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ENVIRONMENTAL REGULATION

AND U.S. ECONOMIC GROWTH

Dale W. Jorgenson
and
Peter J. Wilcoxen

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ENVIRONMENTAL REGULATION AND U.S. ECONOMIC GROWTH

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EXECUTIVE SUMMARY

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 1970's and 1980's. Real output grew at an average annual rate of 3.7 percent during the period 1947-1973. By contrast the growth rate from 1973 to 1985 was only 2.5 percent, 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 of pollution abatement costs and economic growth.

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. The consequence of this legislation was a large and abrupt shift of economic resources toward pollution abatement.

The longest time series of data on environmental costs in industry, published by McGraw-Hill Economics (1986), shows that spending on pollution abatement was insignificant in 1967, but grew vigorously from 1968 to 1978. Much of this increase in spending was required to bring existing facilities into compliance with the new regulations. Since 1978 the growth of pollution abatement costs has leveled off, while the proportion of investment devoted to pollution control devices has declined substantially.

The possible responses of producers to new environmental regulations fall into three dif-

ferent categories -- substitution of less polluting products for more polluting ones, investment in pollution abatement devices to clean up waste, and changes in production processes to reduce emissions. Switching toward cleaner inputs is the least disruptive of these responses, since it does not require a re-organization of the production process. A prime example is the substitution of low-sulfur coal for high sulfur-coal by electric utilities during the 1970's to comply with restrictions on sulfur dioxide emissions. Another important example is the shift from leaded to unleaded fuels to assist in cleaning up motor vehicles emissions.

A 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 emission of particulates from combustion. The regulations promulgated in the United States by the Environmental Protection Agency encouraged the use of this approach by setting standards for emissions on the basis of "best available technology". As Freeman (1978) has noted, producers often responded by installing precisely the equipment specified by the Agency, even through the regulations were based on emissions levels rather than specific pollution control devices.

The substitution of more costly but less polluting inputs or undertaking investments in end-of-pipe abatement will raise an industry's total costs. The costs of retrofitting existing facilities will be capitalized immediately, resulting in a windfall loss to owners of capital when the new regulations are introduced. Additional investments required to meet environmental standards will bid up the price of investment goods and divert resources from the accumulation of other forms of capital. Future behavior of the industry will only be affected by changes in the marginal costs of using existing facilities or changes in the costs of controlling new sources of pollution.

Process changes involve redesigning production methods to reduce emissions. An example would be the introduction of fluidized bed technology for combustion, which results

in reduced emissions. Gollop and Roberts (1983) have constructed a detailed econometric model of electric utility firms, based on a cost function that incorporates the impact of environmental regulation on the rate of productivity growth. They conclude that annual productivity growth of electric utilities impacted by more restrictive emissions controls declined by .59 percentage points over the period 1974-1979. This is the result of switching to new technologies as a consequence of 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 term growth We show that pollution abatement has emerged as a major claimant on the resources of the U.S. economy. The cost of environmental regulation is a long run reduction of 2.59 percent in the level of the U.S. gross national product. This is more than ten percent of the share of total government purchases of goods and services in the national product during the period 1973-1985.

Since the impact of pollution control differs substantially among industries, we have also assessed the impact of environmental regulation on individual industries. We find that pollution controls have had their most pronounced effects on chemicals, coal mining, motor vehicles, and primary processing industries, such as petroleum refining, primary metals, and pulp and paper. We have analyzed the interactions among industries in order to quantify the full repercussions of environmental regulations. We find that the long run output of the automobile industry has been reduced by fifteen percent, mainly as a consequence of motor vehicle emissions controls. The long run output of the coal industry has been reduced by almost eight percent, primarily by cost increases resulting from restrictions on sulfur dioxide emissions.

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ENVIRONMENTAL REGULATION AND U.S. ECONOMIC GROWTH

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Dale W. Jorgenson and Peter J. Wilcoxen[1]

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 1970's and 1980's. Real output grew at an average annual rate of 3.7 percent during the period 1947-1973. By contrast the growth rate from 1973 to 1985 was only 2.5 percent, 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 of pollution abatement costs and economic growth.

We begin with the usual disclaimer in economic studies of the costs of environmental regulation. We have not attempted to assess the benefits resulting from a cleaner environment.[2] The conclusions of this study cannot be taken to imply that pollution control is too burdensome or, for that matter, insufficiently restrictive. Recent heightening of environmental concern suggests that there is substantial political support for further restrictions on pollution. It is obviously important to quantify the costs of environmental regulation. We compare these costs with those of governmentally mandated activities that are financed directly from the government budget.

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.

[1] We are deeply indebted to Mun Sing Ho for his work on the model presented in this paper and to Richard Goettle and Edward Hudson for their collaboration on an earlier phase of the research. Barbara Fraumeni, Daekeun Park, and Daniel Slesnick generously provided essential data. We are grateful to Lawrence Goulder and William Hogan for many useful comments on an initial draft of this paper. Needless to say, we alone are responsible for any remaining deficiencies.

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

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.[3] The consequence of this legislation was a large and abrupt shift of economic resources toward pollution abatement.

The longest time series of data on environmental costs in industry, published by McGraw-Hill Economics (1986), shows that spending on pollution abatement was insignificant in 1967, but grew vigorously from 1968 to 1978. Much of this increase in spending was required to bring existing facilities into compliance with the new regulations. Since 1978 the growth of pollution abatement costs has leveled off, while the proportion of investment devoted to pollution control devices has declined substantially.

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

A 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 emission of particulates from combustion. The regulations promulgated in the United States by the Environmental Protection Agency encouraged the use of this approach by setting stan-

[3] A more detailed survey of U.S. environmental policy is presented by Christiansen and Tietenberg (1985).

dards for emissions on the basis of "best available technology". As Freeman (1978) has noted, producers often responded by installing precisely the equipment specified by the Agency, even through the regulations were based on emissions levels rather than specific pollution control devices.

The substitution of more costly but less polluting inputs or undertaking investments in end-of-pipe abatement will raise an industry's total costs. The costs of retrofitting existing facilities will be capitalized immediately, resulting in a windfall loss to owners of capital when the new regulations are introduced. Additional investments required to meet environmental standards will bid up the price of investment goods and divert resources from the accumulation of other forms of capital. Future behavior of the industry will only be affected by changes in the marginal costs of using existing facilities or changes in the costs of controlling new sources of pollution.

Process changes involve redesigning production methods to reduce emissions. An example would be the introduction of fluidized bed technology for combustion, which results in reduced emissions. Gollop and Roberts (1983) have constructed a detailed econometric model of electric utility firms, based on a cost function that incorporates the impact of environmental regulation on the rate of productivity growth. They conclude that annual productivity growth of electric utilities impacted by more restrictive emissions controls declined by .59 percentage points over the period 1974-1979. This is the result of switching to new technologies as a consequence of 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 term growth. Before considering the impact of specific pollution controls we present an overview of this 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 cost of environmental regulation is a long run reduction of 2.59 percent in the level of the U.S. gross national product. This is more than ten percent 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 percent. This is several times the reduction in growth estimated in previous studies based on growth accounting. Earlier estimates have overlooked the important role of reduced capital formation in the long term impact of environmental regulation.

Since the impact of pollution control differs substantially among industries, we have also assessed the impact of environmental regulation on individual industries. We find that pollution controls have had their most pronounced effects on chemicals, coal mining, motor vehicles, and primary processing industries, such as petroleum refining, primary metals, and pulp and paper. We have analyzed the interactions among industries in order to quantify the full repercussions of environmental regulations. We find that the long run output of the automobile industry has been reduced by fifteen percent, mainly as a consequence of motor vehicle emissions controls. The long run output of the coal industry has been reduced by almost eight percent, primarily by cost increases resulting from restrictions on sulfur dioxide emissions.

2. AN OVERVIEW OF THE MODEL

We first divide the U.S. economy into business, household, government, and rest of the world sectors. Since environmental regulations differ substantially among industries, we sub-divide the business sector into the thirty-five industries listed in Table 2.1. These industries correspond approximately to two-digit industry groups in the Standard Industrial Classification. Each industry produces a primary product, the commodity group in which the industry is predominant. Industries also produce secondary products, which are the primary products of other industries. Thirty-five commodity groups are represented in our model, each corresponding to the primary product of one of the industries listed in Table 2.1.

The total supply of each commodity group is provided by domestic production and imports from the rest of the world. This supply is allocated between intermediate and final demands. Intermediate demands are inputs of the commodity into all thirty-five industries. Final demands are 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 are commodities that are not produced domestically. In the model these imports are allocated to intermediate and final demands in the same way as capital and labor services.

To implement our model we have constructed a consistent time series of inter-industry transactions tables for the U.S. economy, covering the period 1947-1985 on an annual basis.[4] 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, are allocated to intermediate and final demands in

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

Table 2.1: 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 manufactures
9	Textile mill products
10	Apparel and other textile products
11	Lumber and wood products
12	Furniture and fixtures
13	Paper and allied products
14	Printing and publishing
15	Chemicals and allied products
16	Petroleum refining
17	Rubber and plastic products
18	Leather and leather products
19	Stone, clay and glass products
20	Primary metals
21	Fabricated metal products
22	Machinery, except electrical
23	Electrical machinery
24	Motor vehicles
25	Other transportation equipment
26	Instruments
27	Miscellaneous manufacturing
28	Transportation and warehousing
29	Communication
30	Electric utilities
31	Gas utilities
32	Trade
33	Finance, insurance and real estate
34	Other services
35	Government enterprises

a "use" table. The quantities of each commodity made by each industry are given in a "make" table. The "use" and "make" tables are presented diagrammatically in Figures 2.1 and 2.2; Table 2.2 provides definitions of the variables that occur in both tables.

2.1. Producer Behavior. The first problem in modeling producer behavior is to represent substitution among inputs. For this purpose we have constructed systems of demand functions for all inputs into each industry. 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.

To simplify the representation of producer behavior we have utilized a hierarchical tier structure in which substitution among capital, labor, energy, and materials inputs is modeled at highest level. Energy and materials inputs are two subaggregates in a tier structure for each industry that includes output and twelve input subaggregates. Substitution at all levels of this tier structure is characterized by parameters that are estimated econometrically. Modeling substitution in this way rules out the conventional separation of inputs between primary factors of production that produce value added and intermediate goods that combine with value added to produce marketable output. This modeling strategy also requires an econometric methodology that is sufficiently flexible to deal with substitution between more than two groups of inputs.[5]

The econometric approach to modeling producer behavior is very demanding in terms of data requirements. An alternative approach is to characterize substitution among inputs by calibration from a single data point.[6] For example, almost all applied general equilibrium

[5] This rules out the assumption of constant elasticities of substitution often used in modeling substitution between capital and labor inputs. For further discussion of the econometric methodology, see Jorgenson (1986).

[6] The calibration approach is discussed by Mansur and Whalley (1984). This approach is employed by Borges and Goulder (1984) in a model for 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 by Jorgenson (1982).

