# The Performance of Traditional Macroeconomic Models of Businesses' Investment Spending

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The rate of capital formation by businesses has long been among the most closely watched elements of the national accounts. During the last decade, this component of investment attracted considerable interest as capital spending helped support our uncommonly high rate of economic growth. Businesses' demand for capital goods grew rapidly, accounting for more than its typical share of the demand for output. Not only did this spending lift the growth of aggregate demand, it also increased our capacity for supplying goods and services, which in turn could allow output to continue growing rapidly in the future.

This article analyzes the performance of conventional models of investment spending by comparing their abilities to describe this spending from 1960 to 1990 as well as their abilities to forecast spending during the 1990s. These comparisons test the models and provide standards for measuring the rate of investment spending. If spending has accelerated recently, these models can help define its timing and magnitude, while suggesting which macroeconomic forces might be propelling the demand for capital. The models represent the previous historical relationships between capital spending and other macroeconomic variables. To the degree the projections from these models coincide with the course of investment, the motives for that spending may be attributed to familiar forces. To the degree the projections fail to describe spending, the nature of their errors might suggest alternative explanations for the behavior of the data.

According to this study, capital formation has been relatively low during much of the 1990s. The models for producers' durable equipment and software suggest that spending fell well below historical norms during the late 1980s and early 1990s, then recovered during the remainder of the 1990s. The models for nonresidential construction suggest that spending has remained unusually low since the late 1980s. This study finds that the rate of capital formation displays considerable inertia. Years of high investment tend to follow years of high investment. More than previously, this study indicates that the rate of aggregate capital formation does not depend closely on the rate of growth of GDP alone or on the cash flow of businesses. Instead, models that describe investment using output and a measure of the cost of capital performed better. Nevertheless, recent shifts in the composition of the stock of capital goods and in the relative prices of capital goods have undermined the performance of these models of aggregate investment spending. In many ways, aggregate capital spending seems to depend more heavily than it has in the past on industries' unique circumstances and changing technologies.

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The first section of the article describes the magnitude and composition of investment in the United States and discusses some of the issues regarding the measurement of investment. The second section describes the six models of investment that are examined in this study. The third section discusses their abilities to fit the data before 1990 and their abilities to forecast spending after 1990. The concluding section observes that errors of the conventional macroeconomic models, the changing composition of capital, and our new methods of measuring the stocks of capital warrant our considering more disaggregated descriptions of investment spending.

## *I. The Composition of Investment*

Households, governments, and businesses invest when they set aside a share of their current income in order to acquire capital assets whose returns promise to increase their incomes in the future. Often the concept of investment emphasizes the purchases of buildings and equipment. In the national accounts, for instance, the concept of fixed investment comprises construction spending and purchases of equipment and software by businesses and governments. But, this capital spending constitutes only a portion of investment. The national accounts do not recognize, for example, households' purchases of appliances, tools, or other durable goods as investments, because these accounts do not attribute any output to these assets.

The measurement of investment becomes more comprehensive when the concept of output is not limited to GDP (Nordhaus and Tobin 1972; Eisner 1985; Jorgenson and Fraumeni 1989; Kirova and Lipsey 1998). From a broad perspective, investment includes not only the acquisition of all tangible capital assets but also expenditures for research and development, education (other than buildings, equipment, and software), environmental improvements, law enforcement, and defense. Our recognizing these expenditures as investments, however, entails our recognizing the income that redounds to the stock of this capital. According to the national accounts, gross private domestic and government investment accounts for about one-fifth of GDP. In Eisner's total income system of accounts, total income exceeded GDP by approximately one-fifth in the 1980s, and total gross tangible investment, which accounted for about one-third of that income, was approximately twice as great as the gross domestic investment reported in the national accounts (Eisner 1985, Table B, p. 28). Jorgenson and Fraumeni's full income accounts emphasize the importance of investment in human capital and of production that is not recorded in market transactions, neither of which appears in current accounting for national income. Their measure of full income was about three times GDP in 1984, and full investment, which accounted for almost half of that income, was more than seven times gross domestic investment as reported in the national accounts (Jorgenson and Fraumeni 1989, Table 5.4, p. 239). Although the accumulation of human capital through education and the growth of the population accounted for most of this broad measure of investment, the accumulation of other capital still exceed-

Table 1

*Real Business Fixed Investment, Government's Capital Spending, and Consumers' Purchases of Durable Goods, as a percent of Real GDP*[a]

| | Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 61–65 | 66–70 | 71–75 | 76–80 | 81–85 | 86–90 | 91–95 | 96–99 |
| Gross Private Domestic Investment | 12.2 | 12.8 | 13.4 | 14.1 | 14.2 | 14.2 | 13.9 | 17.5 |
| Fixed Investment | 11.9 | 12.4 | 13.2 | 13.7 | 13.9 | 13.9 | 13.6 | 16.9 |
| Nonresidential | 6.6 | 7.8 | 8.1 | 8.8 | 9.8 | 9.6 | 9.8 | 12.9 |
| Structures | 4.4 | 4.6 | 4.2 | 4.0 | 4.5 | 3.6 | 2.9 | 3.0 |
| Equipment and Software | 3.1 | 3.9 | 4.4 | 5.1 | 5.6 | 6.1 | 7.0 | 9.9 |
| Residential | 6.0 | 4.9 | 5.5 | 5.2 | 4.1 | 4.4 | 3.8 | 4.0 |
| Structures | 6.0 | 4.8 | 5.4 | 5.2 | 4.0 | 4.3 | 3.7 | 3.9 |
| Equipment | .0 | .1 | .1 | .1 | .1 | .1 | .1 | .1 |
| Government Gross Investment | 4.8 | 4.7 | 4.7 | 4.6 | 4.5 | 4.4 | 4.1 | 3.8 |
| Defense | 1.3 | 1.0 | .6 | .6 | .9 | 1.1 | .9 | .6 |
| Nondefense | 3.4 | 3.5 | 3.6 | 3.6 | 3.5 | 3.4 | 3.3 | 3.1 |
| Consumer Durable Goods | 4.5 | 5.2 | 5.8 | 6.2 | 6.3 | 7.5 | 7.3 | 8.4 |
| Education | 1.5 | 1.7 | 1.8 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| Equipment, Software, Structures / Private Nonfarm Labor | 59.7 | 63.2 | 70.1 | 73.4 | 80.2 | 81.0 | 84.3 | 85.6 |
| Residential Capital per Capita | 8.3 | 9.3 | 12.3 | 18.6 | 24.2 | 27.0 | 29.1 | 30.9 |
| Consumer Durables per Capita | 5.1 | 5.1 | 5.6 | 7.0 | 8.3 | 8.6 | 8.7 | 8.2 |
| Government (Nondefense) per Capita | .5 | .6 | .8 | 1.1 | 1.4 | 1.5 | 1.6 | 1.7 |

[a] The entries are derived from chain-weighted data. Consequently, components do not necessarily sum to totals.

Source: The measure of the labor force is from the U.S. Bureau of Labor Statistics, population is from the U.S. Bureau of the Census, and all other data are from the U.S. Bureau of Economic Analysis and can be found in Table 5 of the *Survey of Current Business*.

ed the national accounts' measure of investment by almost 30 percent.

### *Investment in the National Accounts*

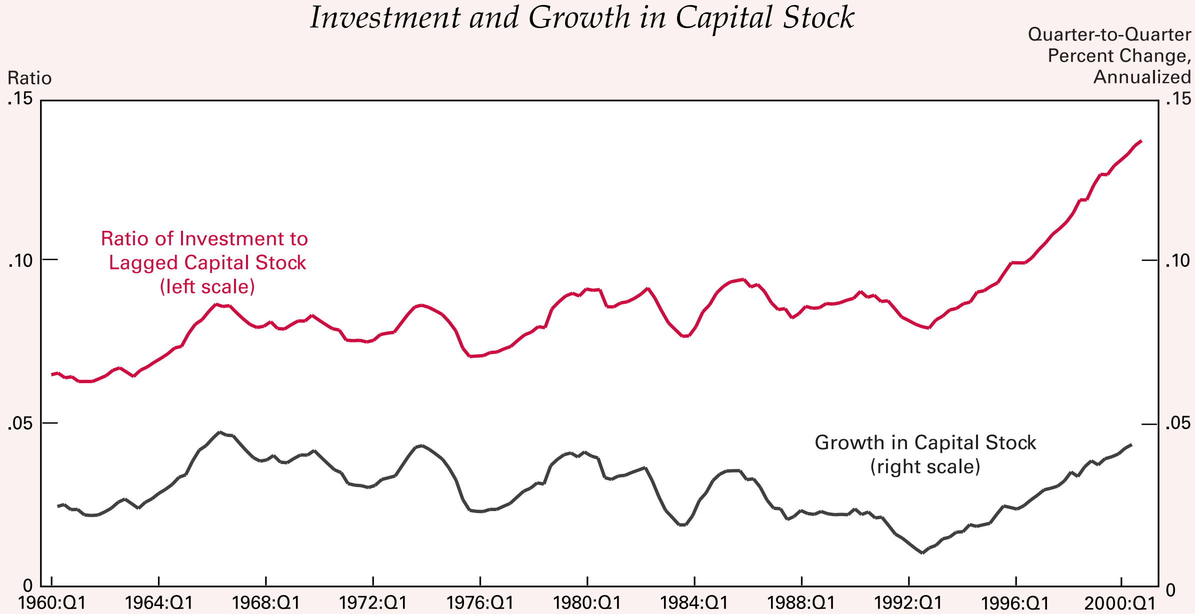
Together, gross private domestic fixed investment, government capital spending, expenditures for education, and consumers' purchases of durable goods account for almost one-third of GDP (Table 1). This share increased by just under 40 percent during the past 50 years. At the same time, the composition of this spending has shifted toward consumers' durable goods and toward the capital assets of businesses, away from government capital spending and residential construction. Currently, businesses' investment spending, comprising nonresidential construction and producers' purchases of durable equipment and software, accounts for approximately one-eighth of GDP. Although businesses' investment increased over the past four decades, it too has shifted, favoring equipment and software, whose share tripled, over nonresidential construction, whose share fell by one-quarter.

*Gross* capital spending of businesses has increased more than *net* investment since the 1960s. In the early 1960s, gross investment in equipment and software nearly equaled that in nonresidential structures. Now, gross investment in equipment and software is approximately three times that of structures. As the stock of capital assets shifted in favor of equipment and software, which depreciate relatively rapidly, away from structures, which depreciate relatively slowly, businesses' capital budgets had to increase relative to GDP in order to maintain their existing stock of capital assets. Consequently, the rate of growth of businesses' stock of capital assets has risen little in the last decade compared to the substantial increase in their gross investment spending relative to their stock of capital (Figure 1).

One standard for judging the pace of capital formation compares the stock of capital assets to the number of people who may use that capital or benefit from its services (Table 1). From the early 1960s to the early 1980s, the stock of businesses' capital assets increased 34 percent relative to the labor force. This 1.5 percent average annual increase in capital per potential laborer fell to just 0.4 percent from the early 1980s to the late 1990s. From the early 1960s to the early

Figure 1

*Investment and Growth in Capital Stock*




Source: Investment is from the U.S. Bureau of Economic Analysis, National Income and Product Accounts, and is provided by Haver Analytics. Capital stock is from the U.S. Bureau of Economic Analysis.

1980s, the stock of residences per capita grew 5.5 percent annually; since then, only 1.7 percent. The stock of consumers' durable goods per capita rose 2.4 percent until the early 1980s, only to change negligibly over the subsequent 15 years. The stock of public capital goods (nondefense) per capita increased 5.4 percent before the early 1980s, 1.3 percent afterward. By these measures, housing and public capital have constituted the principal forms of investment in tangible assets since the early 1960s, and the accumulation of all capital assets has decelerated significantly during the past 15 years.

### *Composition of Businesses' Fixed Investment*

The two broad categories of businesses' investment, nonresidential construction spending and producers' purchases of durable equipment and software, each comprise a variety of capital assets. During the past three decades, the allocation of businesses' capital budgets among these assets has shifted substantially (Tables 2 and 3).

Since the early 1960s, businesses' purchases of equipment have shifted strongly toward information processing equipment.[1] This equipment and related software represented just over 18 percent of producers' expenditures on equipment and software in the early 1960s. By the late 1990s, this share exceeded 44 percent, with most of the growth occurring in computers, software, and communications equipment. At the same time, the shares of industrial equipment and transportation equipment fell from just over 28 and 29 percent, respectively, to just over 18 and 20 percent.

The composition of investment in nonresidential structures did not change as much as that for equipment. In general, the share of construction allocated to industrial, commercial, hospital, and institutional buildings increased over the past four decades, while the shares of public utilities and farms declined.

More interesting than these trends are the cycles in spending on structures. After the price of oil and gas soared in the 1970s, the investment in wells rose sharply. Petroleum and gas wells' share of construc-

[1] The data in these tables show the composition of nominal spending. As noted in Appendix 1, the chain-weighted measures of the components of investment spending in 1996 dollars do not add to the chain-weighted measure of total investment spending. In the case of equipment, the components sum to almost 160 percent of the total in the early 1960s, compared to just over 100 percent of the total by the late 1990s.

Table 2

*Equipment Investment by Type, as a Percent of Total Equipment Investment*

| Type of Equipment | Years 61–65 | 66–70 | 71–75 | 76–80 | 81–85 | 86–90 | 91–95 | 96–99 |
|---|---|---|---|---|---|---|---|---|
| Information processing equipment and software | 18.2 | 21.2 | 24.2 | 26.8 | 36.8 | 40.5 | 42.5 | 44.5 |
| Computers and peripheral equipment[a] | 1.8 | 3.5 | 3.7 | 4.3 | 8.7 | 9.8 | 9.5 | 10.4 |
| Software[b] | 1.0 | 2.4 | 3.6 | 4.0 | 6.5 | 9.7 | 13.5 | 16.7 |
| Communications equipment | 8.4 | 8.3 | 8.7 | 9.8 | 11.9 | 11.7 | 10.1 | 10.1 |
| Instruments | 2.2 | 2.4 | 3.0 | 3.5 | 4.2 | 4.7 | 5.5 | 4.5 |
| Photocopy and related equipment | 1.7 | 2.3 | 3.1 | 2.9 | 2.8 | 2.7 | 2.8 | 1.8 |
| Office and accounting equipment | 2.9 | 2.3 | 2.1 | 2.4 | 2.6 | 1.9 | 1.3 | 1.0 |
| Industrial equipment | 29.1 | 29.3 | 27.1 | 26.0 | 23.1 | 21.6 | 20.5 | 18.4 |
| Fabricated metal products | 2.7 | 3.0 | 4.0 | 4.2 | 3.3 | 2.1 | 2.0 | 1.6 |
| Engines and turbines | 1.2 | 1.5 | 1.8 | 1.0 | .7 | .7 | .7 | .6 |
| Metalworking machinery | 5.9 | 7.4 | 5.9 | 6.0 | 5.0 | 4.6 | 4.6 | 4.3 |
| Special industry machinery, n.e.c. | 6.7 | 6.2 | 5.3 | 4.7 | 4.9 | 5.5 | 5.1 | 4.7 |
| General industrial, including materials handling, equipment | 6.5 | 5.9 | 5.5 | 6.1 | 5.4 | 5.2 | 4.7 | 4.3 |
| Electrical transmission, distribution, and industrial apparatus | 6.1 | 5.4 | 4.6 | 4.0 | 3.8 | 3.6 | 3.2 | 3.0 |
| Transportation equipment | 28.1 | 26.8 | 25.2 | 24.1 | 20.1 | 19.0 | 19.7 | 20.6 |
| Trucks, buses, and truck trailers | 9.9 | 9.7 | 10.4 | 9.7 | 8.2 | 8.0 | 9.2 | 11.8 |
| Autos | 11.7 | 8.9 | 8.9 | 8.1 | 7.5 | 7.3 | 7.0 | 5.4 |
| Aircraft | 2.3 | 4.3 | 2.3 | 2.6 | 2.6 | 2.6 | 2.5 | 2.3 |
| Ships and boats | 1.2 | 1.2 | 1.6 | 1.6 | .9 | .4 | .3 | .3 |
| Railroad equipment | 3.0 | 2.8 | 2.1 | 2.2 | .8 | .6 | .8 | .8 |
| Other equipment | 25.4 | 23.4 | 24.5 | 24.5 | 20.8 | 19.6 | 17.9 | 17.0 |
| Furniture and fixtures | 4.5 | 4.0 | 3.7 | 3.7 | 4.5 | 5.0 | 4.4 | 4.2 |
| Tractors | 3.1 | 3.1 | 3.3 | 3.4 | 2.1 | 1.8 | 1.7 | 1.7 |
| Agricultural machinery, except tractors | 3.9 | 3.8 | 4.4 | 4.0 | 2.2 | 1.8 | 1.7 | 1.5 |
| Construction machinery, except tractors | 3.4 | 3.5 | 3.8 | 4.0 | 2.6 | 2.6 | 2.1 | 2.4 |
| Mining and oilfield machinery | 1.4 | 1.1 | 1.5 | 2.1 | 1.6 | .4 | .4 | .5 |
| Service industry machinery | 4.1 | 3.8 | 3.1 | 2.6 | 2.6 | 2.7 | 2.2 | 1.9 |
| Electrical equipment, n.e.c. | 1.2 | 1.0 | 1.1 | 1.5 | 1.7 | 1.8 | 1.9 | 1.6 |
| Other | 3.7 | 3.1 | 3.3 | 3.3 | 3.4 | 3.4 | 3.4 | 3.1 |
| Sum of Major Components | 100.7 | 100.8 | 101.0 | 101.5 | 100.8 | 100.7 | 100.7 | 100.6 |

