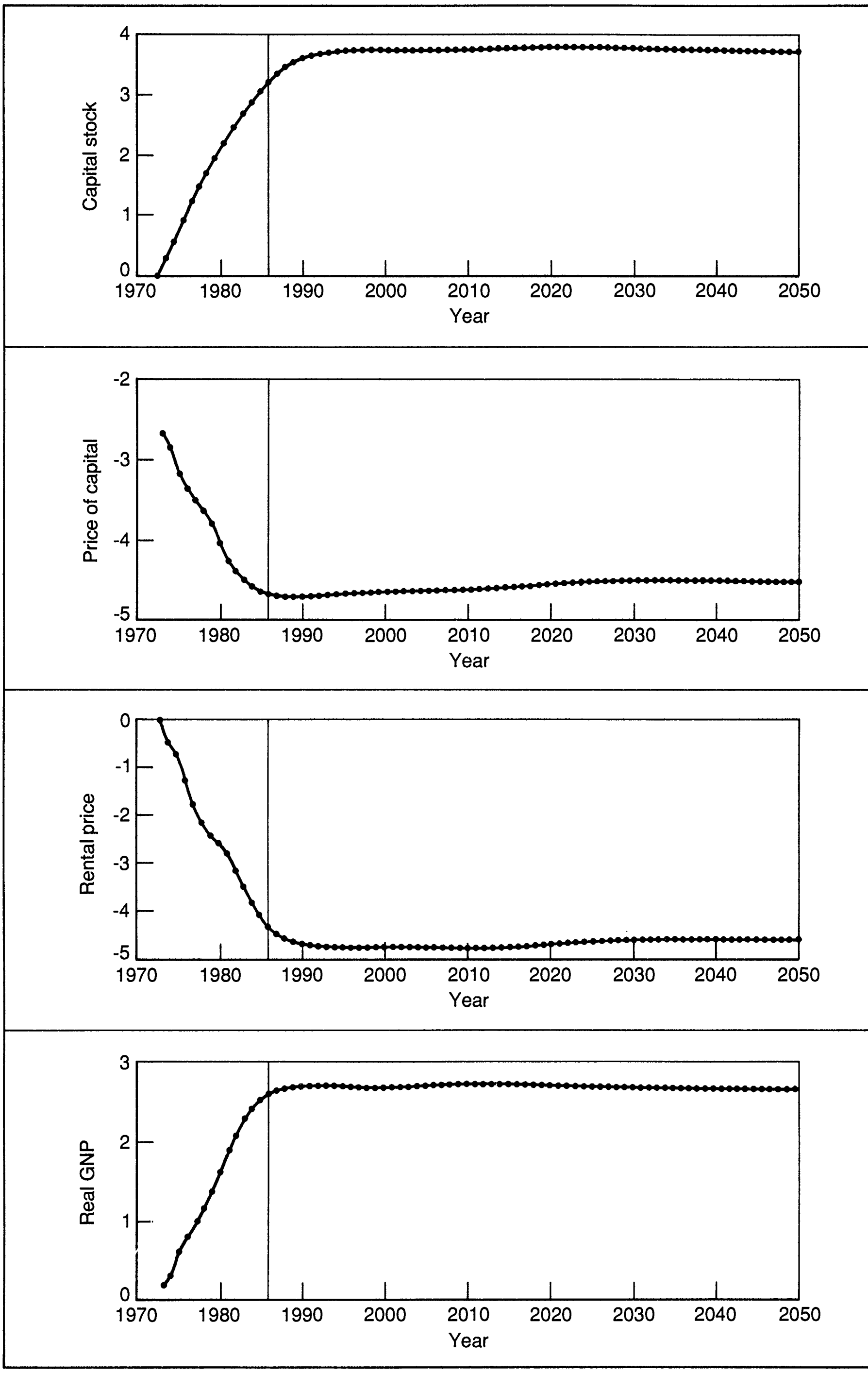


FIGURE 11

THE DYNAMIC EFFECTS OF REMOVING ALL ENVIRONMENTAL REGULATION



4. Conclusions

■ We can summarize the impact of environmental regulation by analyzing the effects on the growth of GNP over the period 1973–1985. These effects are given in Table 3. Mandated