Figure C.1: Organization of the Use Table

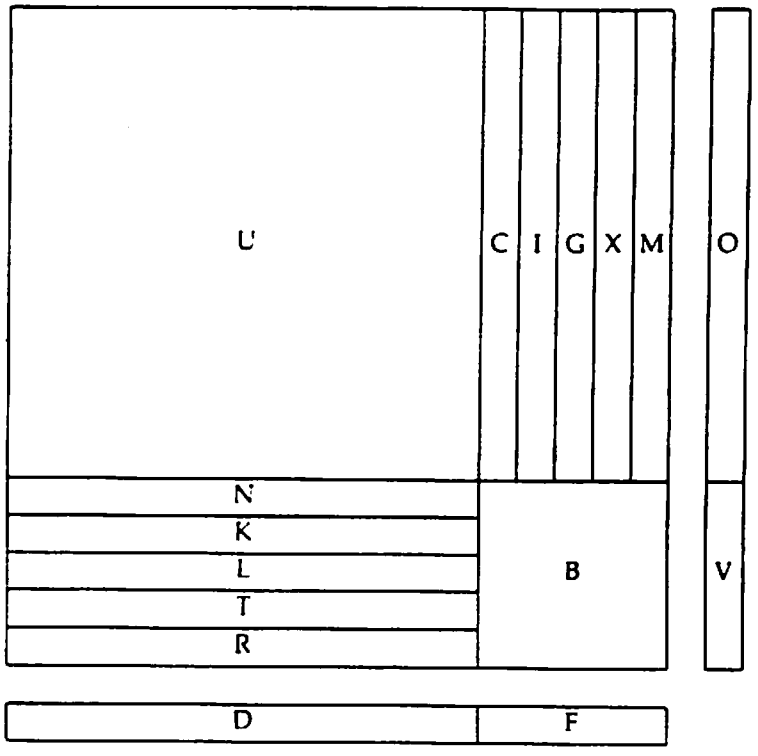


Figure C.2: Organization of the Make Table

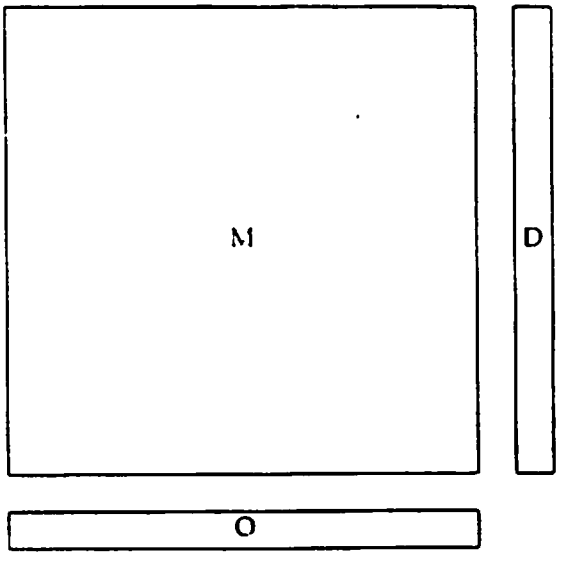


Table C.1: Make and Use Table Variables

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

models employ the assumption of fixed "input-output" coefficients for intermediate goods, following the specification originated by Johansen (1960).[7] 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 2.1. However, the possibility of substitution among intermediate goods, such as energy and materials, is ruled out by assumption.

Empirical evidence on substitutability among inputs is essential in analyzing the impact of environmental regulations. A high degree of substitutability among 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 would avoid the burden of estimation, it would also specify the substitutability among inputs by assumption rather than relying on empirical evidence. This would defeat the main purpose of modeling the impact of environmental policy.

The most important mechanisms for control of 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 price of its output relative to its input prices. Our models of producer behavior incorporate the impact of substitution among inputs on the rate of productivity growth. For this purpose we have made the rate of productivity growth for each industry endogenous.[8]

We can summarize the representation of producer behavior in our model of the U.S. economy in terms of a price function for each of the thirty-five industries. The price of output

[7] Exogenously fixed input-output coefficients are used in determining emissions of pollutants in models presented, for example, by Forsund and Strom (1976), Kneese, Ayres and d'Arge (1970), Leontief (1970), and Ridker and Watson (1980). Forsund and Strom employ the specification of substitution among commodities introduced by Johansen (1960) and utilized in almost all applied general equilibrium models. The materials balance approach introduced by Kneese, Ayres, and d'Arge is considered in a general equilibrium setting by Maler (1974). A detailed survey of fixed coefficient input-output models employed in environmental economics is given by Forsund (1985).

[8] 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).

is a function of prices of capital, labor, energy, and materials inputs. The price function must be homogeneous of degree one, nondecreasing, and concave in the input prices. These restrictions are incorporated into the system of input demand functions for each industry. The endogenous rate of productivity growth in each industry is a function of the four input prices.

Our models of producer behavior are based on two-stage allocation.[9] At the first stage the value of the output of each industry is allocated among four commodity groups – capital, labor, energy, and materials. The price function for the industry is homothetically separable in the prices of commodities within each group. At the second stage the value of each group is allocated among these commodities, utilizing the hierarchical tier structure for each industry. Including the prices of energy and materials, there is a total of twelve prices of subaggregates included in our models of producer behavior. Each of these is a function of the prices of other subaggregates or prices of the thirty-five individual commodities included in the model.[10]

To represent our models of producer behavior we first require some notation. There are thirty-five industrial sectors, indexed by i = 1, 2 ... 35. We denote the quantities of outputs by $\{Z_i\}$ and the quantities of inputs of capital, labor, energy, and materials inputs by $\{K_i, L_i, E_i, M_i\}$. Similarly, we denote the prices of outputs by $\{q_i\}$ and the prices of the four inputs by $\{p_K^i, p_L^i, p_E^i, p_M^i\}$. We define the shares of inputs in the value of output by:

$$v_K^i = \frac{p_K^i K_i}{q_i Z_i}, v_L^i = \frac{p_L^i L_i}{q_i Z_i}, v_E^i = \frac{p_E^i E_i}{q_i Z_i}, v_M^i = \frac{p_M^i M_i}{q_i Z_i}, (i = 1, 2 \cdots 35).$$

In addition, we require the following notation:

$v_i = (v_K^i, v_L^i, v_E^i, v_M^i)$ – vector of value shares of the ith industry.

$\ln p_i = (\ln p_K^i, \ln p_L^i, \ln p_E^i, \ln p_M^i)$ – vector of logarithms of the prices of inputs of the ith industry.

[9] Two-stage allocation in the context of producer behavior is discussed in more detail by Jorgenson (1986).

[10] The tier structure for our models of producer behavior is described in detail by Wilcoxen (1988), Appendix A.

The ith industry allocates the value of its output among the four inputs in accord with the translog price function:

$$\ln q_i = \alpha_0^i + \ln p_i{}' \alpha_p^i + \alpha_t^i g_i(t) + \frac{1}{2}\ln p_i{}' B_{pp}^i \ln p_i + \ln p_i{}' \beta_{pt}^i g_i(t) + \frac{1}{2} g_i(t)^2.$$

In this representation the scalars $\{\alpha_0^i, \alpha_t^i, \beta_{tt}^i\}$, the vectors $\{\alpha_p^i, \beta_{pt}^i\}$, and the matrices $\{B_{pp}^i\}$ are parameters that differ among industries, reflecting differences in technology. The functions of time $\{g_i(t)\}$ incorporate changes in productivity within an industry.

The value shares of the ith industry can be expressed in terms of the logarithmic derivatives of the price function with respect to logarithms of the input prices:

$$v_i = \alpha_p^i + B_{pp}^i \ln p_i + \beta_{pt}^i g_i(t).$$

The parameters $\{B_{pp}^i\}$ can be interpreted as *share elasticities* and represent the degree of substitutability among inputs, while the parameters $\{\beta_{pt}^i\}$ are *biases of productivity growth* and represent the impact of changes in productivity on the value shares of the inputs.[11]

The limiting behavior of the time trends $\{g_i(t)\}$ presents a potential problem for our representation of technology. Unless these functions remain bounded, at least one of the value shares must become negative for sufficiently large values of the time trend.[12] Accordingly, we take these trends to be logistic in form so that:

$$g_i(t) = \frac{1}{1 + e^{-\mu_i(t-\tau_i)}},$$

where the scalars $\{\mu_i, \tau_i\}$ are parameters that differ among industries. In the limit each of these time trends goes to unity, so that the biases of productivity growth $\{\beta_{pt}^i\}$ can simply be added to the constant terms $\{\alpha_p^i\}$.

If levels of productivity were allowed to grow indefinitely, the existence of a steady state solution to our model of the U.S. economy would require that the rates of growth must be the

[11] For further discussion of share elasticities and biases of productivity growth, see Jorgenson (1986).

[12] For example, the time trends were taken to be linear in time $\{g_i(t) = t\}$ in the formulation presented by Jorgenson (1984), so that the trends would not remain bounded.

same in all industries. Otherwise, the industry with the highest rate of productivity growth would eventually come to dominate the economy. We can express the endogenous rates of productivity growth $\{v_t^i\}$ in terms of the logarithmic derivatives of the price functions with respect to time:

$$-v_t^i = (\alpha_t^i + \beta_{pt}^{i\prime} \ln p_i + \beta_{tt}^i g_i(t))\, \dot{g}_i(t).$$

The derivatives $\{\dot{g}_i(t)\}$ go to zero in the limit, so that the level of productivity in each industry approaches a constant. The logistic formulation has the advantage of representing productivity growth during the sample period in a flexible way, while producing long run behavior of the economy that is consistent with the existence of a steady state.

We have described models of producer behavior for the thirty-five industries included in our model of the U.S. economy. These models determine the allocation of the value of the output of each industry among the inputs of the thirty-five commodity groups, capital and labor services, and noncompeting imports given in the "use" table presented in Figure 2.1. Each industry produces a primary product and, possibly, one or more secondary products. The value of each industry's output must be allocated among primary and secondary products, as in the "make" table in Figure 2.2. One approach to modeling the production of primary and secondary products is to consider these products to be jointly produced within each industry.[13]

An alternative approach to modeling the production of individual commodities is to treat the quantities produced by different industries as imperfect substitutes. In this approach the price of each commodity can be treated as a function of the prices of the outputs of all industries that produce the commodity. Our model includes such a price function for each of the thirty-five commodities represented in the model. Using price functions for each industry and each commodity, we can determine prices for the outputs of the thirty-five industries and

[13] For example, this approach is employed for the agricultural sector of the ORANI model by Dixon, Parmenter, Sutton, and Vincent (1982). For further discussion of econometric approaches to joint production, see Jorgenson (1986).

the domestic supplies of the thirty-five commodities.

We also treat imports and domestic production of each commodity as imperfect substitutes.[14] We represent the price for the total supply of each commodity as a function of the price of imports, the price of the commodity produced domestically, and a logistic time trend like that employed in our models for individual industries. We generate value shares for imports and domestic production of each commodity from the price function for total supply. The time trends represent factors other than relative prices that affect the relative value shares. Since the logistic function approaches unity in the limit, these time trends eventually disappear.

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 household sector consumes capital services in the form of housing and consumers' durables. We assume that capital is perfectly malleable and mobile among sectors, so that 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. The supply of capital available in each period is the result of past investment. This relationship is represented in the form of an accumulation equation, giving 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.

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.[15] Our model of the U.S. economy includes this forward-looking relationship for the price of invest-

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

[15] Further details, see Jorgenson (1989).

ment goods in each time period. The price of capital services determined by the model enters into the price of investment goods for earlier periods through the assumption of perfect foresight or rational expectations. Under this assumption the price of investment goods in every period is based on expectations of future capital service prices and discount rates that are fulfilled by the solution of the model.

The final demands for 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 represent the price of investment goods as a function of the prices of commodities accumulated by the business and household sectors, including producers' and consumers' durables, residential and nonresidential structures, and inventories. We generate value shares for all types of investment goods from this price function. These value shares are used to allocate the value of the investment goods among commodity groups, as in the column denoted I in the "use" table, Figure 2.1.

2.2. *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 exhaust emissions of motor vehicles will affect household demands for vehicles and motor fuel. The first problem in modeling consumer behavior is to represent substitution among commodities that are purchased by households. For this purpose we have constructed a system of demand functions for the household sector. As in our models of producer behavior, we identify purchases of energy and capital services separately, since these commodity groups are directly affected by environmental regulation.

To simplify the representation of consumer behavior we have utilized a tier structure like the one employed in our models for individual industries. At the highest level of the tier structure we model substitution among five commodity groups -- energy, food, non-durable goods, capital services, and other services. Substitution within these commodity groups is

modeled in a hierarchical tier structure that incorporates fifteen subaggregates. Substitution at all levels of the tier structure is characterized by parameters that are estimated econometrically.[16]

Households are treated as consuming units in our model of consumer behavior. Each household behaves in the same way as an individual maximizing a utility function. We can summarize the representation of consumer behavior in terms of an indirect utility function for each household. These indirect utility functions must be homogeneous of degree zero in prices faced by the household and total expenditure on all commodities. They must also be nonincreasing in the prices, nondecreasing in total expenditure, and quasi-convex in prices and expenditure.[17] These restrictions are incorporated into the system of demand functions for each household.