[a] Includes new computers and peripheral equipment only.
[b] Excludes software "embedded," or bundled, in computers and other equipment.
Source: BEA's *Survey of Current Business*, Table 5.8. Data provided by Haver Analytics.

tion then fell by two-thirds after the price of oil and gas fell in the 1980s. Similarly, the construction of commercial buildings increased substantially with the growth of service industries in the 1970s and 1980s. This investment subsequently fell once the construction boom produced a surfeit of space by the late 1980s. Changing technologies in the past two decades also allowed many of these industries to use space more efficiently. Electric utilities' share of nonresidential construction spending tended to increase with the use of electricity until the 1970s. After rising electric rates and public policy fostered conservation in the use of electric power, this share fell by two-thirds during the 1980s and 1990s. Finally, the share of construction devoted to hospitals rose throughout much of the last four decades, but fell after the 1980s as changes in government policies and private health care programs reduced the demand for hospital beds.

Table 3
*Structures Investment by Type, as a Percent of Total Nonresidential Structures Investment*

| Type of Equipment | 61–65 | 66–70 | 71–75 | 76–80 | 81–85 | 86–90 | 91–95 | 96–99 |
|---|---|---|---|---|---|---|---|---|
| | Years | | | | | | | |
| Nonresidential buildings, excluding farm | 60.5 | 60.0 | 57.6 | 49.6 | 56.8 | 71.5 | 66.3 | 70.4 |
| Industrial | 14.9 | 18.7 | 15.0 | 15.2 | 12.4 | 13.5 | 16.0 | 12.8 |
| Commercial | 24.0 | 23.3 | 27.5 | 23.6 | 31.0 | 39.9 | 31.9 | 36.0 |
| Religious | 4.6 | 3.0 | 1.6 | 1.5 | 1.4 | 2.1 | 2.0 | 2.2 |
| Educational | 3.2 | 3.0 | 1.8 | 1.0 | 1.2 | 2.2 | 2.9 | 3.7 |
| Hospital and institutional | 4.8 | 5.1 | 6.7 | 4.9 | 5.3 | 6.0 | 7.0 | 5.6 |
| Other[a] | 9.0 | 6.7 | 5.1 | 3.5 | 5.6 | 7.8 | 6.3 | 10.0 |
| Utilities | 22.7 | 25.6 | 27.5 | 26.4 | 18.1 | 15.4 | 18.9 | 15.4 |
| Railroads | 2.6 | 2.5 | 2.2 | 2.7 | 1.9 | 1.4 | 1.6 | 1.9 |
| Telecommunications | 5.2 | 5.7 | 6.8 | 6.0 | 4.7 | 5.1 | 5.2 | 5.0 |
| Electric light and power | 9.3 | 11.8 | 13.8 | 13.7 | 9.3 | 6.7 | 8.5 | 4.7 |
| Gas | 4.8 | 5.0 | 3.4 | 2.5 | 1.9 | 2.0 | 3.1 | 3.3 |
| Petroleum pipelines | .8 | .7 | 1.3 | 1.5 | .3 | .2 | .5 | .5 |
| Farm | 5.8 | 4.8 | 4.8 | 5.3 | 2.1 | 1.3 | 1.6 | 1.6 |
| Mining exploration, shafts, and wells | 10.6 | 7.5 | 8.0 | 16.5 | 20.7 | 8.3 | 9.2 | 10.0 |
| Petroleum and natural gas | 10.0 | 6.9 | 6.9 | 15.0 | 19.6 | 7.8 | 8.4 | 9.4 |
| Other | .7 | .7 | 1.0 | 1.5 | 1.1 | .5 | .8 | .6 |
| Other[b] | 1.4 | 1.8 | 2.0 | 1.9 | 2.3 | 3.2 | 4.0 | 2.3 |
| Sum of major categories | 101.0 | 99.7 | 99.9 | 99.7 | 99.9 | 99.8 | 100.0 | 99.7 |

[a] Consists of hotels and motels, buildings used primarily for social and recreational activities, and buildings not elsewhere classified, such as passenger terminals, greenhouses, and animal hospitals.

[b] Consists primarily of streets, dams and reservoirs, sewer and water facilities, parks, and airfields.

Source: BEA's *Survey of Current Business*, Table 5.6. Data provided by Haver Analytics.

The composition of investment by industry reflects the cycles in mining, the growth of service and electronics industries, and the greater role of financial institutions in leasing capital goods to other enterprises (Table 4). From the early 1960s to the late 1990s, financial institutions' share of investment rose from 1.8 percent to 9.7 percent of businesses' capital spending. Banks, finance companies, insurance companies, and other intermediaries have substituted leases for some of their loans—companies that formerly borrowed to finance their own purchases increasingly rent their assets.

## II. Models of Businesses' Investment

Forecasters and policymakers frequently attempt to explain the behavior of the aggregate capital spending of businesses by means of concise statistical models. These macroeconomic models essentially look beyond the details of each industry's investment spending or the demand for each type of capital good in order to isolate the more fundamental influences that govern capital formation. This aggregate approach confronts considerable difficulties in combining the diverse capital goods properly in order to construct useful aggregates. It also takes a large risk by not explicitly considering the various economic conditions that prevail in specific industries. But, against these costs, it offers the potentially substantial benefit of describing the common tide upon which the specific fortunes of these diverse industries might ride.

All models of investment recognize that businesses intend to profit from their investments. Yet, the models express this common theme in distinctive ways as they describe the influence of economic conditions on investors' perceptions of future profits and, in turn, on their demand for capital goods. Rising orders, for example, might foster investment. But, do these orders principally influence the demand for investment goods directly, through their effect on businesses' cash on hand, or through a higher return on assets? Does this influence depend substantially on the cost of

Table 4
*Investment by Industry, as a Percent of Total Investment*

| Industry | 61–65 | 66–70 | 71–75 | 76–80 | 81–85 | 86–90 | 91–95 | 96–99 |
|---|---|---|---|---|---|---|---|---|
| Mining | 4.7 | 3.9 | 3.7 | 7.0 | 9.1 | 3.3 | 3.2 | 3.2 |
| Metal Mining | .3 | .3 | .3 | .5 | .2 | .1 | .2 | .1 |
| Coal Mining | .3 | .3 | .4 | .7 | .5 | .2 | .3 | .3 |
| Oil and Gas Extraction | 3.8 | 3.0 | 2.7 | 5.4 | 8.1 | 2.7 | 2.5 | 2.5 |
| Construction | 2.2 | 2.1 | 2.2 | 1.8 | 1.0 | 1.1 | 1.2 | 1.6 |
| Manufacturing | 14.5 | 17.7 | 15.6 | 15.3 | 14.1 | 12.9 | 14.3 | 13.7 |
| Durable Goods | 7.7 | 9.8 | 8.3 | 8.3 | 7.8 | 6.7 | 7.1 | 7.5 |
| Primary and Fabricated Metals | 2.5 | 3.2 | 2.4 | 2.1 | 1.5 | 1.3 | 1.4 | 1.3 |
| Industrial Machinery and Equipment | 1.1 | 1.6 | 1.5 | 1.6 | 1.5 | 1.2 | 1.2 | 1.3 |
| Electronic and Other Electric Equipment | .7 | 1.0 | 1.0 | 1.1 | 1.6 | 1.3 | 1.5 | 1.9 |
| Motor Vehicles and Equipment | 1.2 | 1.3 | 1.0 | 1.1 | .9 | .8 | 1.1 | 1.1 |
| Nondurable Goods | 6.8 | 7.9 | 7.3 | 7.0 | 6.2 | 6.1 | 7.1 | 6.2 |
| Food and Kindred Products | 1.5 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.3 | 1.1 |
| Paper and Allied Products | .9 | 1.0 | .9 | 1.0 | .9 | 1.1 | 1.0 | .8 |
| Printing and Publishing | .5 | .6 | .6 | .6 | .7 | .8 | .7 | .8 |
| Chemicals and Allied Products | 1.9 | 2.3 | 2.1 | 2.3 | 1.6 | 1.7 | 2.2 | 2.0 |
| Transportation | 5.1 | 5.5 | 5.0 | 5.4 | 3.8 | 3.3 | 4.1 | 5.0 |
| Trucking and Warehousing | 1.4 | 1.2 | 1.3 | 1.2 | 1.1 | 1.2 | 1.4 | 1.5 |
| Transportation by Air | .8 | 1.5 | 1.0 | 1.3 | 1.0 | 1.0 | 1.2 | 1.7 |
| Communications | 4.9 | 5.4 | 5.7 | 5.8 | 5.7 | 5.5 | 5.9 | 6.6 |
| Telephone and Telegraph | 4.6 | 5.1 | 5.4 | 5.4 | 4.9 | 4.6 | 4.8 | 5.1 |
| Radio and Television | .3 | .3 | .3 | .4 | .7 | .9 | 1.1 | 1.5 |
| Electric, Gas, and Sanitary Services | 5.8 | 6.7 | 6.8 | 6.2 | 6.8 | 6.6 | 5.6 | 4.2 |
| Wholesale Trade | 2.3 | 2.7 | 3.1 | 3.6 | 5.4 | 4.7 | 5.5 | 5.9 |
| Retail Trade | 3.8 | 4.1 | 4.0 | 3.7 | 4.1 | 4.8 | 5.1 | 4.6 |
| Finance, Insurance, and Real Estate | 44.7 | 39.4 | 41.4 | 39.3 | 39.8 | 46.8 | 42.3 | 41.7 |
| Financial and Insurance Institutions | 1.8 | 2.4 | 3.3 | 4.3 | 6.7 | 9.1 | 9.0 | 9.7 |
| Real Estate | 42.7 | 36.8 | 37.7 | 34.7 | 32.6 | 37.1 | 32.8 | 31.3 |
| Services | 6.0 | 6.8 | 6.7 | 6.3 | 7.2 | 8.5 | 9.7 | 10.4 |
| Hotels and Other Lodging Places | 1.1 | .9 | .8 | .7 | .9 | .8 | .7 | 1.0 |
| Auto Repair, Services, and Parking | 1.0 | 1.1 | 1.1 | 1.3 | 1.2 | 1.0 | 2.2 | 1.5 |
| Health Services | .8 | .8 | .8 | .8 | 1.3 | 1.4 | 1.5 | 1.4 |

Source: Investment by industry is from self-extracting ZIP files available on the BEA's web-site.

acquiring capital goods? The various models of investment provide different perspectives that reflect their different theories of investors' behavior.

This section presents six models of investment spending by businesses, each representing an elemental description of the relationship between investment and various measures of economic conditions. Individually, the six models allow us to assess their particular explanations of investment spending. Together, they cover the principal factors at work in most forecasting models, which often combine and extend the approaches taken by these basic models.

These basic models of investment spending, like most, rest on a common fiction inasmuch as they combine diverse capital goods into a few aggregates, and they treat all businesses as one investor. The models, therefore, do not explicitly recognize differences among types of investment goods or the difficulties in constructing aggregates (Appendix 1). Nor do they recognize differences among businesses' technologies, products, goals, market power, size, and other circumstances. The models also do not explicitly consider the particular influences of rising energy prices, health care reforms, and changes in work rules or labor's skills. As a result of these differences, no model of aggregate investment rests on an unimpeachable foundation, especially as the relative fortunes of different industries or the contributions of different technologies shift over time.

Because each of the basic models emphasizes one view of investment, and because the success of each view can vary with economic conditions, we should not expect any one of these models to prevail over the others. Instead, these models often complement one another, as we should expect given their common roots and the degree to which their particular approaches amount to related ways of representing the motives of investors.

Most of the models invoke similar frameworks. Investors conceive of an optimal amount of capital to employ given recent business conditions. They then adjust their investment spending in order to approach that optimum, $K^*$, gradually.

$$\Delta K_t = \lambda(K_t^* - K_{t-1}) \qquad 0<\lambda<1.$$

The models can describe either net investment spending, which is the change in the stock of capital as shown above, or as has been more common, gross investment, which also includes the purchases needed to maintain the stock of capital.

$$\begin{aligned} I_t^n &= \Delta K_t \\ I_t^g &= \Delta K_t + \delta K_{t-1} \\ &= \lambda K_t^* + (\delta - \lambda)K_{t-1}. \end{aligned}$$

This partial adjustment reflects the many delays and costs investors incur as they install new capital. It also reflects their intent to avoid overreacting to temporary changes in their circumstances. The models typically express the optimal stock of capital as a weighted sum of past values of the variables that each model deems most important for determining investors' demand for capital, variables such as businesses' output, cost of capital, or cash flow. In adopting this method of extrapolating the past in order to forecast the future, the models implicitly assume that the correlations among past, present, and future values of these variables are stable.[2] Otherwise, this approach could misrepresent investors' willingness and ability to respond to changing conditions.

### *The Accelerator Model*

Because capital goods are a factor of production, the demand for new capital goods depends on businesses' plans for expanding production in the future. According to the accelerator model, businesses estimate their potential need for capital from the recent course of output. Consequently, their acquisition of new capital, their investment spending, is proportional to the difference between their requirements and their existing stock of capital (Clark 1917; Chenery 1952; Knox 1952). According to the accelerator model, businesses essentially cannot substitute one factor of production for another in producing a specific flow of output most efficiently.[3]

Table 5

*The Models of Investment*

Accelerator

$$I_t = \sum_{i=0}^{n} a_i Q_{t-i} + cK_{t-1}$$

Neoclassical

$$I_t = \sum_{i=0}^{n} a_i \frac{Q_{t-i}}{UCC_{t-i}} + \sum_{i=0}^{n} b_i \frac{Q_{t-i}}{UCC_{t-1-i}} + cK_{t-1}$$

Modified Neoclassical

$$I_t = [\sum_{i=0}^{n} a_i \log(Q_{t-i}) + \sum_{i=0}^{n} b_i \log(UCC_{t-i})]K_{t-1} + cK_{t-1}$$

q

$$I_t = \sum_{i=0}^{n} a_i[(q_{t-i} - 1)K_{t-1-i}] + cK_{t-1}$$

Cash Flow

$$I_t = \sum_{i=0}^{n} a_i \left(\frac{F}{P_k}\right)_{t-i} + cK_{t-1}$$

Time Series

$$I_t = \sum_{i=1}^{n} a_i I_{t-i} + \sum_{i=0}^{n} b_i Q_{t-i}$$

Explanation of Symbols

| | |
|---|---|
| $F$ | cash flow |
| $I$ | investment |
| $K$ | existing stock of capital goods |
| $P_K$ | price index for capital goods |
| $Q$ | output |
| $q$ | ratio of financial markets' valuation of capital to its replacement cost |
| $UCC$ | user cost of capital |

The equation for the accelerator model is the first entry in Table 5. The terms, including current and lagged output, represent investment's gradual response to changes in businesses' output. Before intentions become expenditures, a demand for greater productive capacity must pass through stages of planning, approval, contracting, and installation. Furthermore, when businesses intend to invest aggressively, thereby straining their suppliers' capacity for delivering capital goods, their suppliers impose delays by putting some projects on back order. Because these

[2] If these parameters are not stable, then they should not change too greatly, and they should tend to revert to their former values.