TABLE 3 **Summary of the Effects on Growth over 1974–1985**

Simulation	Change in Growth Rate
Operating Costs	.034
Investment	.074
Old Source Investment	.026
Motor Vehicles	.051
All Effects	.191

investment in pollution control equipment has the largest impact, while motor vehicle emissions control is not far behind. The added operating costs due to pollution abatement play a minor role in the growth slowdown. The three types of environmental regulation together are responsible for a drop in GNP growth of .191 percentage points.

A number of studies have attempted to measure the effect of pollution control on productivity and economic growth.[18] For example, Denison (1985) found that the growth rate of the U.S. economy was reduced by only .07 percentage points over the period 1973–1982 due to pollution controls. His estimate is based on an aggregate production function and does not take into account the important differences in environmental restrictions among industries. In addition, Denison did not model the dynamic response of the U.S. economy to pollution controls. Our model incorporates differences among industries in pollution abatement and captures the effect of environmental costs on the rate of capital formation. Accordingly, our estimate of the impact of environmental regulation on U.S. economic growth is several times that reported by Denison.

We can also summarize the impact of higher operating costs associated with environmental regulation on economic growth, using the results given in Table 3. U.S. economic growth would have been .034 percentage points higher during the period 1973–1985 in the absence of the operating costs resulting from environmental regulation. These operating costs had a small but significant effect on long-run output and the rate of growth of the economy in the 1970s and early 1980s. In addition, these costs affected the distribution of economic activity with industries such as primary metals experiencing a considerable drop in output. However, operating costs arising from pollution abatement are not the only effects of environmental regulation.

The impact of pollution abatement investment on the rate of GNP growth during the period 1973–1985 is also given in Table 3. The growth of GNP would have been .074 percentage points higher in the absence of mandated investment in pollution control. Slower productivity growth contributed .015 percentage points to this total, while the rest came from slower growth of the primary factors of production. Mandated investment in pollution control had two effects. First, it lowered the long-run capital stock and reduced long-run consumption. Second, it reduced the rate of capital accumulation in the early years of regulation. This reduced the rate of growth of GNP. The impact of eliminating mandated investment in pollution abatement devices was substantially larger than that of eliminating operating costs.

The dampening effect of investment for pollution control on capital accumulation is exacerbated by the investment required to bring existing sources of emissions into compliance with environmental standards. We have taken the share of investment attributable to new investment goods as the 1983 share. The difference between the actual shares in earlier years

[18] A detailed survey of studies of the impact of environmental regulation on productivity and economic growth in the United States is presented in Christiansen and Tietenberg (1985).

and the 1983 share gives the proportion devoted to existing sources of emssions. The data presented in Figure 6 show that this expenditure reached as much as 3% of total investment during the mid-1970s.

We modified our simulation of U.S. economic growth to assess the importance of mandated investment in pollution abatement equipment for existing sources of emissions. For this purpose, we increased the level of investment expenditures for the years 1973 to 1983 by the share attributable to pollution abatement for existing sources. This raises the rate of capital accumulation for the mid-1970s, but there is no long-run effect on economic growth. Eliminating investment in pollution control devices for both new and existing sources raises the average rate of growth for the period 1973–1985 by .100 percentage points. We estimated an increase in the growth rate of .074 percentage points for the investment required for new sources alone, so we can attribute an increase of .026 points to the investment required to bring existing sources into compliance.

Finally, the rate of growth of the U.S. national product over the period 1973–1985 would have been .051 percentage points higher in the absence of motor vehicle emissions controls. This is a surprisingly large effect. It is nearly twice as large as the gain from eliminating mandatory investments for bringing existing sources of emissions into compliance with environmental standards and about half as large as removing all operating costs and all investment requirements for pollution control in industry.

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