Our model of consumer behavior is based on two-stage allocation.[18] At the first stage total expenditure is allocated among five commodity groups. The indirect utility function that underlies the two-stage allocation process is homothetically separable in the prices of the commodities within each group. In the second stage total expenditure on each group is allocated among these commodities, utilizing the hierarchical tier structure. The prices of fifteen subaggregates are included in our model of consumer behavior. Each of these is a function of the prices of subaggregates or prices of individual commodities represented in the model.[19] These price functions are analogous to those included in our models of producer behavior.

To represent our model of consumer behavior we require some additional notation. First, there are J households, indexed by $j = 1, 2 \ldots J$. The number of households varies over the sample period, 1947-1985, but is approximately one hundred million at the end of the period. There are five commodity groups included in personal consumption expenditures,

[16] 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 (1987a).

[17] For further discussion of the econometric methodology, see Jorgenson (1984).

[18] Two-stage allocation in the context of consumer behavior is discussed in more detail by Jorgenson, Slesnick, and Stoker (1988).

[19] The tier structure for our model of consumer behavior is described in detail by Wilcoxen (1988), Appendix A.

indexed by n = 1, 2 ... 5. The price of the nth commodity group is denoted p_n, assumed to be the same for all households. The quantity of the nth commodity group demanded by the jth household is denoted x_{nj}. Finally, to allow for differences in preferences among households, the indirect utility function depends on a vector of attributes of the jth household A_j.

We require the following additional notation:

$p = (p_1, p_2 \cdots p_5)$ – the vector of prices of all commodity groups.

$Y_j = \sum_{n=1}^{5} p_n x_{nj}$ – total expenditure of the jth consumer.

$w_{nj} = p_n x_{nj}/Y_j$ – expenditure shares of the nth commodity group in the budget of the jth household.

$w_j = (w_{1j}, w_{2j} \cdots w_{5j})$ – vector of expenditure shares for the jth household.

$\ln(p/Y_j) = (\ln(p_1/Y_j), \ln(p_2/Y_j) \cdots \ln(p_5/Y_j))$ – vector of logarithms of ratios of prices to expenditure by the jth household.

$\ln p = (\ln p_1, \ln p_2 \cdots \ln p_5)$ – vector of logarithms of prices.

The jth household allocates its total expenditure among the five commodity aggregates at the top tier of our model of consumer behavior in accord with the translog indirect utility function:

$$\ln U_j = \ln(\frac{p}{Y_j})' \alpha_p + \frac{1}{2}\ln(\frac{p}{Y_j})' B_{pp} \ln\frac{p}{Y_j} + \ln(\frac{p}{Y_j})' B_{pA} A_j, \quad (j=1, 2 \cdots J).$$

In this representation the vector α_p and the matrices B_{pp} and B_{pA} are constant parameters that are the same for all households. The vectors of attributes A_j incorporate differences in preferences among households. The elements of these vectors are one-zero dummy variables that classify households by the following demographic characteristics: family size, age of head, region of residence, race, and urban versus rural. Cross-classifying households by these characteristics, we can distinguish a total of 672 household types.

The expenditure shares of the jth household can be derived from the logarithmic form of Roy's identity:

$$w_j = \frac{1}{B_j}(\alpha_p + B_{pp} \ln\frac{p}{Y_j} + B_{pA} A_j), \qquad (j=1, 2 \cdots J),$$

where the denominators $\{B_j\}$ take the form:

$$B_j = \iota'\alpha_p + \iota' B_{pp} \ln\frac{p}{Y_j} + \iota' B_{pA} A_j, \qquad (j=1, 2 \cdots J),$$

and ι is a vector of ones.

To derive a model of aggregate consumer behavior we assume that aggregate demand functions can constructed from individual demand functions by exact aggregation.[20] This implies that individual expenditure shares are linear in functions of the attributes $\{A_j\}$ and total expenditure $\{Y_j\}$ that vary among households. These conditions will be satisfied if and only if the terms involving the attributes and expenditures do not appear in the denominators of the individual expenditure shares, so that:

$$\iota' B_{pp} \iota = 0,$$
$$\iota' B_{pA} = 0.$$

In addition, we find it convenient to employ the normalization:

$$\iota'\alpha_p = -1.$$

Under this restriction any change in the parameters will be reflected in a change in the individual expenditure shares.

The exact aggregation restrictions and the normalization given above imply that the denominators $\{B_j\}$ reduce to:

$$B = -1 + \iota' B_{pp} \ln p,$$

where the subscript j is no longer required, since the denominator is the same for all commodities and all households. Under these restrictions the individual expenditure shares can be written:

$$w_j = \frac{1}{B}(\alpha_p + B_{pp} \ln p - B_{pp} \iota \ln Y_j + B_{pA} A_j), \; (j=1, 2 \cdots J).$$

[20] For further discussion of exact aggregation, see Jorgenson, Lau and Stoker (1982) and Lau (1982).

The individual expenditure shares are linear in the logarithms of expenditures $\{\ln Y_j\}$ and the attributes $\{A_j\}$, as required for exact aggregation.

Aggregate expenditure shares, say w, are obtained by multiplying the individual expenditure shares by total expenditure for each household $\{Y_j\}$, adding over all households and dividing by aggregate expenditure $\sum Y_j$:

$$w = \frac{1}{B}(\alpha_p + B_{pp} \ln p - B_{pp}\iota \frac{\sum Y_j \ln Y_j}{\sum Y_j} + B_{pA} \frac{\sum Y_j A_j}{\sum Y_j}).$$

The parameters of the system of aggregate demand functions are precisely the same as those of the household demand functions. The parameters B_{pp} represent the degree of substitutability among commodity groups within the household sector, while the parameters B_{pA} reflect changes in the demographic composition of the population and variations in relative expenditure levels for different demographic groups. Under homogeneity of degree zero the parameters $B_{pp}\iota$ represent the impact of changes in the level of aggregate expenditure and its distribution among households.

Unless preferences are homothetic, so that the parameters $B_{pp}\iota$ are all zero, the composition of personal consumption expenditures varies with the level of aggregate expenditure and its distribution. Even if the distribution is fixed, at least one of the expenditure shares must become negative for a sufficiently large value of aggregate expenditure. Under our assumption that levels of productivity become constant for all industries, expenditure per capita approaches an upper limit. Our projections of the future population of the U.S. converge to a stationary level, so that aggregate expenditure approaches a constant level in a steady state of the economy.[21]

We have described a model for the allocation of 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

[21] Projections of the population and the long run behavior of the economy are discussed in greater detail in Section 2.3 below.

given in the column denoted C in the "use" table, Figure 2.1. Our model of personal consumption expenditures can be used to represent the behavior of individual households, as in the studies of regulatory policy for petroleum and natural gas by Jorgenson and Slesnick (1985, 1987b). 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 imbed this model of personal consumption expenditures into a higher-level model that determines consumer choices between labor and leisure and between consumption and saving.

In our model of the U.S. economy there is a single time endowment that is exogenously given. The time available from the U.S. population grew substantially during our sample period, 1947-1985. For later periods we project the future growth of the U.S. population and transform the results into a projection of the time endowment. In each period this endowment is divided between leisure time and the labor market. Labor market time is allocated among the thirty-five industries represented in the model. In addition, labor services are included in final demands for personal consumption expenditures and public consumption. We assume that labor is perfectly mobile among sectors, so that the price of labor services in each sector is proportional to a single wage rate for the economy as a whole.

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. The price of leisure time is equal to the market wage rate, reduced by the marginal tax rate on labor income. This price 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.[22] We greatly simplify 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 consump-

[22] The cost of living index corresponding to the indirect utility function employed in our model for personal consumption expenditures is discussed by Jorgenson and Slesnick (1983).

tion expenditures and leisure time. This produces an allocation of the exogenously given time endowment between leisure time and the labor market. The value of time allocated to the labor market is equal to labor income.

Using the representative consumer model, we take the price of full consumption to be a function of the price of leisure time, the cost of living index, and a logistic time trend like the one employed in our models of producer behavior. We generate value shares for leisure time and personal consumption expenditures from the price function for full consumption. The time trend represents factors other than relative prices that affect the value shares. An example is the entry into the labor market of a much higher proportion of females in the U.S. population toward the end of our sample period. The time trend disappears in the limit, as in our models of producer behavior.

Our third and final stage of our model of the household sector is a model of intertemporal consumer behavior. We describe 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 this 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.[23]

The Euler equation for full consumption is forward-looking, so that 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 for earlier periods through the assumption of perfect foresight or

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

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.

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

The dynamics of adjustments to changes in environmental policy are determined by the intertemporal features our model of the U.S. economy. These features are crucial to modeling the impact of environmental policy. For example, investment in equipment for pollution abatement has been a very substantial proportion of investment in producers' durable equipment during parts of our sample period, 1947-1985. This mandated investment has increased the price of investment goods, thereby requiring adjustments of capital service prices and discount rates over the future time path of the economy. Reductions in investment for capital accumulation have reduced the capital available for production in subsequent time periods. Environmental policy affects another important determinant of the dynamics of our model through the impact of relative prices on productivity growth. This effect disappears in the long run, but is very important during a period of approximately two decades after changes in environmental policy have taken place.

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 outputs of the thirty-five industries represented in the model. The output prices are determined from the price func-

tions for these industries. Given these prices, the price functions for the thirty-five commodities included in the model determine the domestic supply prices for these commodities. Finally, the domestic supply price is combined with the price of imports to determine the total supply price for each commodity. These commodity prices enter the determination of intermediate demands by industries and final demands by 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 of the U.S. economy, 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 supply of labor services is determined exogenously by the time endowment of the household sector. This time endowment is allocated between the labor market and leisure time by our model of consumer behavior.

The demand side of the intratemporal model can be divided between intermediate and final demands for the thirty-five commodity groups, capital and labor services, and noncompeting imports presented in the "use" table, Figure 2.1. 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 value of output must be equal to the value of input. The value shares determine inputs per unit of output for each industry as functions of the input and output prices. The input-output coefficients for capital and labor services in each industry are multiplied by the output of the industry to obtain the input quantities. These quantities are added over the thirty-five industries to obtain total intermediate demands for capital and labor services.

Input-output coefficients are commonly taken to be exogenous in applied general equili-

brium models. In our intratemporal model the input-output coefficients are determined endogenously. This is critical to our analysis of the impact of environmental policy, since an important objective of environmental regulation is to induce substitution away from polluting products. We combine the input-output coefficients with final demands to determine industry outputs. Final demands can be 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. We next consider the determination of quantities of the thirty-five commodities for each these final demand categories.

Our model of consumer behavior allocates the value of full consumption between the goods and services that make up personal consumption expenditures and leisure time. Given aggregate expenditure on goods and services and its distribution among households, this model allocates personal consumption expenditures among commodity groups, including capital and labor services and noncompeting imports. Given the commodity prices, this allocation determines the quantity of each commodity included in personal consumption expenditures. The value of aggregate expenditure is endogenous, but its distribution among households is exogenous.

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 less personal consumption expenditure and less 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 capital stock in the private sector, claims on 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 are equal to 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 we take the government deficit and the current account balance 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.

We next consider purchases by the government and rest of the world sectors in order to complete the determination of final demands for our model of the U.S. economy. Wherever possible, we have assigned government enterprises to the corresponding industry. For example, we assign 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 are 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 models of producer behavior. Exports to the rest of the world sector are part of final demands.

We determine final demands for public consumption from 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 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 household sector 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 household sector wealth to generate revenues from property and wealth taxes.