[3] The elasticity of substitution among factors of production is low, which is consistent with a Leontief technology.

lags can be shorter for some projects (such as installing personal computers) than others (installing a new assembly line), and because some larger investment projects are installed gradually, a greater demand for output today lifts investment spending over many subsequent quarters. Because investors seldom regard capital goods as liquid assets, these lags on output also represent their measured reactions as they distill transient changes in the demand for their output from more enduring changes in the growth of their markets. These fixed weights reflect the correlations among the current and past values of output, which investors apply to the recent course of output in order to derive their forecast of future output.

The lagged stock of capital serves two purposes in the accelerator model. Because businesses' demand for new investment goods depends on the difference between their potential need for capital assets and their existing stock of capital, the coefficient on this variable partly represents the speed at which they attempt to close this gap. Businesses also need to replace and renew their capital assets as they age or become obsolete. To the degree productive capacity tends to decay at a constant rate, this last term in the accelerator model also measures the investment that businesses must make in order to maintain their productive assets. The first effect opposes the second. The greater is the existing stock of capital, other things equal, the fewer new investments businesses need undertake in order to reach their optimal stock of capital. But, the greater is their capital, the more they must invest in order to maintain and replace aging assets.

The accelerator model is a simple description of investment spending that relies on a short history of output and the lagged stock of capital to determine the demand for new capital goods. This simplicity exacts a price, however. The structure of the model allows it to explain investment best when the trend for the ratio of capital to output changes smoothly over time. The model dictates that the ratio of output to capital rises somewhat above that trend when the rate of growth of output is unusually high. Because investment reacts slowly when output accelerates, the growth of the stock of capital rises toward that of output after some delay. During this time, output rises relative to the stock of capital. A higher output-capital ratio persists until output decelerates, and the conservative reaction of investors causes the growth of capital to fall more slowly than that of output. This feature of the accelerator model—that the demand for capital depends on changes in the growth of output—coupled with investors' fixed lag in responding to the growth of output, implies not only that the supply of capital services needed to produce a quantity of output varies in an uneconomical manner, but also that investors fail to comprehend fully their need for future capital assets even when the growth of output increases and then remains constant.

*The accelerator model is a simple description of investment spending that relies on a short history of output and the lagged stock of capital to determine the demand for new capital goods.*

These characteristics imply that the accelerator model likely explains businesses' investment spending best when the average growth of output over long periods tends to be constant. Even when this growth is not constant, the accelerator model nevertheless might describe investment spending reasonably accurately, provided that investment depends strongly on the recent course of output and the average growth of output does not change too greatly.

### *The Neoclassical Model*

Whereas the accelerator model proposes that businesses' demand for capital is nearly proportional to their planned rate of production, the neoclassical proposes that competitive businesses invest in order to maximize their profits. The demand for new capital, consequently, varies with output, the relative price of capital goods, interest rates, and the incidence of taxes (Jorgenson 1963; Hall and Jorgenson 1967; Jorgenson 1971). The neoclassical model, therefore, rests on a specific description of the economy's aggregate production function, which describes the maximal output that businesses can obtain from any stock of capital goods combined with other factors of production.

In maximizing their profits, competitive businesses choose the amount of capital that they must employ to meet the demand for their output at least cost. Competitive businesses, individually, cannot influence the prices at which they can sell their output or the prices that they pay to obtain capital goods or other inputs. Altogether, these businesses supply the output that their customers demand at prevailing prices when the economy is in equilibrium. In these circumstances, the economy's production function describes the amount of capital that businesses must employ in order to meet their customers' demand most profitably given prevailing prices.

The rate of return that competitive businesses earn on their optimal stock of capital equals their cost of employing this capital, which includes their cost of funds, their net tax liabilities, and their capital consumption charges. With common simplifying assumptions regarding the form of the production function, the optimal stock of capital in the neoclassical model is proportional to output divided by the cost of capital.[4] (See Appendix 1.)

$$K^* = \alpha \frac{Q^*}{UCC^*}.$$

As was the case for the accelerator model, the demand for new capital goods is then proportional to the difference between the optimal and the existing stocks of capital, because spending responds comparatively slowly to changes in the demand for output. Investors consider the recent history of both output and the cost of capital when they assess their potential need for capital goods in the future. Inasmuch as investors likely respond to changes in the course of output differently than they do to changes in the cost of capital, the neoclassical model admits two sets of lags for these variables (Bischoff 1971). To the degree these lags are to reflect investors' forecasts of output and the cost of capital, this model, much like the accelerator model, depends on correlations among current and past values of these variables remaining fairly stable over time. Like the accelerator model, the neoclassical model includes the lagged value of the stock of capital. Here too, its coefficient represents the rate at which investors renew and replace capital as well as the rate at which they intend to close the gap between their potential need for capital and their existing stock of capital.

The neoclassical model attempts to measure the otherwise unobservable but critical return on marginal investments by specifying investors' behavior in sufficient detail. This approach allows the model more latitude in explaining investment spending, especially when the ratio of output to capital in the economy varies significantly in response to changes in the cost of capital. However, if these specific assumptions misrepresent the behavior of investors too greatly, the model might be neither more general nor more accurate than other approaches that appear to be less rigorous. For example, if businesses recognize that their plans for supplying output influence prices and interest rates, then the neoclassical model might predict that investment rises too strongly in response to a higher demand for output or a drop in the cost of capital. Conversely, if a greater demand for output coincides with individual companies' loss of market power, then investment spending might exceed that predicted by the neoclassical model. Moreover, if the price of capital goods rises in response to businesses' demand for more capital, then investment can rise more than the change in the cost of capital might predict.

*The neoclassical model appeals to forecasters and policymakers because it attempts to define the optimal stock of capital by balancing the return on capital with the cost of capital, two important elements in most theories of investment.*

Nonetheless, the neoclassical model appeals to forecasters and policymakers because it attempts to define the optimal stock of capital by balancing the return on capital with the cost of capital, two important elements in most theories of investment. The explicit representation of the cost of capital in the model also shows how changes in economic policy directly influence the demand for capital.

[4] The production function is Cobb-Douglas, businesses are perfect competitors who minimize the cost of producing a given output, factors of production are paid their marginal products, capital markets also are perfectly competitive, and investors, who have identical assessments of future conditions, use linear extrapolations of recent economic conditions to form their expectations of future conditions. The Cobb-Douglas production function fixes the elasticity of substitution between factors of production at 1, implying that labor's and capital's shares of output are constant. In the national accounts, capital's share is relatively constant near 1/3; labor's share, near 2/3.

### *A Modified Neoclassical Model*

An alternative version of the neoclassical model proposes that the stock of capital expands at a rate that is a constant fraction of the rate required to reach its optimum. This alternative view also happens to separate the influence of output on investment from that of the cost of capital, rather than binding them in one variable. Not only does this approach allow past values of output and the cost of capital more distinct weights, it also allows the model to compare the contributions of output and the cost of capital in explaining investment spending.

Suppose the expansion of the stock of capital is a function of the ratio of the optimal to the existing stock of capital.[5]

$$\frac{K_t}{K_{t-1}} = \left(\frac{K_t^*}{K_{t-1}}\right)^{\lambda} \qquad 0<\lambda<1$$

$$\frac{I_t^n}{K_{t-1}} = \frac{\Delta K_t}{K_{t-1}} \approx \lambda \cdot (\log(K_t^*) - \log(K_{t-1}))$$

$$\frac{I_t^g}{K_{t-1}} = \frac{\Delta K_t}{K_{t-1}} + \delta \approx \lambda \cdot (\log(K_t^*) - \log(K_{t-1})) + \delta.$$

This description of investment, when combined with the expression for the optimal stock of capital that appears in the neoclassical model, yields a model that distinguishes the contribution of output from that of the cost of capital.

$$\log(K_t^*) = \log(\alpha) + \log(Q^*) - \log(UCC^*).$$

This division, which conveniently separates the contribution of output from that for the cost of capital, recognizes more discretely any differences in the magnitude and timing of investment's response to these variables.[6, 7]

### *The q Model*

The q model proposes that the demand for capital varies directly with the ratio of the market value of the capital assets of businesses to the replacement value of those assets. This ratio, q, essentially compares the return on capital with the rates of return required by investors who finance that capital. Values of q that exceed unity foster investment spending, while values of q that are well below unity depress the demand for new capital goods (Tobin 1969, 1982).

*The q model proposes that the demand for capital varies directly with the ratio of the market value of the capital assets of businesses to the replacement value of those assets.*

The description of the demand for capital behind the q model is as old as financial theories of investment. Investors' demand price for capital derives from the present value of the returns they expect to earn from their investment. When this demand price exceeds the cost of acquiring capital, investment spending increases. As the rate of investment rises, the supply price of capital tends to rise. As the stock of capital rises, the most profitable investment opportunities are exhausted, and the demand price for capital falls. Eventually, the demand and supply prices of capital will become more nearly equal, thereby reducing the rate of investment spending.

This theory applies to existing capital assets as well as new capital goods. Financial markets continually assess companies' prospective returns. The resulting valuation of their equity and debt securities is the demand price for their assets. When companies' prospective returns rise relative to the rates of return required by their shareholders and creditors, then the value of their securities will increase relative to the book or replacement value of their capital assets. Accordingly, q was relatively high when the returns on capital were relatively high in the 1960s and 1990s, and q was lowest when returns were lowest in the late 1970s and early 1980s (Figure 2).

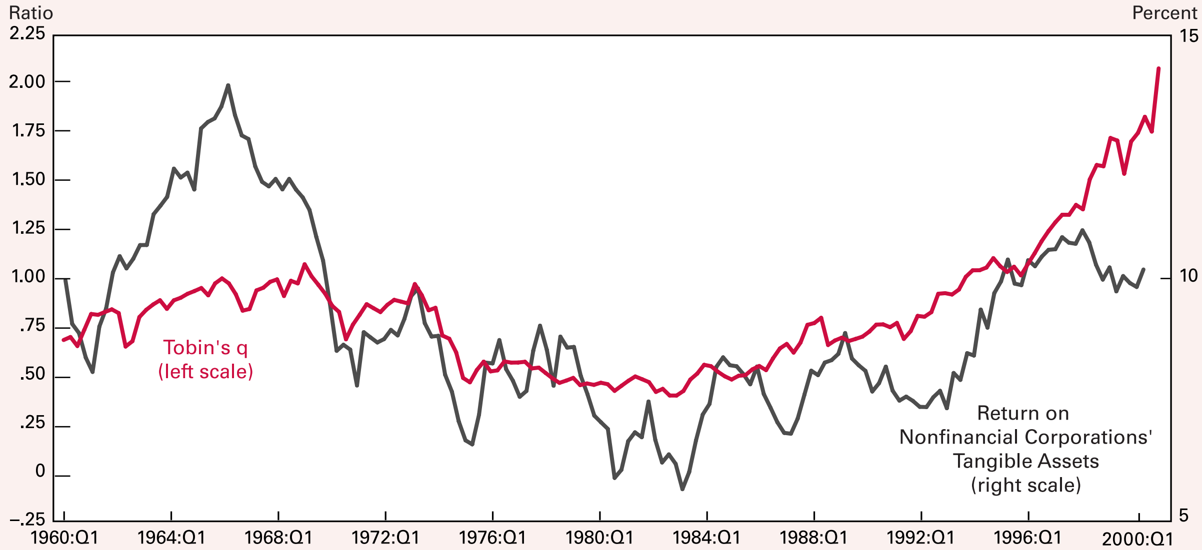
[5] The second and third lines of the expression below follow from the first because the log of the left side of the first line approximately equals the rate of growth of the stock of capital.

[6] If the elasticity of substitution between capital and labor were a constant other than 0 or 1, as in a constant elasticity of substitution (CES) production function, its value would be reflected in the difference between the sums of the lag coefficients on the terms for output and the user cost of capital.

[7] The use of logs of the values of output and the cost of capital presumes that the statistical processes for the rates of growth of these variables are stable. Because this article estimates the other models with all variables expressed as proportions of the stock of capital, these models also essentially presume stable processes for the rates of growth of output, the cost of capital, and cash flow.

Figure 2

*Tobin's q and the Return on Nonfinancial Corporations' Tangible Assets*




Source: Return on nonfinancial assets is calculated using data from the *Flow of Funds Accounts of the United States*, Board of Governors of the Federal Reserve System. Tobin's q is generated with data from the *Flow of Funds Accounts*, the New York Stock Exchange *Fact Book*, and Haver Analytics, as defined in Appendix II.

The version of the q model that appears in this article simply uses a short history of q to explain investment. These fixed lags would represent investors' optimal forecasts of future values of q if the correlations among the values of q remained relatively stable over time.

Because a direct measure of q reflects the value of both existing capital assets and potential investments, it does not isolate incentives for undertaking new investments (Hayashi 1982). For example, should markets for companies' products become more competitive, the rate of return on their existing capital assets might not rise as much as that on new investment opportunities. In these circumstances, the average value of q would understate investors' demand for new capital goods. q also might represent the incentives for investment poorly if existing assets cannot adapt to new tasks or technologies very economically.[8] Should a new technology raise the value of new investments more than that of existing assets, investment spending could rise more than q would predict.

Some models of q, therefore, extend the basic theory with more explicit assumptions about investors' behavior and with more explicit descriptions of production functions, demand curves for output, supply curves for inputs, and other features that govern investors' decisions. These approaches often imply a value for q on new investments.[9] In most cases, these extensions yield investment equations that, like the neoclassical model, depend on output, prices, and the cost of capital (Abel 1980; Hyashi 1982; also Abel et al. 1996).

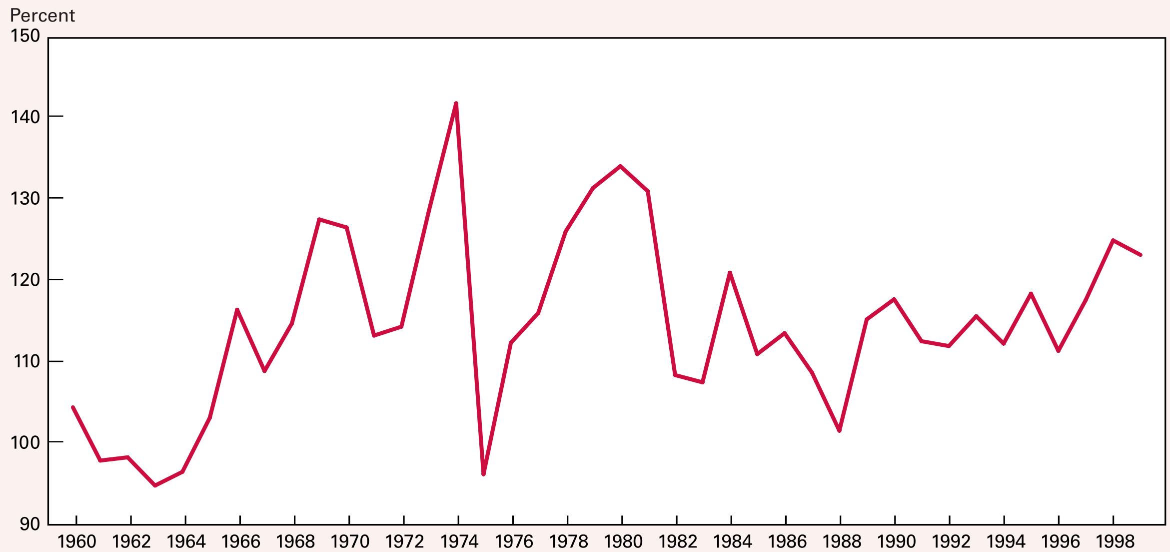
The versions of this model that use direct measures of q (or of marginal q) are not very popular among forecasters or policy analysts. The difficulty of identifying marginal and average returns can compromise the performance of the model (Abel and

[8] See, for example, Pindyck (1991). If companies cannot adjust their employment of capital and other factors of production without cost, companies are not perfectly competitive, factors of production do not earn their marginal products, tax considerations alter the value of new capital goods relative to existing capital, or not all investors expect capital assets to earn the same return, then the simple description of q and its relation to the demand for capital can be misleading. See, for example, Galeotti and Schiantarelli (1991).

[9] These models also typically define a functional relationship between q and marginal q. Accordingly, their descriptions of investment in terms of marginal q induce investment functions in terms of q itself. If investors believe their actions influence prices, however, neither q nor marginal q likely provides a "sufficient statistic" for investment spending.

Figure 3

*Nonfinancial Corporations' Investment Relative to Cash Flow*




Source: The ratio of investment to cash flow from the *Flow of Funds Accounts* is defined as capital outlays for nonfinancial businesses divided by their internal funds.

Blanchard 1986). Moreover, projecting the prices of stocks and bonds in the future is more daunting than forecasting investment by other means. Nevertheless, the q model does provide one way of gauging the degree to which the recent surge in stocks' prices might correspond to the increase in investment spending.

### *The Cash Flow Model*

The previous descriptions of investment essentially assume that the demand for capital goods does not depend very greatly on the means by which investors finance their capital spending. In the neoclassical and q models, the provision of financing affects the demand for capital only by altering the cost of funds that are available to companies in fully efficient capital markets, provided by fully informed suppliers. The cash flow model recognizes that businesses rely on three sources of funds—internal cash flow, new debt, and new equity—and that the yields on debt and equity do not represent the full cost of using these funds (Meyer and Kuh 1957; Duesenberry 1958; Grundfeld 1960; Lintner 1967; and Myers and Majluf 1984).

Cash flow—profit after taxes plus depreciation allowances less payments to shareholders—constitutes the principal source of financing companies' capital budgets. Since the 1940s, nonfinancial corporations' purchases of capital goods seldom have strayed from their cash flow for very long (Figure 3).[10] Accordingly, businesses' internal cash flow has consistently represented more than 85 percent of their capital budgets. The highest peaks in spending relative to cash flow tend to occur when profits fall more abruptly than capital spending during recessions.

Debt financing includes public issues of bonds or commercial paper, private placements, loans, leases, and other securities that usually offer creditors predetermined yields and claims against the earnings or assets of businesses. Since the 1940s, debt financing typically has accounted for virtually all of the net external financing of businesses' inventories, plant, and

[10] Not only do nonfinancial corporations provide internal capital markets for funding their own projects, but they also support the capital spending of other companies through equity investments, loans, mergers, leases, joint development or marketing agreements, and other alliances (Gomes-Casseres 1996; Navin and Sears 1955; Baskin 1988; Baskin and Miranti 1997; Carosso 1970).

equipment. New issues of equity, which include common and preferred stock or partnerships, seldom have represented a substantial source of funds since 1960.

Not only do businesses use debt to finance their investment spending when their opportunities exceed their cash flow, they also might reduce their average cost of capital by financing a portion of their capital assets with debt. Businesses can deduct their interest payments from their taxable income; they cannot deduct their payments to their shareholders. Nonetheless, the appeal of debt financing eventually diminishes as managers and shareholders incur a larger risk of losing control of their companies with greater leverage.[11] Moreover, when creditors are less optimistic than borrowers, companies will regard the risk premiums that they must pay on their debt as increasingly excessive as their leverage increases.[12] An optimal degree of leverage balances the advantages of debt financing against its costs.

Businesses whose demand for new capital assets greatly exceeds their cash flows eventually might issue new equity in conjunction with their debt in order to maintain a satisfactory degree of leverage. Because new shareholders, almost by definition, are less optimistic and less assured than existing shareholders, they generally require a greater rate of return than existing shareholders. This new equity financing typically is sufficiently expensive to be a last resort, undertaken only when it brings more competent management, allows existing owners to liquidate or diversify their assets, or enables companies to expand sufficiently rapidly to secure greater economic rents without incurring excessive leverage.

Cash flow serves two purposes. It finances capital budgets and, in reflecting the return on existing assets, it can represent the return investors might expect of new investments. The terms that contain lagged cash flows in the model represent both the adjustment of capital budgets to recent experience and the projection of future earnings from past earnings. These lags also may represent changes in companies' optimal choice of leverage. Because this model typically finds that investors respond slowly to changes in the growth of their cash flow, it predicts that companies' leverage rises when the growth of their earnings subsides and that leverage falls when their earnings accelerate.

### *The Time Series Model*

Unlike the other approaches discussed in this article, the time series model appeals to no explicit theory. Investment spending depends on its history and the history of a few related variables. This model assumes that the trends and cycles evident in recent experience are sufficiently stable to describe the course of capital spending in the future. This approach may be regarded as a model in its own right or as a standard whereby other models may be judged.

*The time series model appeals to no explicit theory: Investment spending depends on its history and the history of a few related variables.*

The time series model's simple appearance belies the reasoning upon which it rests. Investment can depend on many economic variables, all of which are embedded in a larger model of the economy. If, according to this model, these variables mutually depend on their lagged values, then an autoregression can represent investment spending when the full model of the economy is sufficiently linear and the statistical processes for its exogenous variables do not change over time. This autoregression could express investment simply in terms of its own lagged values, or it also could include the lagged values of other variables. This study's version uses both past investment and output to explain investment spending.

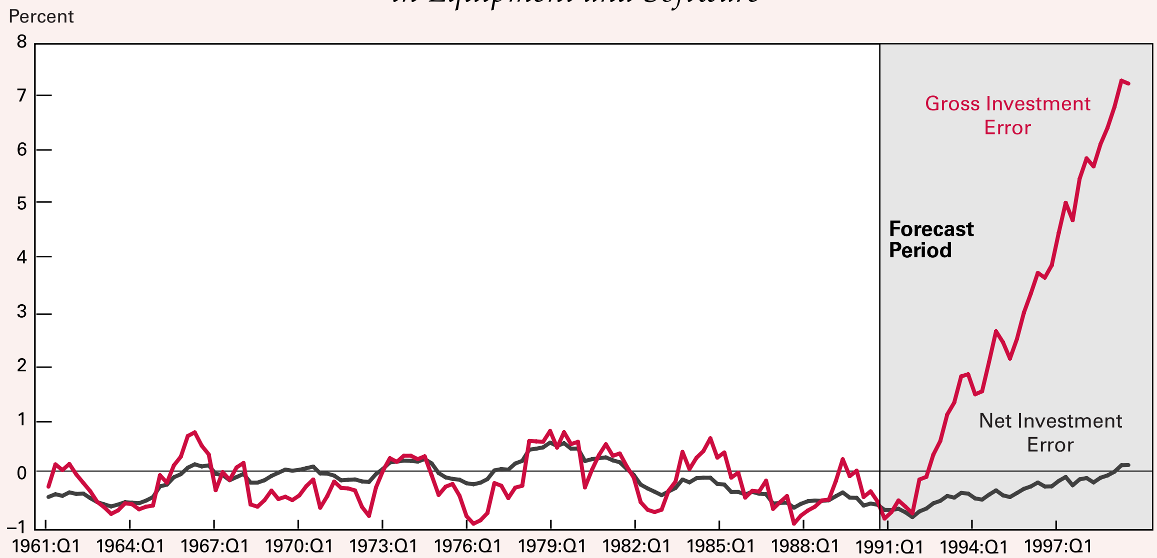
Although time series models impose their own strong assumptions, proponents of this approach believe that other models require even stronger assumptions. To what degree does output determine investment, or does investment determine output, or are both determined by some other common factors? In order to cope with these distinctions, models

[11] Borrowers assume commitments and constraints that inherently increase the cost of their funds as their leverage increases. Debt contracts entitle creditors to a senior claim against borrowers' assets. These contracts also can impose minimum loan-to-value ratios, coverage ratios (earnings relative to debt service charges), working capital ratios (net short-term assets relative to long-term debt), or other restrictions on borrowers. Should a company fail to meet these standards, it cedes some control over its operations to its creditors.

[12] When creditors and shareholders have identical discount rates and regard a company's prospects similarly, when interest expenses are taxed the same as other corporate income, and when bankruptcy costs are negligible, then the company's average cost of capital (combining debt and equity financing) is independent of its leverage (Modigliani and Miller 1958, 1963; Duesenberry 1958; Lintner 1967; Myers 1989).

Figure 4

*Modified Neoclassical Model's Errors in Projecting Investment in Equipment and Software*




invoke assumptions about the behavior of businesses, the structure of markets, and other potentially controversial characteristics of the economy. If output and the cost of capital do not determine investment spending, for example, the accelerator and neoclassical models are misspecified. The time series model avoids these problems by analyzing the dynamics of investment and related variables. But, in order to measure these dynamics, it assumes that the correlations among these variables remain stable over time.

However accurately autoregressions might forecast investment, they tell no stories. They cannot explain why a tax cut might foster more investment spending than a commensurate reduction in interest rates. Forecasting that investment will increase 10 percent might not be as important as describing the reasons that demand likely will increase at this pace. Forecasts frequently are judged by this reasoning. Furthermore, should changes in policy or the business environment alter the correlations among the variables over time—which, for example, often is the intention of policymakers or the consequence of technological changes—then the time series model could fail to explain the course of investment. Autoregressions are not uniquely vulnerable in this regard. But, other models hope to achieve greater stability by modeling the structural determinants of investment more explicitly, thereby more fully incorporating the consequences of policy in the model itself.[13] The neoclassical model, for instance, allows changes in corporations' taxes to influence investment's response to output.

## III. The Performance of the Models

This article estimates the six models of investment spending from 1960 to 1990, applying each model to each of the two major components of businesses' fixed investment, durable equipment and software and nonresidential structures. The estimated models were then used to predict investment from 1991 to 1999.

[13] Correlation coefficients among variables are not necessarily stable when they depend on values assumed by other variables or when variables are bound by nonlinear relationships. Models attempt to uncover more stable statistical relationships by recognizing the structural links among variables (Haavelmo 1944; Duesenberry 1948; B. Friedman 1978; Sims 1982).

Table 6
*Selected Statistics for the Investment Period 1960:I to 1990:IV for the Models of Investment*
Percent

| Model | Mean Absolute Error | Root Mean Squared Error | Percent of Absolute Errors Exceeding 0.66 std | Percent of Absolute Errors Exceeding 1.5 std | Autocorrelation Coefficient | Number of Lags |
|---|---|---|---|---|---|---|
| Equipment | | | | | | |
| Time Series | .05 | .07 | .0 | .0 | .01 | 4 |
| Accelerator | .26 | .32 | 34.5 | .9 | .95 | 12 |
| Neoclassical | .34 | .40 | 56.9 | 8.6 | .97 | 12 |
| Modified Neoclassical | .25 | .31 | 40.8 | 1.7 | .97 | 8 |
| q Model | .30 | .35 | 49.1 | 3.4 | .95 | 12 |
| Cash Flow | .33 | .41 | 51.7 | 5.2 | .96 | 12 |
| Structures | | | | | | |
| Time Series | .03 | .04 | 1.6 | .0 | –.00 | 4 |
| Accelerator | .11 | .13 | 45.7 | .9 | .94 | 12 |
| Neoclassical | .10 | .12 | 39.7 | .9 | .94 | 12 |
| Modified Neoclassical | .08 | .10 | 28.7 | .8 | .92 | 6 |
| q Model | .10 | .12 | 40.0 | .9 | .94 | 12 |
| Cash Flow | .10 | .12 | 35.7 | 1.7 | .94 | 12 |

The time series model appears to fit spending best through 1990 and forecast best during the remainder of the 1990s. The other models at best fit spending only moderately well until the late 1980s, when their predictions generally began to exceed the rate of investment by a substantial margin. After 1990, the models' forecasts initially continued to exceed investment in equipment and software, but their errors generally fell significantly by 1999. Their forecasts of investment in nonresidential structures, however, continued to exceed spending by a substantial margin throughout the 1990s.

### *Estimating the Models*

The estimates of each model reflect the historical correspondence between investment spending and other macroeconomic variables. As a result of the shift in the composition of the stock of durable equipment toward information processing equipment, which became especially great during the 1990s (Table 2), none of the models for *gross* investment in equipment and software forecasted this spending very well after 1990. The neoclassical model, for example, predicted too little gross investment spending relative to the stock of capital during this interval, because its implicit estimate of the rate of depreciation of capital became too low when the composition of the stock of equipment shifted (Figure 4). The model's forecast of *net* investment, on the other hand, is significantly more accurate.

Because models of aggregate investment, by design, omit the finer details associated with the composition of capital and investment, the rate of depreciation of capital, which has risen especially sharply in recent years, is outside their ken.[14] Accordingly, the following describes the performance of the equations for net investment spending. The structure of each model corresponds to the equations that appear in Table 5, except that all equations are divided by the lagged value of the capital stock. The models, therefore, explain the rate of growth of the stock of nonresidential structures and the stock of equipment and software.

Table 6 describes the models' abilities to fit the data through 1990. Figures 5 through 8 also show the correspondence between the models' projections and the course of investment for the period of estimation, which ends at the vertical line. In general, the models explained the course of investment in equipment and software better than that for structures. The times

[14] The figure also shows that the rate of growth of capital has been more volatile than gross investment. In the early 1970s, for example, the rate of growth of capital varied between 1 and 2 percent, while investment relative to capital varied between 0.12 and 0.15 percent. This discrepancy can be attributed partly to variations in depreciation, mostly to variations in the valuation of the components of the aggregate stock of capital. (See Appendix 1.)

Table 7
*Selected Statistics for the Forecast Period 1991:I to 1999:IV for the Models of Investment*
Percent

| Model | Mean Error | Mean Absolute Error | Root Mean Squared Error | Percent of Absolute Errors Exceeding 0.66 std | Percent of Absolute Errors Exceeding 1.5 std |
|---|---|---|---|---|---|
| Equipment | | | | | |
| Time Series | .03 | .07 | .09 | .0 | .0 |
| Accelerator | .20 | .42 | .50 | 61.1 | 16.7 |
| Neoclassical | –.51 | .51 | .56 | 80.6 | 25.0 |
| Modified Neoclassical | –.21 | .27 | .33 | 36.1 | 2.8 |
| q Model | –.64 | .64 | .66 | 100.0 | 33.3 |
| Cash Flow | –.24 | .32 | .39 | 38.9 | 13.9 |
| Structures | | | | | |
| Time Series | –.02 | .02 | .03 | .0 | .0 |
| Accelerator | –.27 | .27 | .30 | 86.1 | 52.8 |
| Neoclassical | –.41 | .41 | .42 | 100.0 | 100.0 |
| Modified Neoclassical | –.35 | .35 | .35 | 100.0 | 94.4 |
| q Model | –.42 | .42 | .43 | 100.0 | 97.2 |
| Cash Flow | –.33 | .33 | .34 | 100.0 | 77.8 |

series model fit the data best for both components of investment. Of the remaining models, the modified neoclassical model performed best.

The times series model fits investment in equipment and software remarkably accurately, conforming to almost 98 percent of the variation in spending.