We add the capital income of government enterprises, determined endogenously, and

nontax receipts, given exogenously, to tax receipts to obtain total revenues of the government sector. The key assumption of our model of the government sector is that the government budget surplus (or deficit) is given exogenously. We subtract the government budget surplus (or add the government budget deficit) to obtain government expenditures. To arrive at government purchases of goods and services, we subtract interest paid to domestic and foreign holders of government bonds, together with government transfer payments to domestic and foreign recipients. The shares of individual commodity groups in government purchases are taken to be exogenous. We determine the quantity of each commodity included in final demands by the government sector by dividing values of government purchases by the corresponding commodity price.

Exports to the rest of the world are determined by demand equations that depend on world income and ratios of commodity prices in U.S. currency to the exchange rate. 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. 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 is equal to the value of exports less the value of imports, plus interest received on domestic holdings of foreign bonds, less private and government transfers abroad, and less 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 that the exchange rate is endogenous.

To construct a solution to our model of the U.S. economy we first require values of all the exogenous variables. These variables are set equal to their historical values for the sample period, 1947-1985. We project all the exogenous variables for the post-sample period, 1986-2050, and take these variables to be constant at their 2050 values through the year 2100. Since the time trends have converged to constant values by the year 2050, we set the trends equal to these limiting values for the period 2050-2100. For this period functions of time do not appear in the behavioral equations for our models of producer and consumer behavior. The

purpose of holding the exogenous variables constant over the period 2050-2100 is to allow sufficient time for the endogenous variables determined by the model to converge to their stationary values.

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 project 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.[24] In projecting future levels of educational attainment we assume that future demographic cohorts will have the same level of attainment as the cohort reaching age 35 in the year 1985. We transform our population projection into a projection of the time endowment used in our model of the labor market by assuming that the relative wages are constant at 1985 levels for the 2232 population groups distinguished in the model.

Final demand for personal consumption expenditures depends on aggregate expenditure and its distribution among households. The level of aggregate expenditure is determined within our model of consumer behavior, but its distribution among households is exogenous. We project the distribution of households by assigning individuals in our population projections to the 672 household types distinguished in our model of personal consumption expenditures. We assume that the total expenditure relative to aggregate expenditure remains fixed for each household type at its 1985 value, so that our projections of the distribution of aggregate expenditure among households is driven by the distribution of households by type.

Finally, 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 project a gradual decline in the government deficit to the year 2025. After that time this deficit is held at four percent of the nominal value of the government debt. This would have the effect of maintaining a constant ratio of the value of

[24] 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 by Wilcoxen (1988), Appendix B.

the government debt to the value of the national product at a four percent inflation rate in a stationary solution to our model. We set future prices of imports and exports in foreign currency equal to 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 project that the exogenous current account balance for the rest of the world sector will fall gradually to zero by the year 2000. After that time we project a current account surplus sufficient to produce a stock of net claims on foreigners by the year 2050 equal to the same proportion of national wealth as in 1982.

Given the exogenous variables we can divide the construction of a solution to our model into two steps. The first step is to construct a stationary solution of the model. The second step is to construct a transition path from initial conditions at the start of the simulation to the stationary state. We obtain a stationary solution for the model by merging our intertemporal and intratemporal models. Our intertemporal model determines the time path of full consumption consistent with the forward-looking Euler equation from our model of consumer behavior. This model determines the time path of capital stock from the backward-looking accumulation equation.

In the stationary solution to our model both full consumption and capital stock are constant. We determine the stationary rate of return from the Euler equation and the stationary level of investment from the accumulation equation. We then solve the intratemporal model for a stationary price system and production levels for the thirty-five industries included in the model. The stationary solution for our model of the U.S. economy corresponds to constant values of all exogenous variables. We take the stationary solution as our projection of the U.S. economy for the year 2100.

We calculate a transition path to the steady state of our model, beginning with a given initial stock of capital. The computation uses an initial guess of the time path of the value of full consumption. Given the initial stock of capital, we employ the intratemporal model to determine a solution for the first year of the transition path. We utilize the accumulation

equation to produce a new stock of capital for the next year and determine a solution for that year, and so on, until we have a complete time path of the economy to the year 2100. We can determine a discount rate for each year from the equation for the price of capital services. Given the time path of discount rates, we use the Euler equation to obtain a new guess of the time path for full consumption, beginning with the value for 2100 and working backward to the initial period. We re-iterate this procedure until it converges to a solution of our intertemporal model.

The solution of our intratemporal model in every time period is also based on an iterative procedure. This procedure begins with an initial guess of the price of capital services, the value of gross private domestic investment, the value of public consumption, and the exchange rate. Since the supply price of labor is the numeraire for our price system, we can determine a system of prices that balances demand and supply for the thirty-five commodities represented in the model. The initial guess of the price of capital services is adjusted to balance supply and demand, while the initial guesses of investment, public consumption and the exchange rate are adjusted to satisfy the income-expenditure identities for the household, government and rest of the world sectors.

The size of the economy corresponding to the steady state of our model is effectively determined by the stationary time endowment. 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 neo-classical growth model of the Cass-Koopmans type.[25] For example, the rate of return in the stationary solution of our model is independent of environmental policy, just as in a one-sector neo-classical 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.

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

In the short run the supply of capital in our model of the U.S. economy 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 consumption of goods and leisure into the future, so that 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 households. We then estimate the overall impact of environmental regulation by a simulation eliminating both types of pollution control.

We have performed a number of simulations of the U.S. economy in which pollution controls are removed. These simulations differ from the base case in the steady state, the initial equilibrium, and the transition path between the two. Since 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 capital stock fixed gives the short run impact of a change in environmental policy. Since agents 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.

Environmental regulations mandate pollution abatement activities that affect the costs of production for individual industries. In presenting the results of our simulations 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 performance of the economy. For this purpose we focus attention on a few key variables. 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.

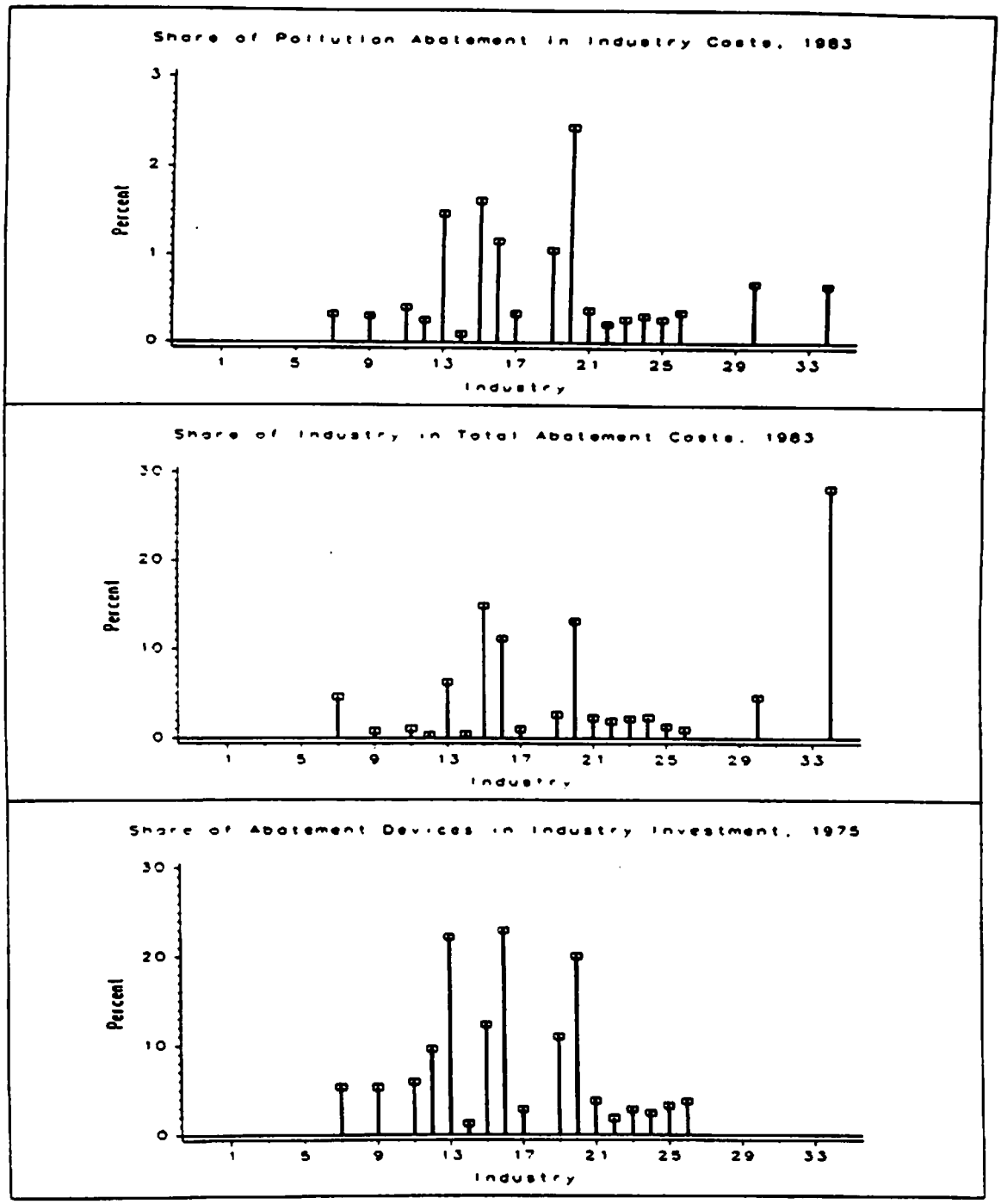
The second step in our analysis of the impact of environmental regulation is to analyze the transition path of the U.S. economy from the initial equilibrium to the new steady state. We describe the time path of capital stock as the most important indicator of the process of economic adjustment to a change 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 reflects the price of investment goods and the rate of return, which is critical to the allocation of the national output between consumption and investment. 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.

3.1. *Operating Costs.* We have used data collected by the Bureau of the Census (various annual issues) to estimate investment in pollution abatement equipment and operating costs of pollution control activities for manufacturing industries.[26] The investment data give capital expenditures on pollution abatement equipment in current prices, while data on operating costs give current outlays attributable to pollution control. 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 nearly 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 paper.

Figure 3.1 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

[26] A detailed description of the data is given by Wilcoxen (1988), Appendix D.

Figure 3.1: The Impact of Environmental Regulation



investment for the manufacturing industries. Inspection of the first panel shows that pollution control expenses form only a small part of total costs for individual industries. The largest share is for the primary metals industry at slightly more than two percent. Second, the expenses for pollution abatement are concentrated in a relatively small number of industries. Three sectors -- chemicals, petroleum refining, and primary metals -- account for fifty-five percent of total spending. Third, investment in pollution abatement equipment consumes more than twenty percent of total investment for paper and pulp, petroleum refining, and primary metals industries.

To simulate the impact of environmental regulation on current costs of production in each industry, we reduce total production costs by the cost of pollution abatement. If sufficient data were available, it would be desirable to develop explicit cost functions for pollution abatement in each industry. However, data on pollution abatement costs broken down by commodity group are unavailable, so that we reduce input costs in the same proportion for all commodities. For example, if electric utilities devoted one percent of total costs in a given year to pollution abatement, then we reduce all costs of the electric utility industry by one percent to reflect the elimination of pollution controls. This is equivalent to assuming that the technology for pollution abatement is identical to the technology for production of output in each industry. The most important advantage of this assumption is that it can be implemented with existing data.

Our 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 estimates presented in Figure 3.1 are tabulated for individual manufacturing industries in Table 3.1. The 1983 cost shares are a maximum for the period, 1973-1983, since pollution controls have increased steadily over the period. 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.[27]

Table 3.1: Percentage of Total Costs Devoted to Abatement in 1983

Sector	Percentage	Sector	Percentage
7	.3	19	1.1
9	.3	20	2.3
11	.4	21	.3
12	.2	22	.2
13	1.6	23	.2
14	.1	24	.3
15	1.6	25	.3
16	1.3	26	.3
17	.3		

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 toward high-sulfur grades. We model the impact of lifting these emissions controls by subtracting the differential between high cost and low cost coal from the costs of coal production.