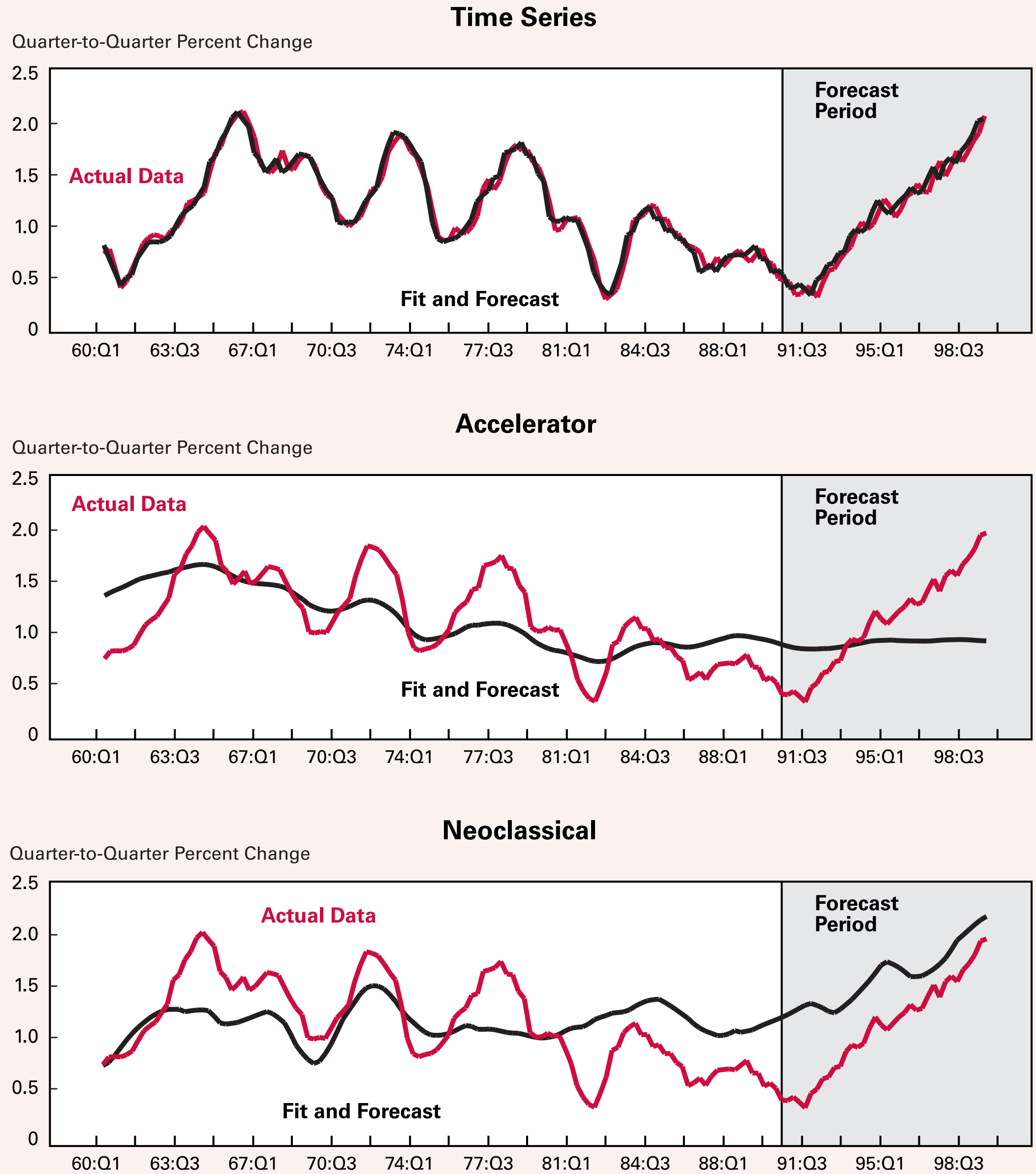
*The time series model appears to fit spending best through 1990 and forecast best during the remainder of the 1990s.*

Nonetheless, its fitted values reached their peaks or troughs one quarter after those of investment, a seemingly minor quibble that can suggest greater problems when using the model to forecast investment very many quarters in advance. The accelerator model explained only about 46 percent of the variation in spending. The peaks and troughs of its fitted values also follow those of investment, albeit with a longer lag than the time series model, and the pattern of its fitted values corresponds to that of investment much less closely than did the projections of the time series model. The modified neoclassical model, which explained about 51 percent of the variation in spending, conformed to the data better than the neoclassical model, which explained only 11 percent. In the late 1970s both of these equations, like the accelerator model, failed to follow the substantial acceleration of investment. They then failed to reflect the drop in investment during the last half of the 1980s. The q model's projections, which varied much less than those of the other models, nevertheless explained about 34 percent of the variation in spending. It, too, failed to reflect the surge in capital formation in the late 1970s followed by the subsidence in the early and late 1980s. The cash flow model explained about 11 percent of the variation in spending as a result of its relatively large errors in the mid 1960s and 1980s.

The times series model explained about 92 percent of the investment in nonresidential structures, a performance much better than that of the other models. The time series model's one-quarter lag in explaining spending on new structures, like that for equipment and software, suggests a potential difficulty with the model, however. The accelerator model failed to conform to the data, explaining only about 3 percent of the variation in spending. Again, the modified neoclassical model, which explained about 33 percent of spending, fit the data better than the neoclassical model, which explained only 11 percent. Neither

Figure 5

*Growth in Stock of Equipment and Software*



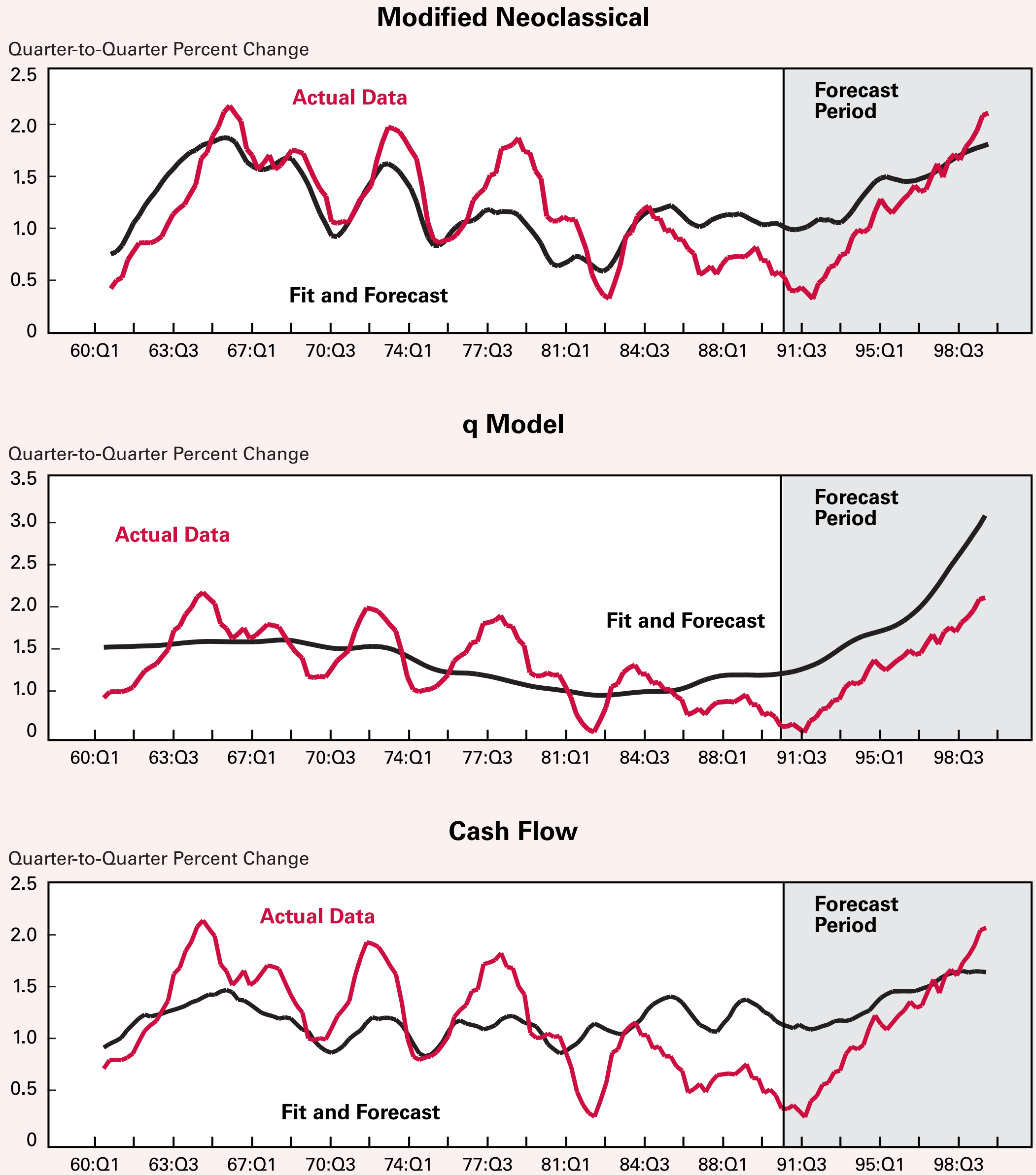

explained the pattern of investment during the 1980s particularly well, but the modified neoclassical model benefited by projecting a lower average rate of net investment. The q model, like the accelerator model, failed to conform to the data, explaining only 4 percent of investment. The cash flow model explained about 20 percent of spending. It, like the neoclassical models, failed to conform to the data for the 1980s very well and could not explain the significant drop in nonresidential construction during the late 1980s.

### *The Forecasts*

Table 7 and Figures 5 through 8 describe the forecasts of the six models of investment. These forecasts use the actual values of the variables that appear on

Figure 5, con't

*Growth in Stock of Equipment and Software*

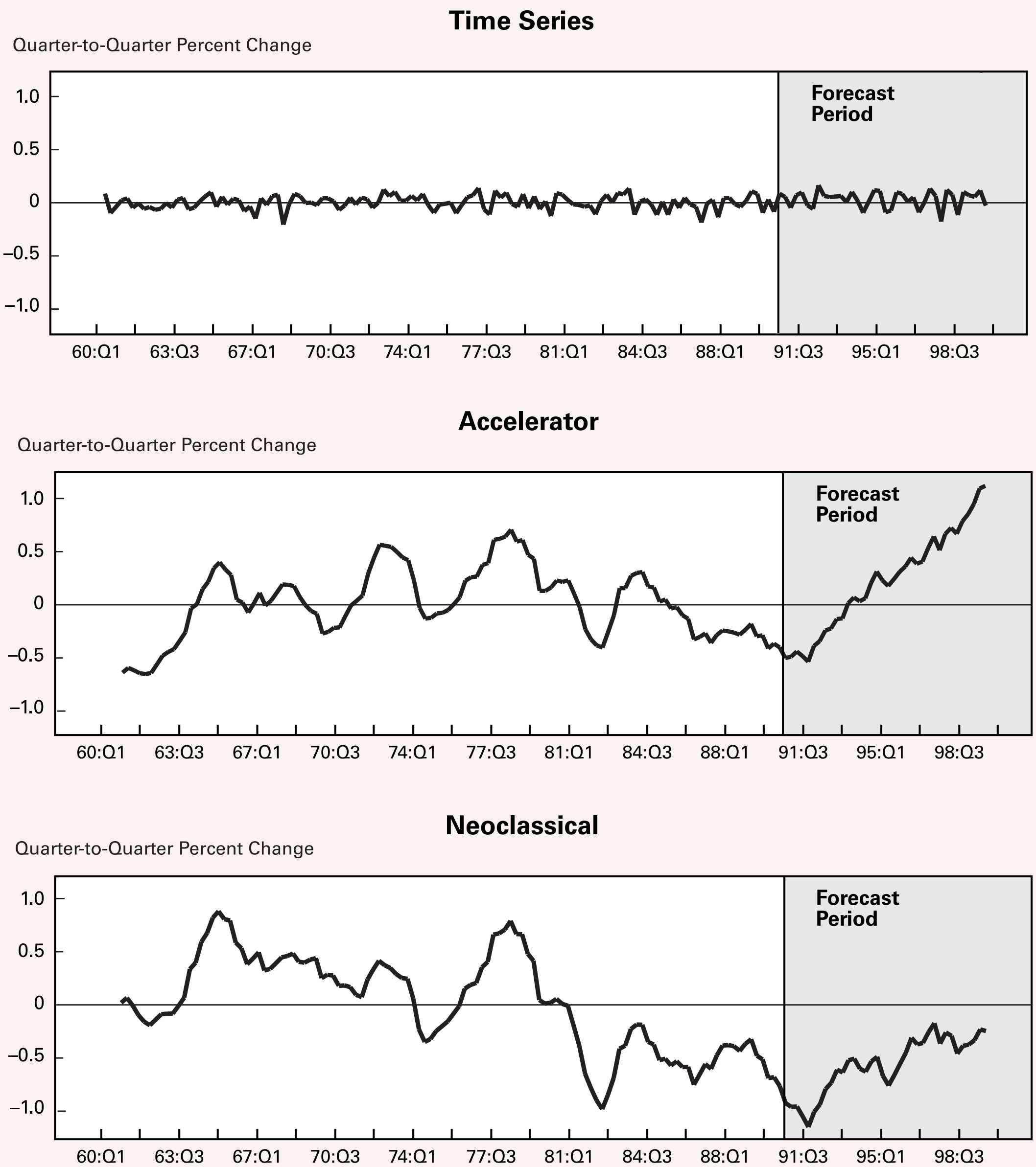



the right side of the equations combined with the estimates of the coefficients from the data before 1991. The statistics in Table 7 indicate that the models' average errors after 1990 are generally greater than their errors over their period of estimation. Statistical theory counsels tolerance in this regard: Models' errors ordinarily increase as they are applied to new data that differ substantially from the data over which they were estimated. By this standard, the models' errors for equipment and software are small compared to their errors before 1991. The comparatively large errors for nonresidential structures, however, suggest that all models except the times series model continued to misrepresent construction as badly as they did in the late 1980s.

The time series model for investment in equipment and software performs nearly as well after 1990

Figure 6

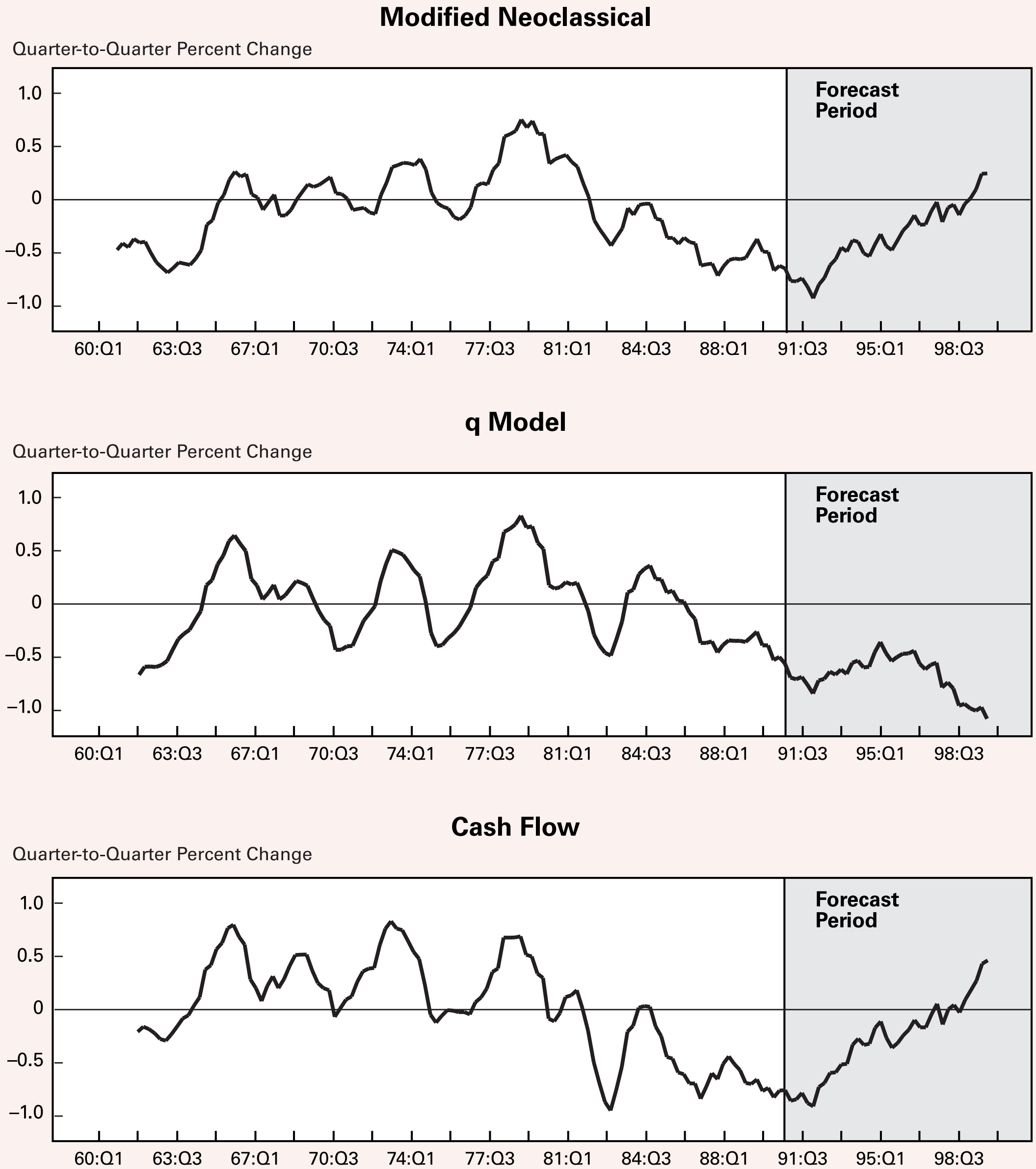
*The Models' Errors in Projecting Growth in Stock of Equipment and Software*




as it did over the years to which it was fitted. Its one-quarter lag in forecasting spending persists throughout the forecast interval. Given that the remaining models had missed the subsidence in spending on equipment and software during the late 1980s, a slump that continued into the early 1990s, the forecasts of most of these models recovered after 1992. The accelerator model's forecasts least resemble the course of spending—its forecast of a constant rate of growth of capital strongly misrepresents the surge in investment. Both of the neoclassical equations, which anticipated too much spending in the early 1990s, described the especially strong rise in spending after 1993. The neoclassical model's average error was greater than that of the modified neoclassical model over this interval, partly because it continued to pre-

Figure 6, con't

*The Models' Errors in Projecting Growth in Stock of Equipment and Software*

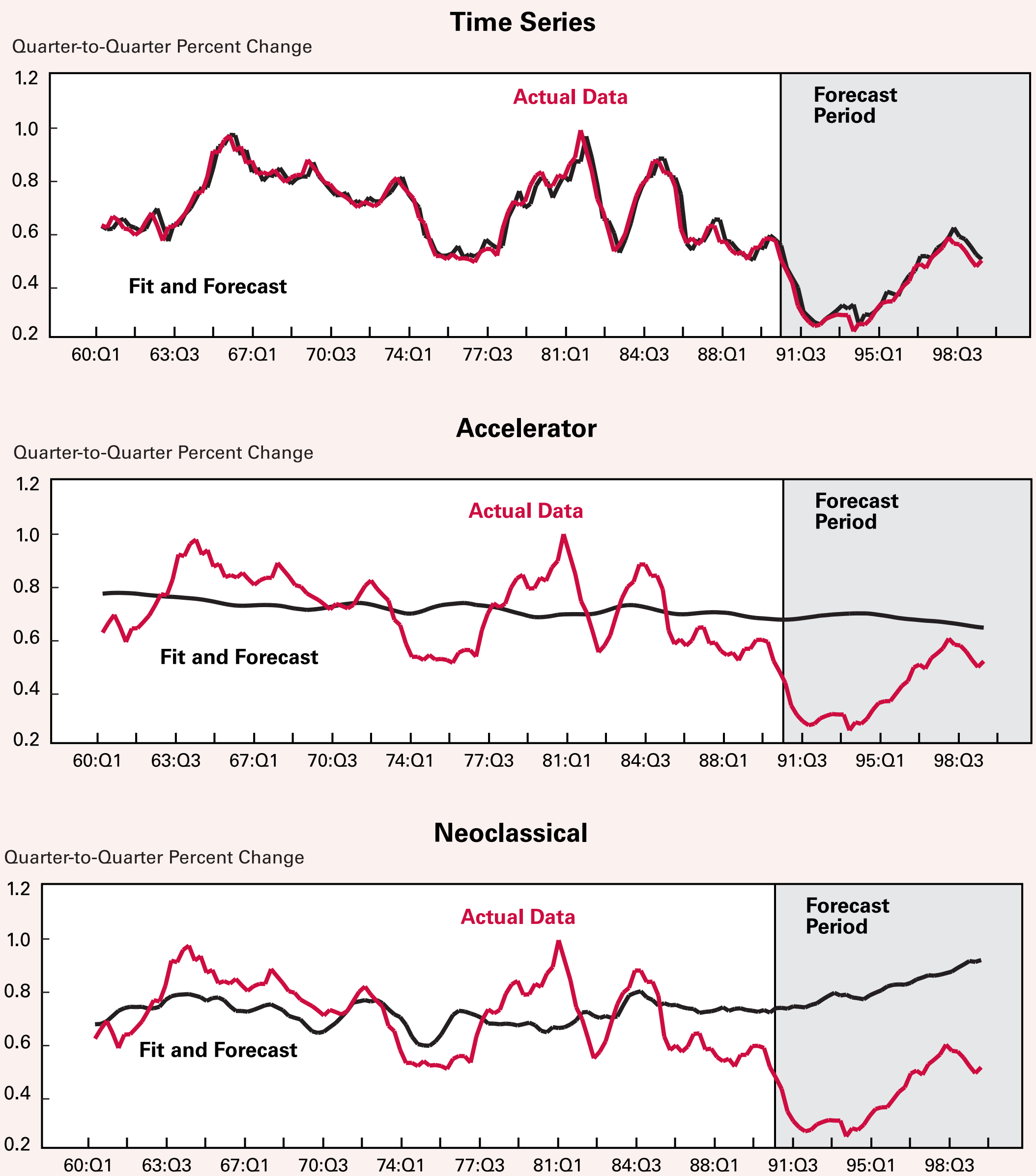



dict a higher average rate of spending. However, the neoclassical model predicted the acceleration of spending during the late 1990s better than the modified model. Although the q model also erred substantially during the 1990s by consistently forecasting an excessive rate of spending, the model did forecast the acceleration of spending relatively well until 1999, when its error increased. The cash flow model, like the modified neoclassical model, began the forecast interval by forecasting too much investment. But, its error over the interval fell, because it failed to forecast the strong acceleration in capital formation—spending overtook its forecast.

The time series model for investment in nonresidential structures performed nearly as well after 1990 as it did over the years to which it was fitted. Its one-

Figure 7

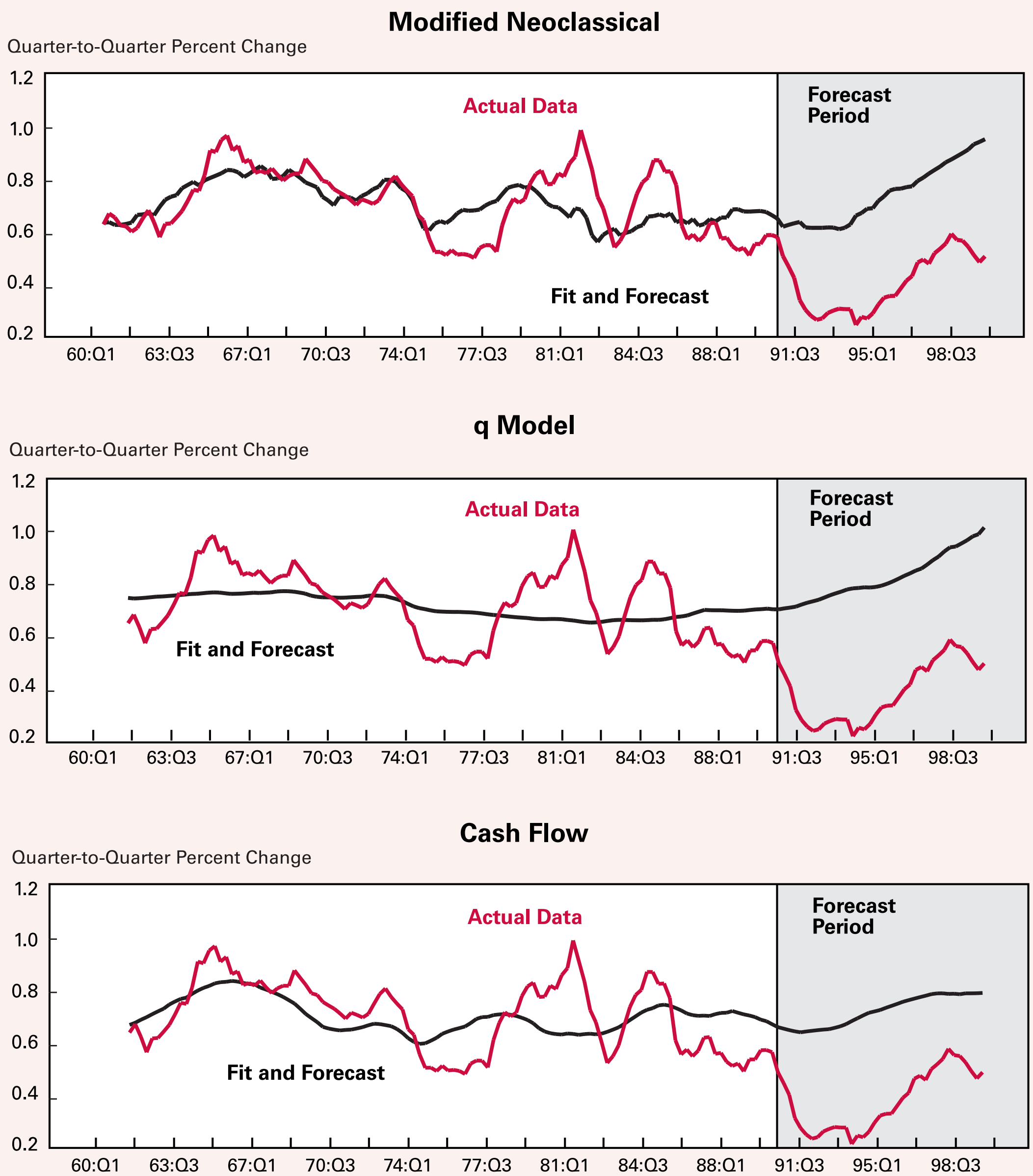
*Growth in Stock of Structures*




quarter lag in forecasting spending persisted throughout the forecast interval. The other models forecasted investment in nonresidential structures poorly. After failing to explain a substantial drop in investment during the first third of the decade, their errors remained large throughout the 1990s. This performance suggests that a significant shift in the demand for structures occurred in the late 1980s or early 1990s, a shift unrelated to the price of structures or to businesses' earnings, sales, and cost of capital. The neoclassical and q models generally forecasted steady growth in the stock of structures throughout much of the 1990s. For about half of this period, however, investment in structures fell and remained remarkably low. Although this investment subsequently recovered strongly, it did not exceed the rela-

Figure 7, con't

*Growth in Stock of Structures*



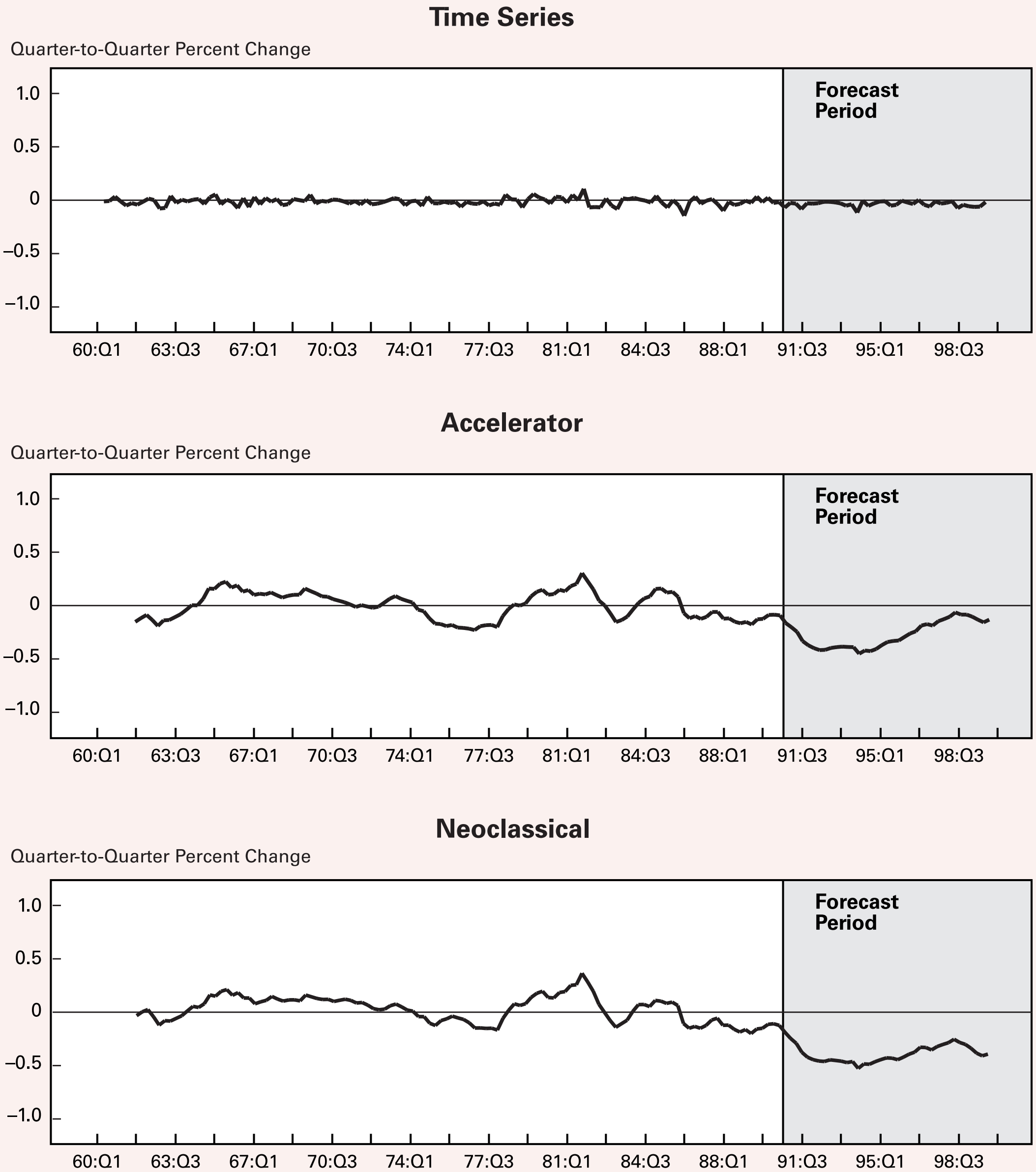

tively modest rates it attained in 1989 and 1990. Not only did the gap between the forecasts and spending remain large in the 1990s, but the neoclassical and q models also failed to reflect the pattern of investment, especially the slump in spending at the end of the decade. Although the performance of the cash flow model generally resembles those of the neoclassical and q models, the cash flow model's forecast stops rising in 1998 at the time that the growth of the stock of nonresidential structures fell.