Including the coal industry, a total of twenty industries is subject to pollution abatement regulations. We have used the share of abatement costs in total costs for each industry to estimate the share of total costs, excluding pollution abatement. We denote the share for the ith industry by $\{\lambda_i\}$. The shares for individual industries subject to environmental regulation are given in Table 3.2 for the years 1973-1983. Since the shares of total costs for pollution abatement had stabilized by 1983, our last available observation, we assume that the shares for later years are constant at the 1983 value.

[27] Details are given by Wilcoxen (1988), Appendix D.

Table 3.2: Values of λ by Industry

Year	Industry									
	3	7	9	11	12	13	14	15	16	17
1973	.9545	.9987	.9988	.9980	.9989	.9938	.9995	.9925	.9906	.9983
1974	.9563	.9988	.9985	.9983	.9988	.9956	.9994	.9941	.9949	.9987
1975	.9695	.9991	.9990	.9989	.9992	.9980	.9996	.9952	.9965	.9985
1976	.9717	.9983	.9985	.9982	.9986	.9938	.9995	.9925	.9931	.9980
1977	.9681	.9983	.9982	.9983	.9986	.9922	.9994	.9912	.9931	.9982
1978	.9631	.9983	.9981	.9985	.9987	.9922	.9994	.9906	.9934	.9982
1979	.9522	.9981	.9980	.9982	.9987	.9921	.9993	.9903	.9946	.9979
1980	.9411	.9982	.9978	.9981	.9986	.9924	.9994	.9903	.9955	.9980
1981	.9440	.9978	.9979	.9971	.9983	.9912	.9993	.9890	.9936	.9977
1982	.9490	.9977	.9977	.9967	.9979	.9886	.9994	.9863	.9912	.9980
1983	.9506	.9968	.9969	.9959	.9975	.9852	.9991	.9837	.9883	.9967

Year	Industry									
	19	20	21	22	23	24	25	26	30	34
1973	.9957	.9933	.9987	.9992	.9989	.9989	.9990	.9988	.9956	.9950
1974	.9961	.9952	.9986	.9992	.9990	.9986	.9991	.9987	.9952	.9945
1975	.9978	.9958	.9989	.9993	.9991	.9990	.9992	.9988	.9943	.9942
1976	.9959	.9918	.9985	.9990	.9988	.9987	.9974	.9987	.9942	.9940
1977	.9958	.9904	.9983	.9990	.9988	.9987	.9987	.9986	.9939	.9938
1978	.9960	.9905	.9984	.9990	.9987	.9986	.9988	.9985	.9938	.9937
1979	.9957	.9904	.9982	.9989	.9987	.9983	.9990	.9986	.9939	.9937
1980	.9950	.9887	.9982	.9989	.9985	.9974	.9988	.9985	.9943	.9936
1981	.9941	.9863	.9980	.9988	.9982	.9972	.9986	.9981	.9947	.9935
1982	.9926	.9811	.9977	.9986	.9980	.9969	.9985	.9982	.9947	.9933
1983	.9893	.9755	.9963	.9978	.9973	.9960	.9973	.9965	.9931	.9934

To simulate the effect of eliminating the operating costs associated with pollution controls for all industries we insert the cost shares $\{\lambda_i\}$ presented in Table 3.2 into the cost functions for these industries. More precisely, we modify the translog price functions as follows:

$$\ln q_i = \ln\lambda_i + \alpha_0^i + \ln p_i{}' \alpha_p^i + \alpha_t^i g_i(t) + \frac{1}{2}\ln p_i{}' B_{pp}^i \ln p_i + \ln p_i{}' \beta_{pt}^i g_i(t) + \frac{1}{2} g_i(t)^2.$$

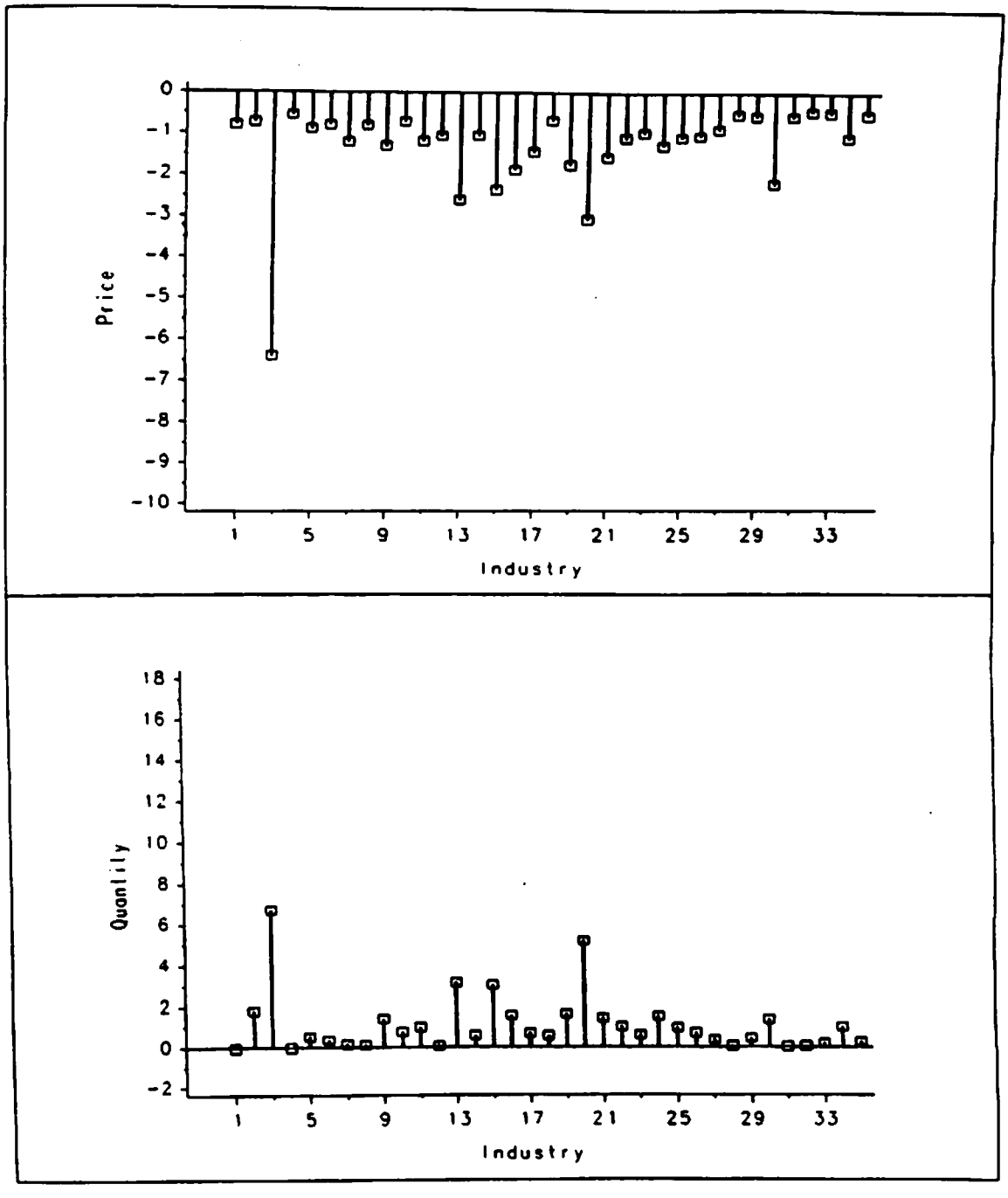
This has the effect of excluding operating costs associated with pollution control from total costs in each industry.

The long run impact of eliminating the operating costs of pollution abatement is summarized in Table 3.5 below. The output of the economy, as measured by the real gross national product, is raised by .728 percent. The capital stock rises by .544 percent. Since our model of the U.S. economy 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 percent. The price of capital services declines by .907 percent, almost the same proportionate decline as in the price of investment goods. The resulting decrease in the prices of goods and services produces a rise in full consumption of .278 percent. This increase is less than that of the national product, since full consumption includes leisure time as well as personal consumption expenditures. Finally, the exchange rate, which gives the domestic cost of foreign goods, falls slightly, indicating an increase in the international competitiveness of the U.S. economy.[28]

The long run effects of eliminating operating costs associated with pollution abatement on the prices and outputs of individual industries are shown in Figure 3.2. 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 percentage changes in industry output levels. Not surprisingly, the principal beneficiaries of the elimination of operating costs turn out to be 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

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

Figure 3.2: The Effects of Removing Abatement Costs on Industries



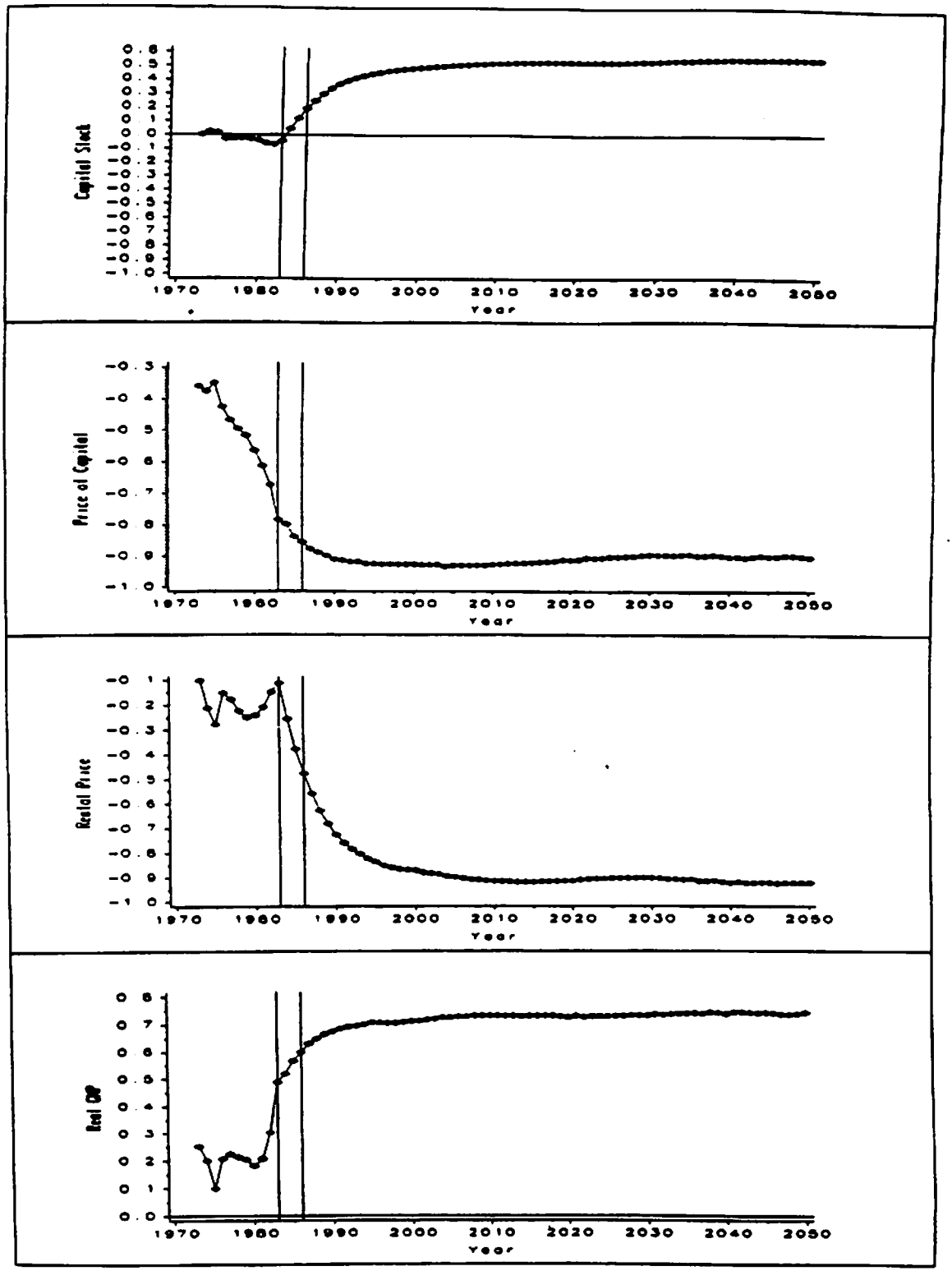
relative to the total costs of the coal industry. Turning to manufacturing industries, the primary metals, paper, and chemicals industries have the largest gains in output from the elimination of operating costs for pollution abatement. Several other sectors benefit from the removal of operating costs 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. In Figure 3.3 we analyze the dynamics of the process of adjustment 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 capital stock and the price of capital services to adjust fully to the change in environmental policy. The graph of 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 that 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, consumption rises in anticipation. However, the rise of consumption is dampened by an increase in the rate of return that produces greater investment.