### *Diagnosis*

The time series model is the only model that uses lagged investment to explain current investment, a characteristic that is both an asset and a liability. The

Figure 8

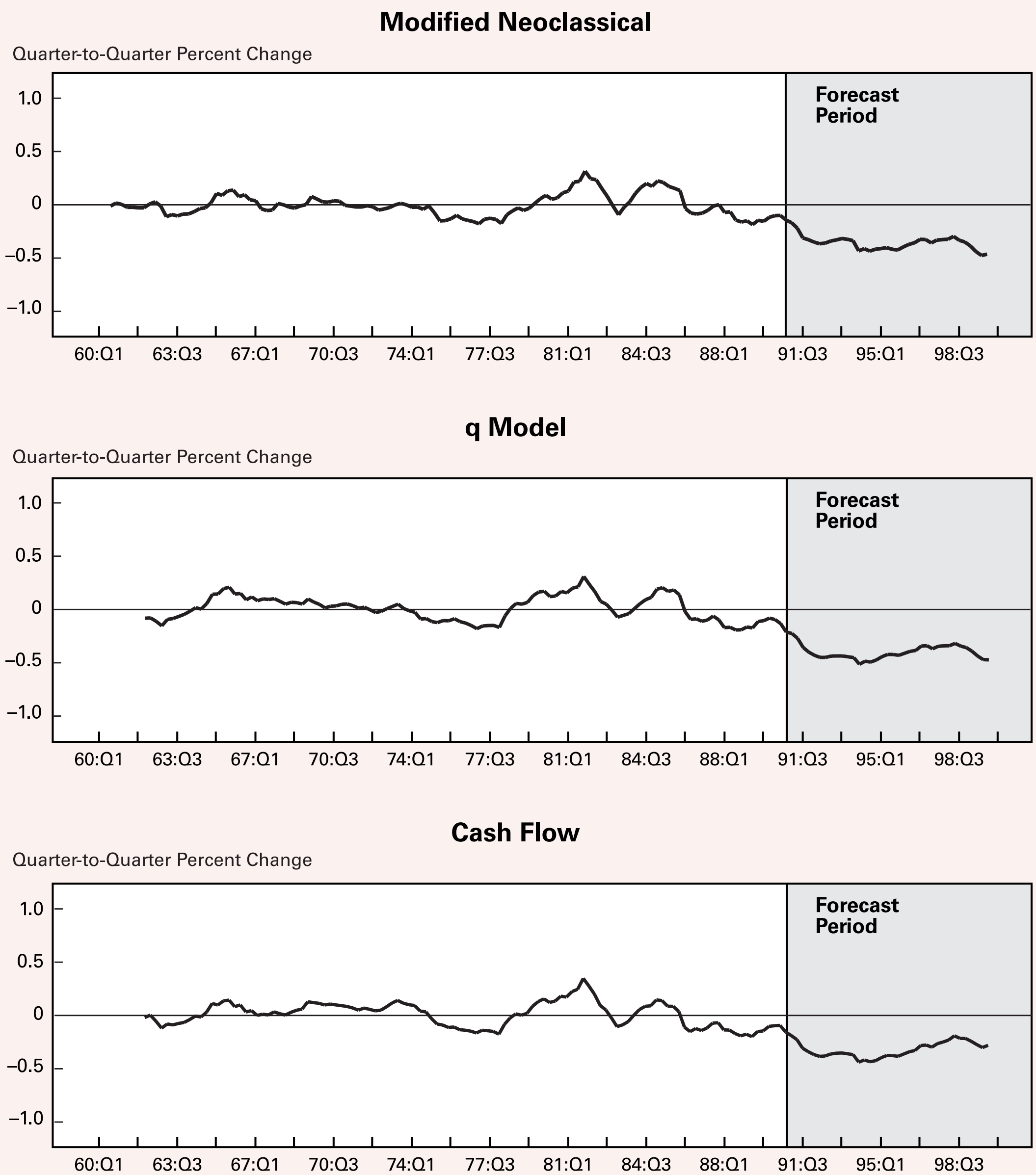
*The Models' Errors in Projecting Growth in Stock of Equipment and Software*




time series model's success rests on the inertia in capital formation over the past four decades. Within the context of this model, last quarter's rate of growth of the stock of capital provides more than 90 percent of the information for its forecast. The contribution of growth in earlier quarters or of output is very modest by comparison. Accordingly, the inertia in capital formation allowed the model to explain investment one quarter in advance during the 1990s as accurately as it had in the previous 30 years. On the other hand, this strong dependence on last quarter's investment caused its longer-run forecasts of capital formation to deteriorate steadily. Without a constant correction, its forecast would more nearly resemble that of the accel-

Figure 8, con't

*The Models' Errors in Projecting Growth in Stock of Equipment and Software*



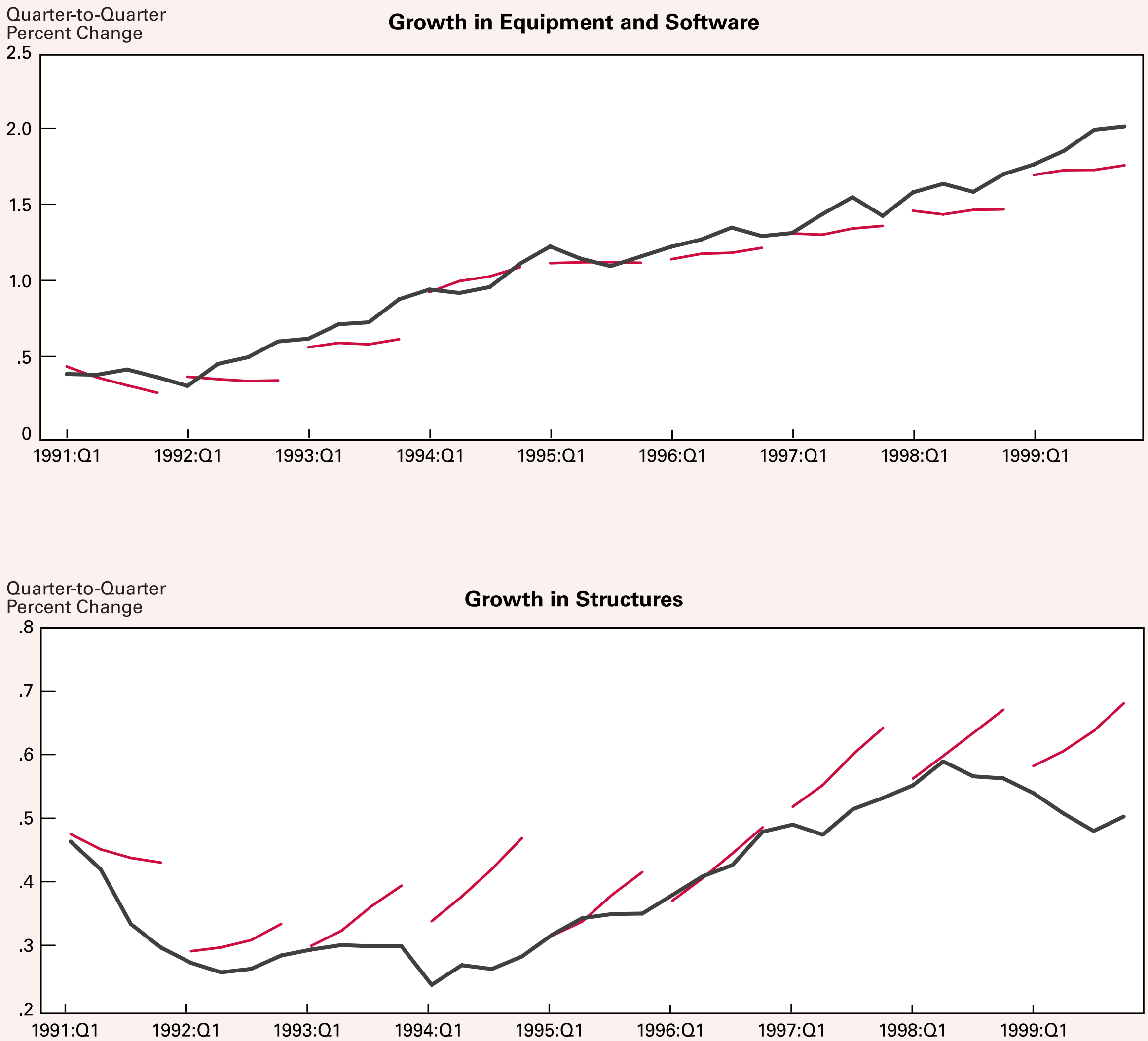

erator model (Figure 9).[15] Conversely, if the other models were allowed to take into account their previous period's error, their performance would resemble more closely that of the time series model. Without these constant corrections, however, we can see more clearly the models' ability to explain the determinants of capital formation, particularly over intervals longer than one quarter.

The accelerator model's failure can be attributed to its attempt to reconcile its presumption of a

[15] Because their errors are highly correlated (Table 6), the other models would fit the data and forecast spending much more accurately by taking last quarter's forecast error or, equivalently, last quarter's spending into account.

Figure 9

*Time Series Model's Dynamic Forecast of Growth*

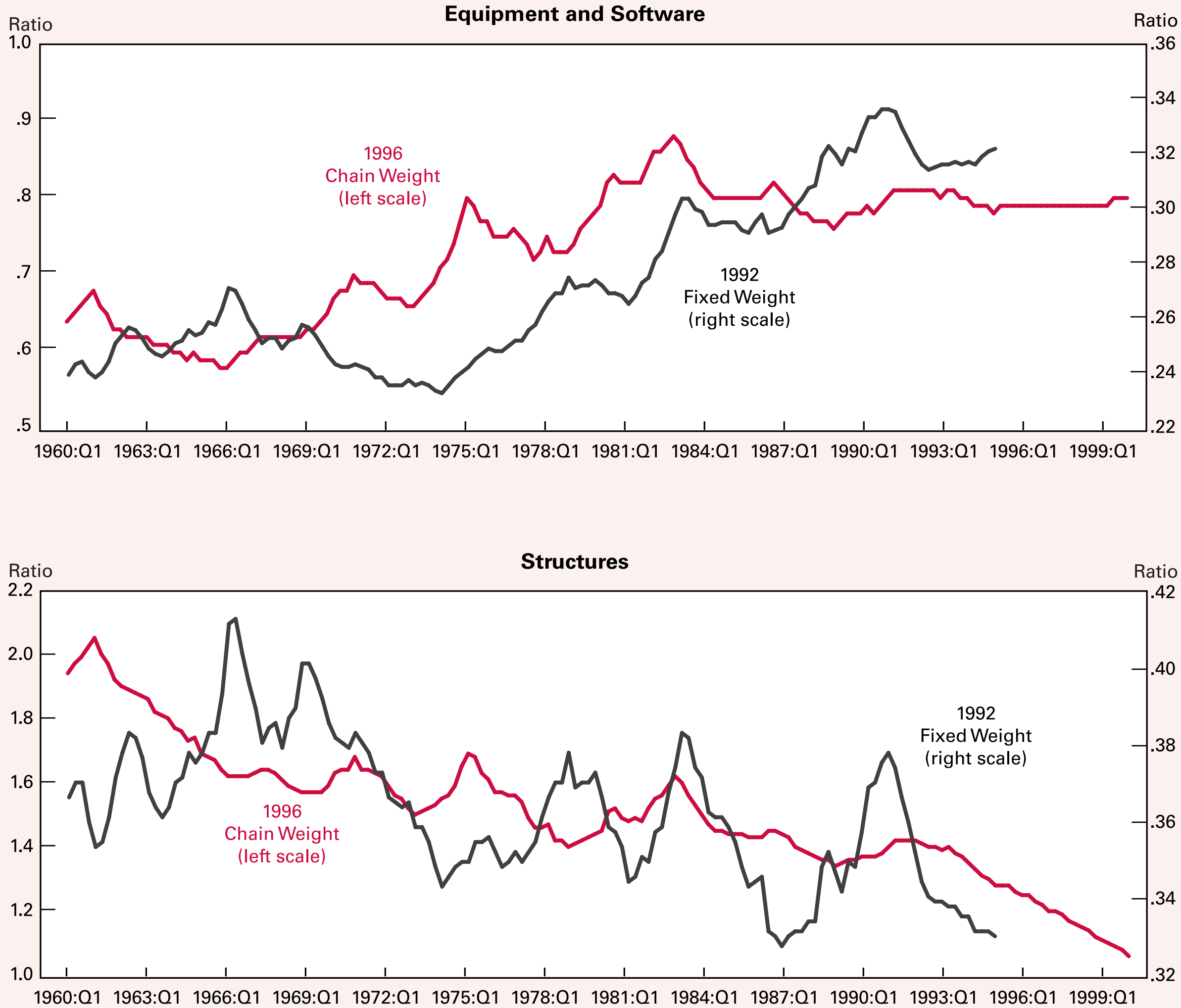



smooth trend for capital-output ratio with the data (the gray lines in Figure 10). Through the early 1980s, the ratio of the stock of equipment and software to output rose on average 4.2 percent annually. Afterward, the ratio followed a different course and remained relatively constant. Therefore, the accelerator model's coefficients, which strongly reflect the course of the ratio in the earlier period, do not coincide with the subsequent experience very well. A more successful model for equipment and software would need to cope with this break in the data. The capital-output ratio for structures also failed to coincide with the accelerator model's presumption of a smooth trend. This ratio fell relatively rapidly in the early 1960s and late 1990s, and during the 1970s and 1980s it varied considerably.

In the past, the accelerator model explained investment with more success, partly because the data for aggregate output and capital were constructed using fixed-weight, rather than today's chain-weight measures. This innovation has altered both the trends and variations in capital relative to

Figure 10

*Capital/Output Ratios*



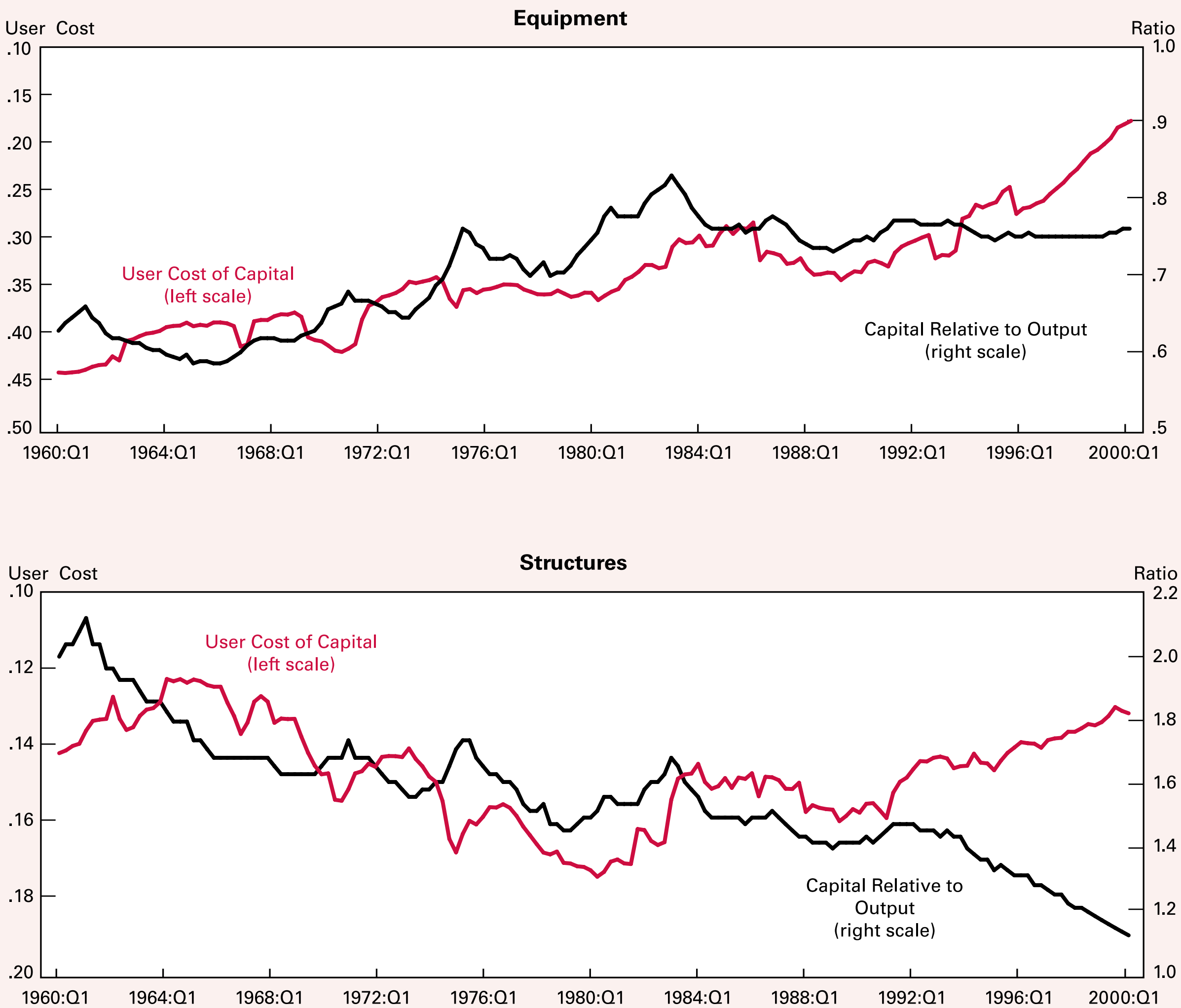

Source: Output, the Bureau of Economic Analysis' measure of nonfinancial corporations' gross domestic product, is from the National Income and Product Accounts, and is provided by Haver Analytics. The stock of capital is from the U.S. Bureau of Economic Analysis.

output (the red line in Figure 10). In particular, the chain-weight measure of the capital-output ratio for equipment was constant during the last two decades, while the fixed-weight measure continued to rise. Also, the chain-weight measure of capital-output ratio for structures has been significantly more volatile than the fixed-weight measure since the mid 1980s. Much of the statistical behavior of capital formation and the models' ability to explain capital formation, therefore, depends on the way that we measure the stocks of capital or flows of output and investment.