3.2. *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 study the impact of investment for pollution control. An examination of the data on investment presented in Fig-

Figure 3.3: The Dynamic Effects of Removing Abatement Costs



ure 3.1 reveals several striking features. First, the paper, petroleum refining, and primary metals industries each spent more than twenty percent of their total investment on pollution control devices in 1975. Other sectors were not far behind and the share of this investment in gross private domestic investment was also high, as shown in Figure 3.4.

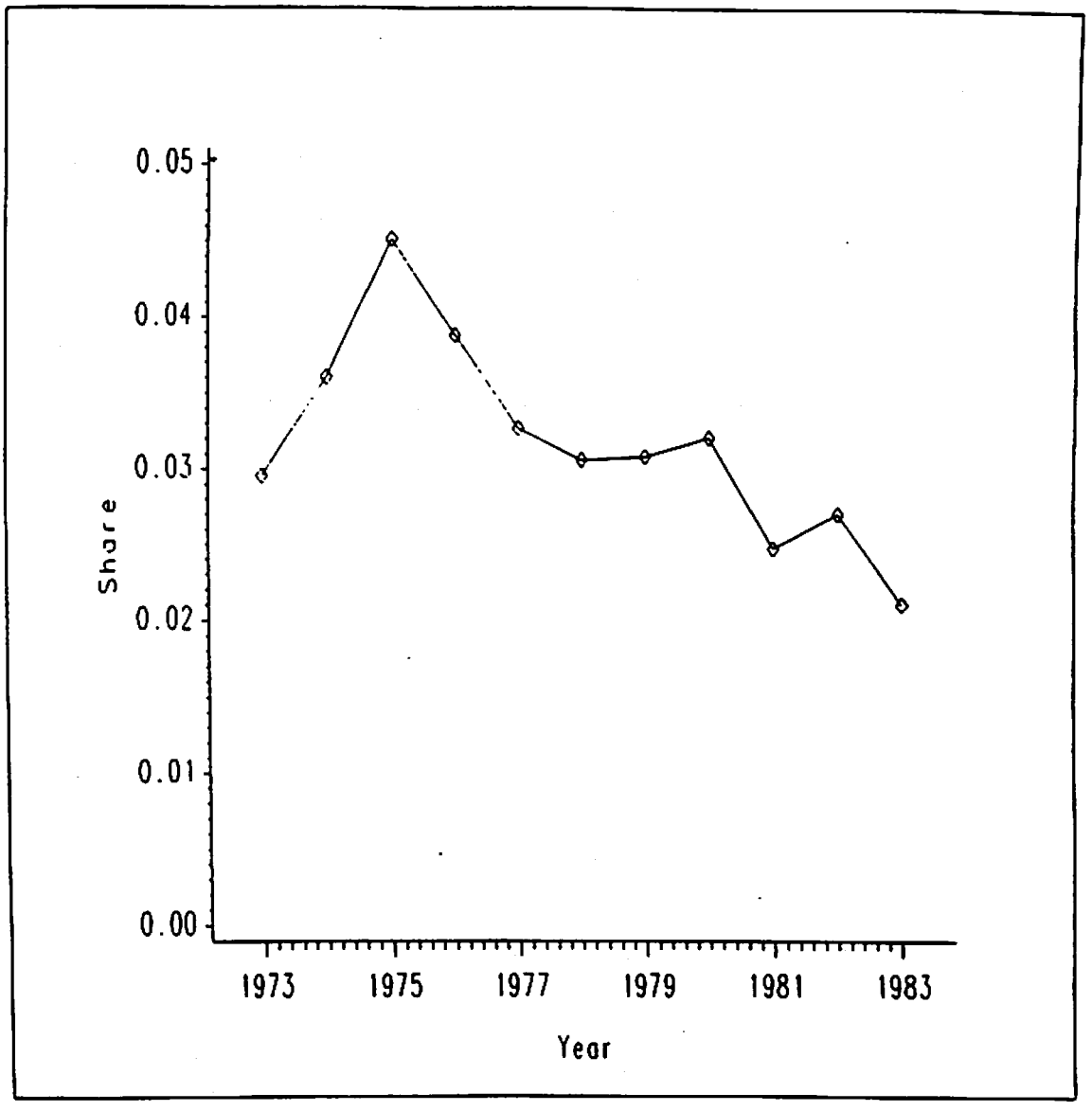
The data given in Figure 3.1 bring out another important feature of environmental regulation. The level of investment for pollution abatement rose to a peak in the early 1970's and then declined substantially. This can be attributed to the fact that much of the early effort at pollution control was directed at reducing emissions from existing sources by retrofitting equipment already in place. The appropriate method for modeling 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 assume 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. In order to estimate the increase in the price of investment goods resulting from pollution abatement we first obtain the value of pollution control investment for all industries. We deduct this value from gross private domestic investment to obtain the value of investment, exclusive of pollution control. Finally, we estimate the ratio of this investment to total investment, parallelling the treatment of operating costs in the preceding section. The resulting estimates are given in Table 3.3.

Table 3.3: Share of Ordinary Capital in Total Investment

Year	Share	Year	Share
1973	0.9704	1979	0.9691
1974	0.9639	1980	0.9679
1975	0.9548	1981	0.9752
1976	0.9612	1982	0.9729
1977	0.9673	1983	0.9789
1978	0.9693		

Figure 3.4: The Share of Abatement Equipment in Total Investment



In simulating the impact of mandated investments in pollution control on U.S. economic growth it is essential to separate windfall losses suffered by owners of existing capital from the higher costs of new investments. The relatively large proportion of investment that can be attributed to environmental regulation in the 1970's is due to the retrofitting of existing facilities to meet new emissions standards. The cost of pollution abatement for these facilities is a windfall loss to the owners of capital, but does not affect the cost of new investment goods. To simulate the removal of environmental regulation only the pollution abatement equipment required for new sources of emissions should be used in estimating the effect on prices of investment goods.

Unfortunately, the existing data do not provide a separation between investments required for new and existing facilities. We assume that the backlog of investment on 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 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. One alternative approach would be to incorporate costs of adjustment into our models of producer behavior. A second alternative would be to model existing capital and new capital separately. Obviously, these extensions would lead to considerable additional complexity in modeling 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. Furthermore, the impact of windfall losses to owners of existing capital disappears in the long run.

The steady state effects of mandated investment in pollution control devices are given in Table 3.5 below. The largest change is in the capital stock, which rises by 2.266 percent 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, raising 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 percent, almost double the increase resulting from eliminating operating costs of pollution abatement. The 1.290 percent rise in GNP is also nearly twice as large. The exchange rate appreciates by .462 percent, 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 3.5. 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 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 3.6. The process of adjustment is markedly different from that of the previous simulation. 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.

Figure 3.5: The Effects of Removing Abatement Investment on Industries

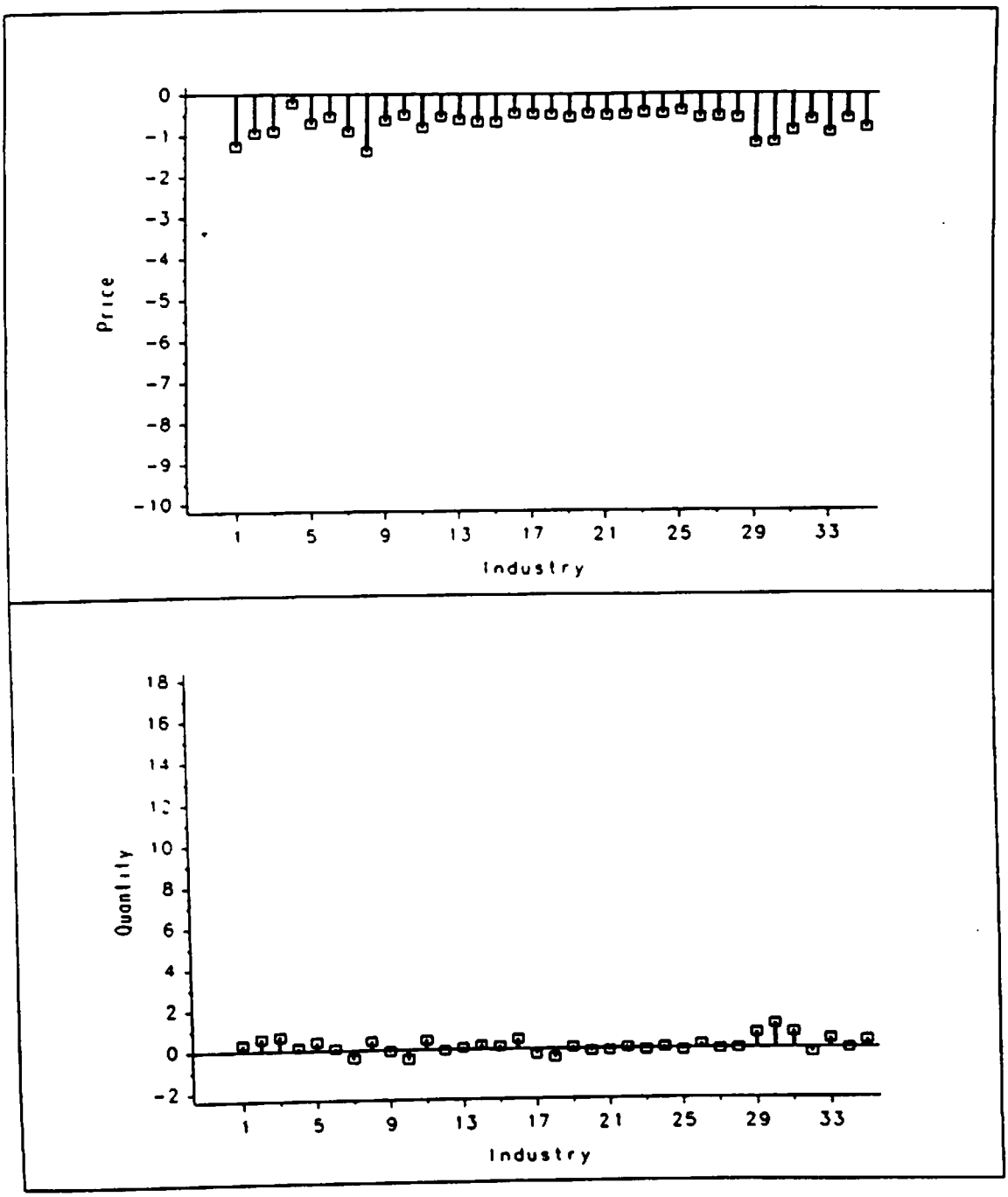
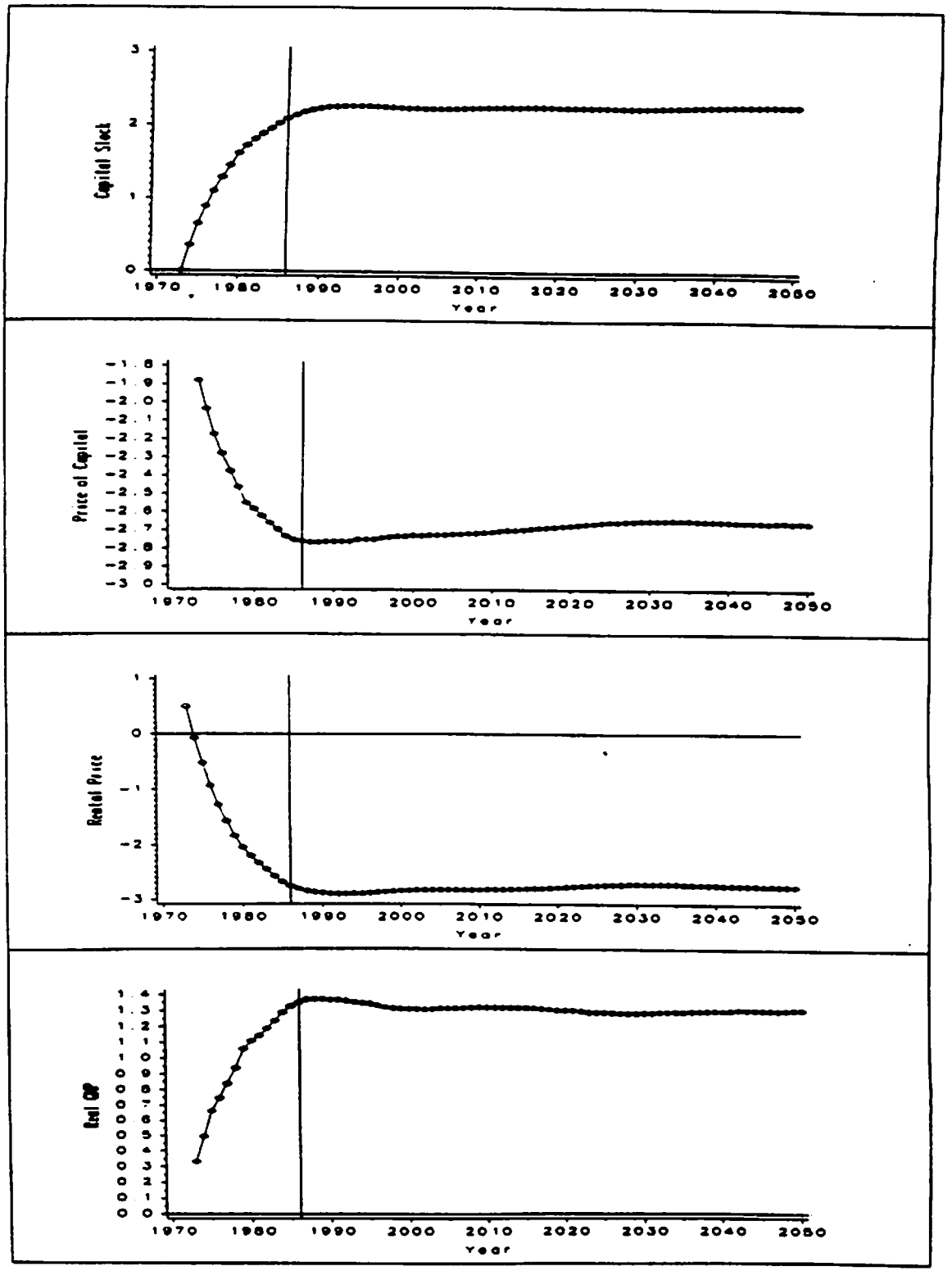


Figure 3.6: The Dynamic Effects of Removing Abatement Investment



3.3. Motor Vehicle Emissions Control. Environmental regulation is not limited to controlling emissions by industries within the business sector. Regulations on motor vehicle emissions take the form of restrictions affecting 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 requires 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. We divide the total cost of pollution abatement equipment between imported and domestic vehicles in proportion to their shares in total supply. Finally, we exclude the cost of this equipment from the total cost of domestic production of motor vehicles. 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 proportion of costs remaining, say λ_{MV} is presented in Table 3.4.

Table 3.4: Motor Vehicle Simulation Shocks

Year	λ^{MV}	λ^{PR}
1973	0.9874	1.0000
1974	0.9850	0.9999
1975	0.9710	0.9986
1976	0.9725	0.9963
1977	0.9733	0.9928
1978	0.9728	0.9883
1979	0.9679	0.9891
1980	0.9539	0.9889
1981	0.9436	0.9867
1982	0.9427	0.9830
1983	0.9453	0.9779

Pollution abatement also imposes additional operating costs on users of motor vehicles. Kappler and Rutledge have separated these additional expenses into three components – increased fuel consumption, increased fuel prices, and increased motor vehicle maintenance. The fuel price premium can be modeled as a change in the cost of 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. Unfortunately, the other two costs are difficult to incorporate into our model. For example, increased car maintenance costs must be allocated between parts and labor. However, an appropriate separation between these costs is unavailable in the data.

Only the costs associated with higher fuel prices were removed in our simulation of U.S. economic growth without motor vehicle emissions controls. Consequently, our results understate the impact of these controls. We estimate the total costs of the petroleum refining industry after eliminating motor vehicles emissions controls by reducing the costs by the fuel price premium associated with production of unleaded fuels. The proportionate reduction in costs of petroleum refining, denoted λ_{PR}, is given in Table 3.4. 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 domestic vehicles.

The economic impact of imposing emissions controls on motor vehicles is similar in magnitude to the impact of pollution controls in industry. The long run capital stock rises by 1.118 percent after the elimination of controls on emissions, while full consumption increases by .282 percent. Real GNP increases by .752 percent in the absence of controls. Finally, the exchange rate appreciates by .392 percent. These results are summarized in Table 3.5 below. Almost all of the economic impact is due to increased motor vehicle prices as a consequence of emissions controls. Changes in the price of investment goods 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 fifteen percent of new capital goods.

The long run impact of eliminating emissions controls on the outputs and prices of indi-

vidual industries is shown in Figure 3.7. The principal beneficiary of the 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 seven percent produces an output change of fourteen percent. Two other industries also benefit significantly from 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 3.8. 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 that 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.

3.4. *The Impact of Environmental Regulation.* To measure the total impact of eliminating all three costs of environmental regulation -- operating costs resulting from pollution abatement in industry, costs of investments required by industry to meet environmental standards, and costs of emissions controls on motor vehicles -- we have performed a final simulation. This simulation is not a simple combination of its three components. Operating costs include capital costs, so that 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 was removed from operating costs in the combined simulation. The results of removing all forms of environmental regulation are summarized in Table 3.5, together with the results of the previous simulations.

The long run consequences of pollution control for different industries are presented in Figure 3.9. 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 the remaining industries have increases in output of one to five percent after pollution

Figure 3.7: The Effects of Removing Vehicle Regulation on Industries

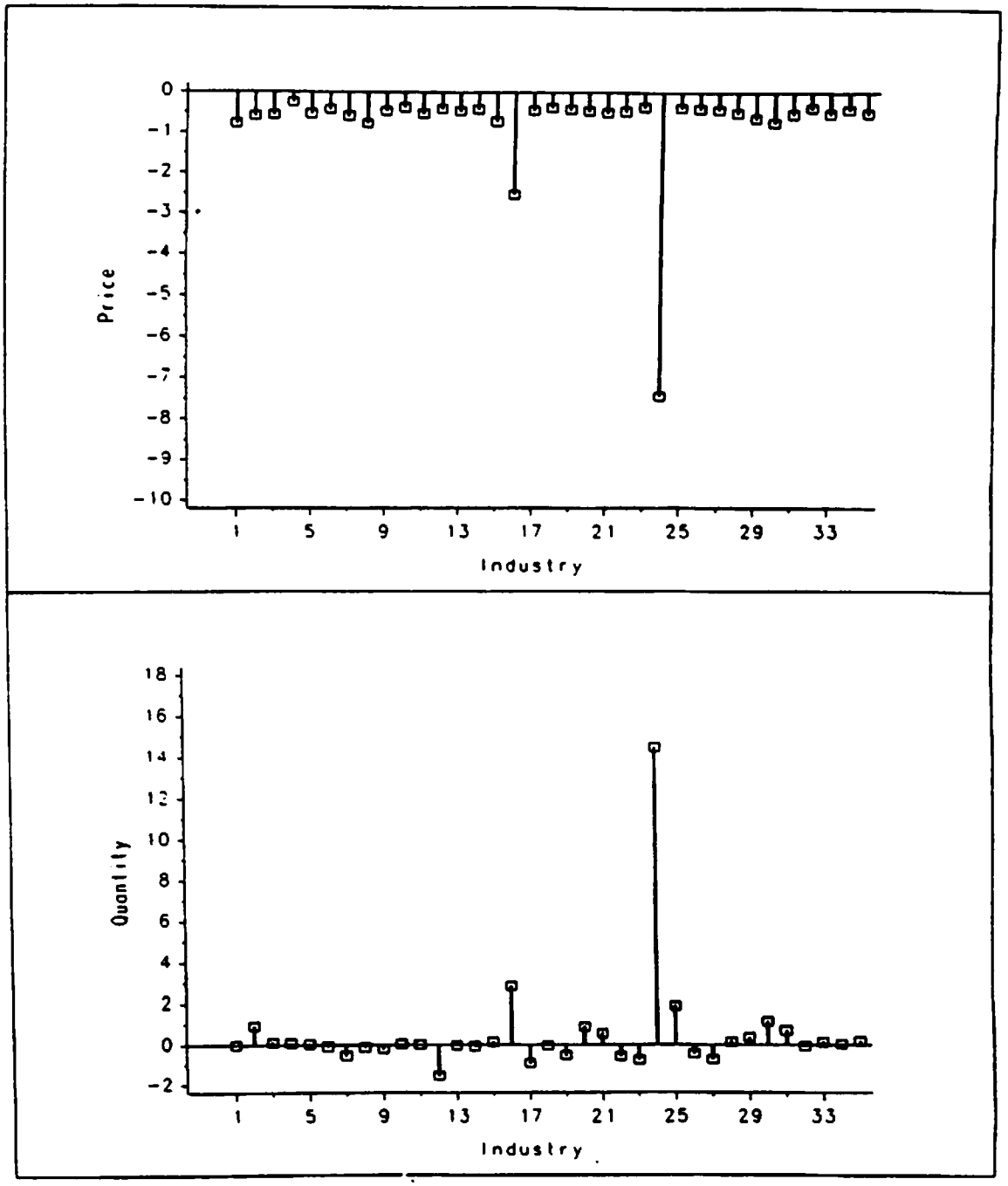


Figure 3.8: The Dynamic Effects of Motor Vehicle Regulation

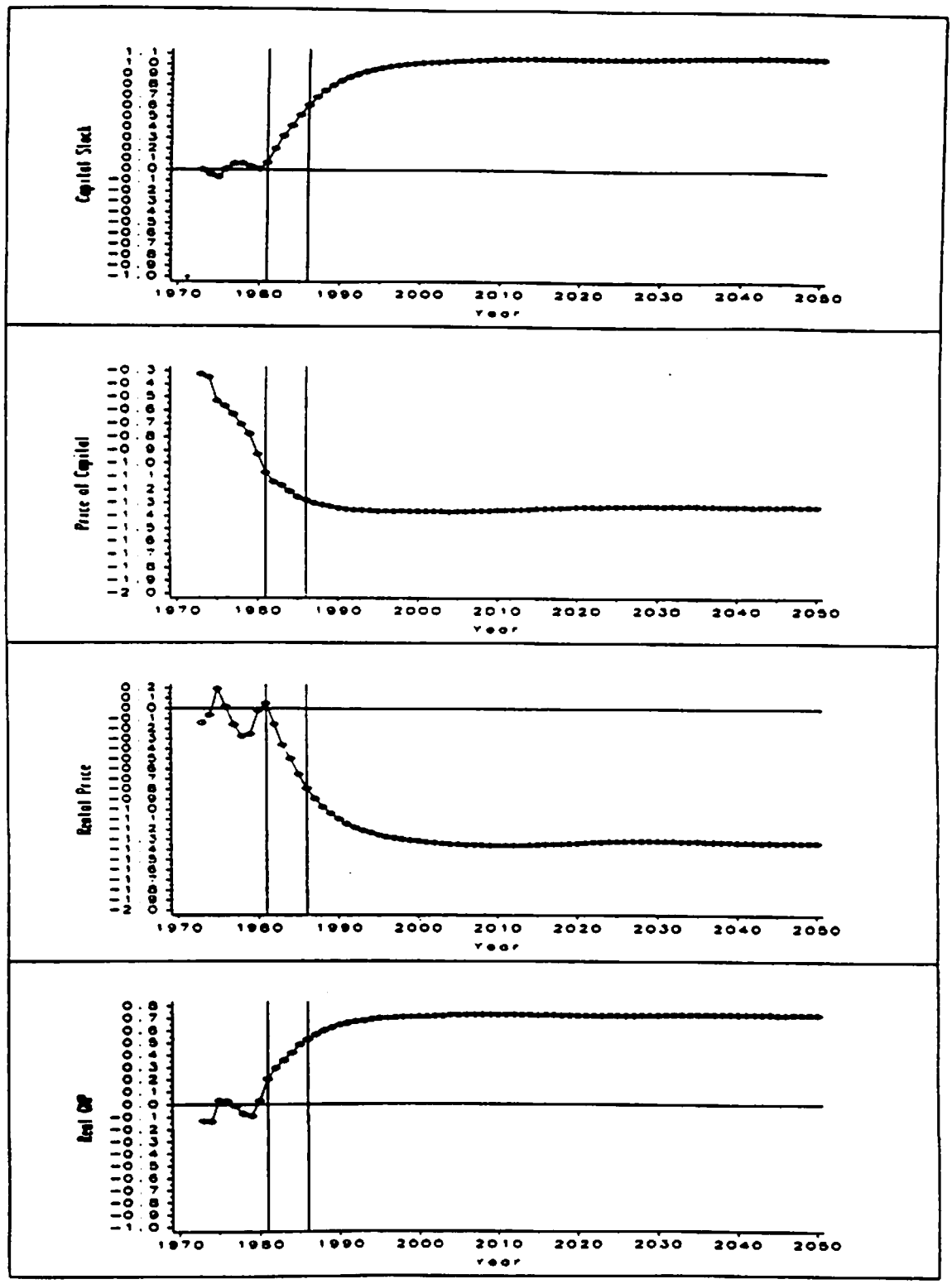
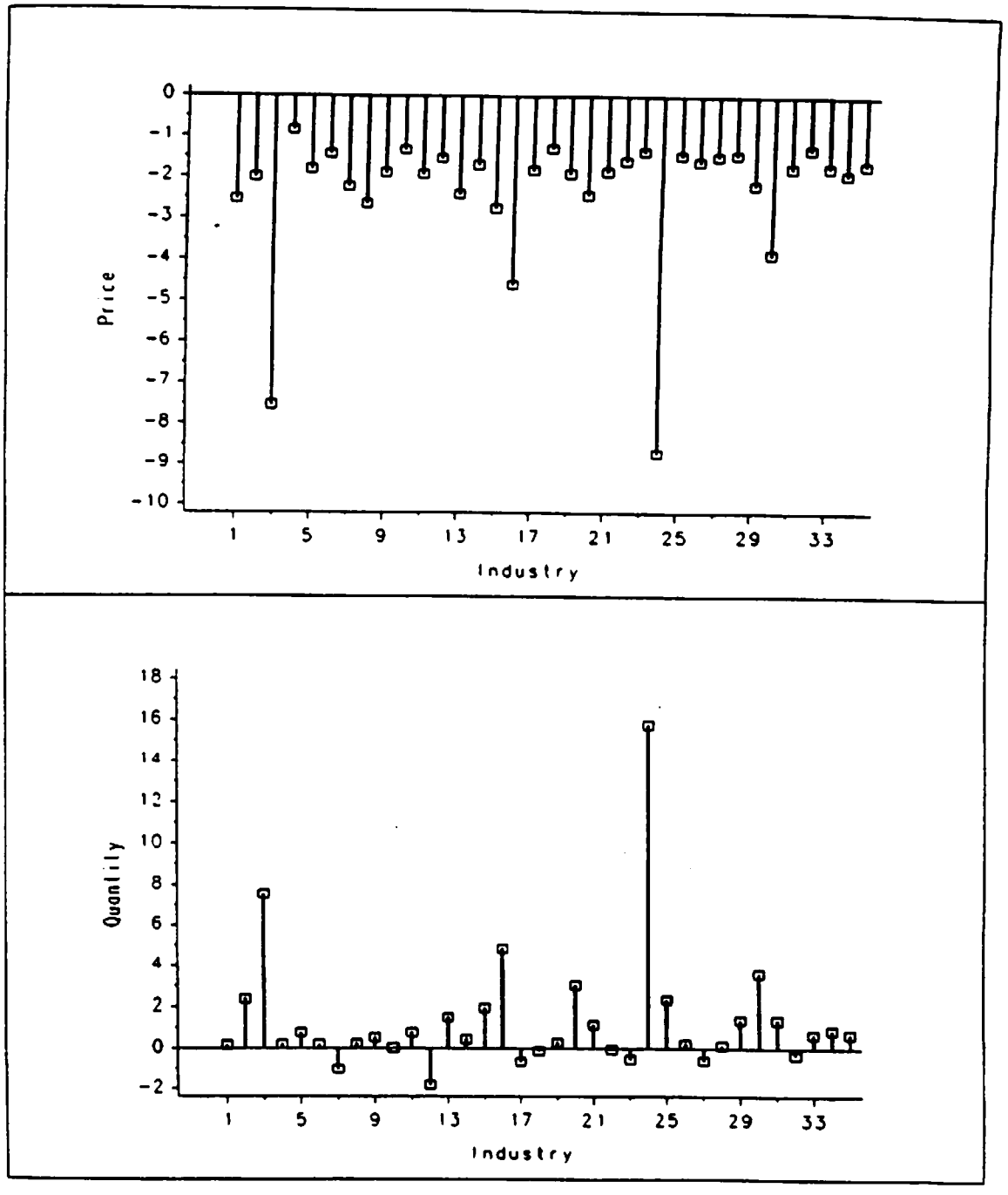


Figure 3.9: The Effects of Removing All Environmental Regulation on Industries

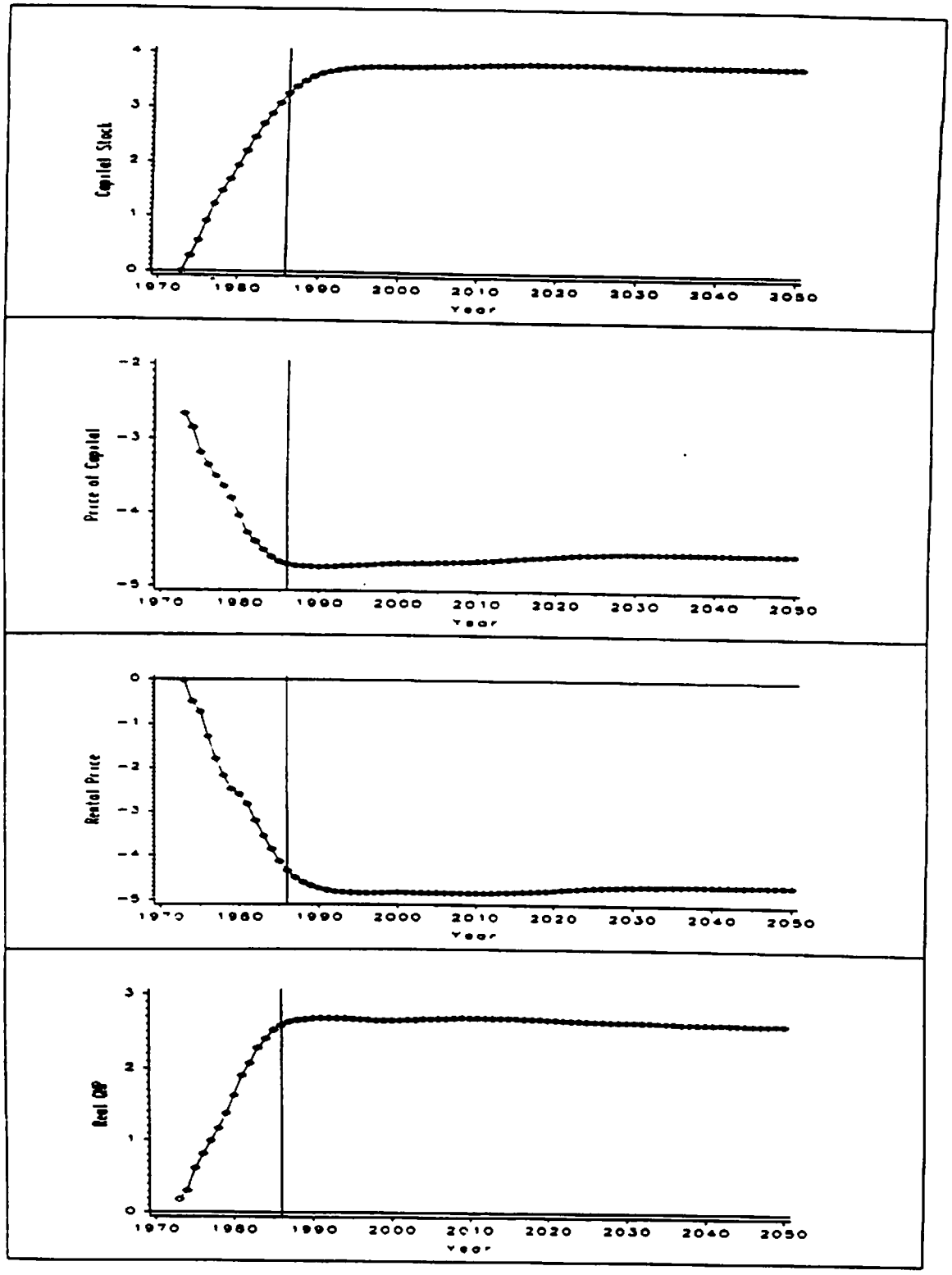


controls are removed. The rest are largely unaffected by environmental regulations. The economy follows the transition path to the new steady state shown in Figure 3.10. Driven by large changes in the price of investment goods, the capital stock rises sharply. The quantity of full consumption rises at a similar rate, as does real GNP. The adjustment process is dominated by the rapid accumulation of capital and is largely completed within two decades.

Table 3.5: The Effects of Removing Environmental Regulation

Variable	Percentage Change in 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

Figure 3.10: 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 4.1.

Table 4.1: 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

Mandated 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.[29] For example, Denison (1985) finds 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. This estimate is based on an aggregate production function and does not take in account the important differences in environmental restrictions among industries. In addition, Denison does not model the dynamic response of the U.S. economy to pollution

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

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 of Denison.

We can also summarize the impact of higher operating costs associated with environmental regulation on economic growth, using the results given in Table 4.1. 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 have a small but significant effect on long run output and the rate of growth of the economy in the 1970's and early 1980's. In addition, these costs affect 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 4.1. The growth of GNP would have been .074 percentage points higher in the absence of mandated investment in pollution control. Slower productivity growth contributes .015 percentage points of this total, while the rest results from lower growth of the primary factors of production. Mandated investment in pollution control has two effects. First, it lowers the long run capital stock and reduces long run consumption. Second, it reduces the rate of capital accumulation in the early years of regulation. This, in turn, reduces the rate of growth of GNP. The impact of eliminating mandated investment in pollution abatement devices is 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 and the 1983 share gives the proportion devoted to existing sources of emissions. The data

presented in Figure 3.4 above show that this expenditure reached as much as three percent of total investment during the mid-1970's .

We have 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 have increased the level of investment expenditures from 1973 to 1983 by the share attributable to pollution abatement for existing sources. This raises the rate of capital accumulation in the mid-1970's, 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 during the period 1973-1985 by .100 percentage points. We have estimated an increase in the growth rate of .074 percentage points for the investment required for new sources alone, so that 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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