The neoclassical models succeeded to a greater degree than the accelerator model because the trends in the capital-output ratios for equipment and structures often corresponded with those for their cost of capital (Figure 11). The rising ratio of the stock of equipment to output before the mid 1980s generally coincided with a falling cost of capital (inverted scale). From the mid 1980s to the early 1990s, both the capital-

Figure 11

*Capital Stock Relative to Output and the User Cost of Capital*




Source: The user cost of capital is calculated using data from the Bureau of Economic Analysis, National Income and Product Accounts, and from DRI's Model of the U.S. Economy, as defined in Appendix II. Output, the BEA's measure of nonfinancial corporations' gross domestic product, is from the National Income and Product Accounts, and is provided by Haver Analytics. The stock of capital is from the U.S. Bureau of Economic Analysis.

output ratio and the cost of capital changed comparatively little. After the early 1990s, however, the cost of capital fell while the capital-output ratio remained relatively constant. For structures, the correspondence between investment and the cost of capital is more tenuous. From 1960 to the early 1970s, the capital-output ratio fell while the cost of capital generally rose. After the spike in the cost of capital during the oil crisis in 1974 and 1975, the cost of capital generally rose, then fell abruptly in the early 1980s back to its value of the early 1970s. During much of this interval, the capital-output ratio tended to vary inversely with the cost of capital. Afterward, the cost of capital generally rose while the capital-output ratio fell until the 1990s, when the capital-output ratio and the cost of capital both declined at a fairly consistent pace. For nonresidential structures, neither the concept of investment nor the cost of capital includes the cost of land, an important component in businesses' decision to develop real estate. Also, the neoclassical model's assumption that markets are in equilibrium and the rents that companies incur on real estate match the cost of capital is most likely to fail for extended periods, especially after excessive development, for assets such as long-lived structures. Finally, the neoclassical model, like the other aggregate models, cannot reflect the consequences of deregulation and technological change in construction, energy, telecommunications, transportation, manufacturing, and managing office and warehouse space that have occurred since the 1970s.

The modified neoclassical model performed better than the neoclassical model, because it allows the influences of output and the cost of capital on investment to be different. The modified model fit the data best by allowing the magnitude of the coefficients for the cost of capital to be lower than that for output. Investment would respond less to a 1 percent change in the cost of capital than to a 1 percent change in output. The growth of investment and output, in other words, was relatively less volatile than the changes in the user cost of capital during the past four decades.[16] The cost of capital and output might have different effects for several reasons. For example, the variation in the measured cost of capital might exceed the variation in effective rents (including the cost of land for structures), or investors might anticipate that the variations in the cost of capital or effective rents tend not to last as long as those for output.

The q model produces the smoothest fit and forecast for investment, despite its dependence on the prices of equities. Because longer-run averages of securities prices tend to vary much less than averages over short periods, and because short-run variations in securities prices do not coincide with short-run changes in investment very well,[17] this model seems better suited to explain longer-run trends in investment than short-run cycles, especially for equipment and software.

Finally, the cash flow model suggests that capital formation during the 1980s and early 1990s did not slump for want of internal funds for businesses' capital budgets. For much of this interval (except for the brief period that saw the blooming of low-grade bond financing in the mid 1980s), cash flow predicted a much higher level of spending. This model's performance, like those of the accelerator, q, and neoclassical models, seems to be compromised by attempting to reconcile the experience after 1980 with previous data. Despite relatively high cash flows, this model, like the others, could not directly consider that the economic profits redounding to businesses' equity capital remained near their post-World War II lows from the early 1980s to the early 1990s (Figure 2), also a period of relatively high real rates of interest. Afterward, the economic return on equity rose significantly, and investment in equipment and software increased more than cash flow predicted, as businesses assumed more leverage in pursuit of profit.

## *IV. Conclusion*

According to the conventional models of investment spending examined in this article, the macroeconomic view of businesses' investment spending has not explained the trends and cycles in capital formation since the mid 1980s as well as it did previously. To some extent, the structure of the models' equations and the themes that they emphasize might have lost none of their relevance; instead, a change in the correlations among macroeconomic variables might have required some fine-tuning of their coefficients. Should these correlations change only infrequently in small ways, with some allowance the models might continue to enjoy considerable success. If, however, the statistical relationships among macroeconomic data have become less stable, then the efficacy of the models themselves becomes more questionable. For example, the models apparently failed to represent businesses' perceptions of the profit on new investments after the mid 1980s as they had in previous years. The results suggest that recent changes in the composition of investment expenditures and changes in our industrial structure, at the very least, require forecasters and policymakers to alter the ways in which they estimate and apply their macroeconomic models of investment spending.

The composition of investment in recent decades has been shifting toward equipment that decays comparatively rapidly, and the relative prices of capital goods have been shifting significantly. In the past, traditional models separated the investment in equipment from that in structures, partly because their characteristics were too distinct to reconcile in one equation. As investors shifted expenditures from structures to equipment, for example, the rate of depreciation of

[16] This evidence would indicate that the elasticity of substitution between capital and labor does not equal one if the cost of capital equaled the marginal product of capital, which in turn equaled the current remuneration of capital. (See Appendix 1.)

[17] This finding is consistent with the modified neoclassical model's assigning a lower weight to the cost of capital than to the growth of output.

capital that appears as a parameter in a universal investment equation would need to change. Similarly, the shift of investment in equipment toward rapidly depreciating information-processing equipment causes models of gross investment in equipment to err by an increasing margin as they underestimate the need to replace seasoned capital. This study partially compensated for this bias by recasting the models in terms of net rather than gross investment.

Ultimately, however, stable models of investment might rest on still finer divisions of investment spending, by separating manufacturing machinery, computers and software, and other types of equipment (Tevlin and Whelan 2000), or by distinguishing manufacturing plants, office buildings, or wells and mines from other nonresidential structures. Indeed, substantial changes in the characteristics and relative prices of the various capital goods might make this approach more compelling for other, more fundamental reasons. Not only do such changes influence the measurement of aggregates for capital, but they also alter the correlations among measures of capital and other variables. In other words, the behavior of investment spending or the stock of capital depends not only on the quantities of capital goods that constitute these aggregates but also on changes in the relative values of these goods. Some changes in the prices of capital goods can alter the performance of models of investment more directly. For example, the neoclassical, q, and cash flow models erred by forecasting too much investment in nonresidential structures during the 1990s, partly because the relative prices of these structures were sufficiently low to elicit this strong forecast. If the price of structures, more than had been customary before the 1980s, reflected weak demand rather than the supply of cheap capital goods, then the models lacked sufficient detail to recognize this shift in order to forecast investment more accurately.

Changes in our industrial structure, therefore, warrant more attention to detail than is customary in the traditional models of investment. For example, the apparently low rate of investment in nonresidential structures beginning in the 1980s partly reflected the drop in drilling for petroleum and natural gas or in the building of base-load electric power plants. The motives for these cuts were not evident in the customary macroeconomic data for businesses' output, cash flow, or cost of capital. Similarly, the macroeconomic models alone cannot explain the rise of investment in information processing, which lifted aggregate investment in durable equipment and software. These shifts in the composition of investment also can weaken our ability to measure aggregate output and investment, especially when the relative prices of products and capital goods change very greatly. As a result of such changes, including the rapid drop in the prices of many types of equipment, the national accounts adopted a chain-weight technique for measuring real output and investment during the 1990s. Consequently, aggregate real stocks of capital now vary to a degree with the valuations of their elements. As our economic structure continues to shift and the relative prices of goods and services continue to change very substantially, macroeconomic models of investment will confront difficulties in measuring aggregate output and capital as well as difficulties in explaining investment spending without appealing more explicitly to the motives of investors in different industries. To the degree the relative prices of capital goods shift, forecasters will not necessarily be able to combine even relatively accurate forecasts of spending for different types of investment goods into a comparatively accurate forecast of total investment spending.

## Appendix 1

### *The Cost of Capital and the Return on Capital*

Suppose investors consider purchasing a quantity of capital assets, $K$, at the price of $P_K$ per unit of capital. The value of their investment after one period would equal the earnings of the capital plus its resale value:

$$P \cdot MPK \cdot K + P_K \cdot K(1 - \delta)(1 + \pi)(1 + \gamma).$$

$P$ denotes the net price of output, and $MPK$, the marginal product of capital, denotes the amount of additional output that each unit of the assets produces over the period. At the end of the period, the value of the capital reflects its depreciation, at rate $\delta$, and the rate at which its blue book price increases due to inflation, $\pi$, and to any change in its price relative to the prices of other goods, $\gamma$.

If instead of purchasing this capital, investors had purchased an equally risky security whose expected real rate of return for one period is $r$ after taxes, then the value of their investment would be

$$P_K \cdot K(1 + r)(1 + \pi).$$

For the investors' expected return on capital to equal this opportunity cost,

$$r \approx \frac{P}{P_K} MPK - \delta + \gamma,$$

or

$$\frac{P_K}{P}(r + \delta - \gamma) \approx MPK.$$

In the absence of corporate income taxes, the left side of this expression is the user cost of capital, and the right side is the return on capital.

The earnings of capital ($P\ MPK$) are taxed as corporate profits at rate $\tau$. This tax reduces the net marginal product of capital. Investors who purchase new capital might qualify for an investment tax credit, *itc* per dollar of eligible investment. Investors also can deduct from their taxable income depreciation allowances with a present value of *pvdep* per dollar of investment. These allowances reduce the effective price of capital goods. With these tax considerations, the equilibrium condition above becomes

$$\frac{P_K}{P}(r + \delta - \gamma)(1 - \tau \cdot pvdep - itc) \approx MPK(1 - \tau),$$

or

$$MPX \approx \frac{P_K}{P}(r + \delta - \gamma)\frac{(1 - \tau \cdot pvdep - itc)}{(1 - \tau)} \equiv UCC.$$

If the production function, which defines the maximal output, $Q$, that businesses can produce from specific amounts of capital and labor inputs, is Cobb-Douglas,

$$Q = AK^{\alpha}L^{(1-\alpha)},$$

then the marginal product of capital equals

$$MPK = D_K(AK^{\alpha}L^{(1-\alpha)}) = \alpha\frac{Q}{K}.$$

Substituting this expression into that for the user cost of capital and solving for $K$ yields the stock of capital assets that maximizes profit

$$K \approx \frac{\alpha Q}{UCC} = \frac{\alpha Q}{\frac{P_K}{P}(r + \delta - \gamma)\frac{(1 - \tau \cdot pvdep - itc)}{(1 - \tau)}}.$$

### *Measuring the Stock of Capital Assets*

All measurement of economic variables presumes some theory. As the measurement of a variable becomes more finely tailored to the specifications of a particular theory, it becomes more accurate and informative for those who accept that theory, at the risk of becoming less compelling to others. The art of measurement, therefore, is to achieve a solid foundation without compromising too greatly a variable's general appeal.

Most of the models of investment in this study propose that investors conceive an optimal amount of capital to employ after they consider their opportunities for producing goods and services at a profit. Investment is the process by which the stock of capital approaches this optimum. Accordingly, measures of stocks of capital as well as the flow of investment are essential elements of these models.

A fundamental feature of the theory of production requires that the quantities of inputs, including capital, be measured independently of the quantities of output as well as the prices of inputs and outputs (Koopmans 1957). Accordingly, our measure of the quantity of capital that a computer manufacturer employs ought not vary according to the value of the computers that the manufacturer produces or according to the prices of the manufacturer's buildings and equipment. The value of capital depends on its price or on the income that it earns, but the contribution of the capital in the production function should not be defined by that income.

Unfortunately, combining various capital goods, differing in type, technology, or vintage, into a well-defined aggregate is possible only in implausible circumstances (Fisher 1969; M. Brown 1976; Burmeister 1976; Blackorby and Schworm 1988; Hulten 1991). Consequently, no measure of the stock of capital is superior to all alternatives; each imposes its particular assumptions and poses its particular biases. The problem is not limited to the stock of capital. Estimates of investment, GDP, and other aggregates that appear in the investment equations pose similar difficulties.

The U.S. Bureau of Economic Analysis and the U.S. Bureau of Labor Statistics each publish a measure of capital. Both begin with estimates of the quantity of capital for distinct types of capital goods, adding newly purchased capital goods to the previous stocks of similar goods and subtracting the depreciation of seasoned capital goods (the perpetual inventory method). The BEA assumes that a greater share of the capital depreciates in its earliest years of service (geometric decay); the BLS assumes that more of the depreciation occurs in later years (hyperbolic decay). The BEA's measure of capital sums the distinct stocks, weighting them by their relative prices using a chain-weighted index (Landefeld and Parker 1997). The BLS's measure of the supply of capital services essentially weights each elemental stock by the proportion of capital's income that accrues to that stock.[18] Although the two techniques have different theoretical properties, they generally do not produce measures of capital inputs that diverge very greatly or very persistently over time, at least until the mid 1990s. And, both measures of capital inputs change from year to year as the result both of the net investment in new capital goods and of changes in the weights applied to the elemental stocks of capital.

The BLS derives each capital good's share of income through its user costs. Assuming each type of capital is paid its user cost, the stock of each multiplied by its user cost should sum to the income of all capital,

$$\text{gross capital income} = \sum K_i \cdot UCC_i$$

$$= \sum K_i \cdot \frac{P_{K_i}}{P}(r + \delta_i - \gamma_i)\frac{(1 - \tau \cdot pvdep_i - itc_i)}{(1 - \tau)},$$

where the common opportunity cost of funds ($r$) in the expression for the user cost is chosen to guarantee this equality. Other things equal, the more rapidly capital loses its value—the greater is (δ–γ)—the greater is its share of capital's income

$$\frac{K_i \cdot UCC_i}{\text{gross capital income}} = (r + \delta_i - \gamma_i)\frac{P_{K_i}}{P}\,\frac{(1 - \tau \cdot pvdep_i - itc_i)}{(1 - \tau)}.$$

In other words, capital that depreciates quickly and whose price falls most rapidly over time—computers for example—must earn more income per dollar of its purchase price ($P_K$) in order to compensate investors for their losses. The BLS's measure of capital services, therefore, tends to give the stocks of equipment and software more weight than the BEA's measure, which relies on the price of capital goods.

The BLS's estimate gives more weight to more profitable capital. To an engineer, a lathe that produces rotors for a return of $1 million when demand is great in the first half of a year does not lose its intrinsic capacity for producing rotors if it then earns $100 thousand after demand falters in the second half of the year. The BLS's measure of capital services for this lathe, however, declines with the value of its output. The BLS's procedure essentially assumes that production is characterized by constant returns to scale, the economy is in equilibrium, that markets for all goods and services are competitive, that those who finance businesses' capital assess its returns the same as the businesses do, and the return to capital equals its marginal product.[19] Economists and accountants continue to debate the proper method of assigning earnings to a company's various factors of production, especially when the demand for its products is not perfectly elastic. Also, investors typically require different returns ($r$) from investments that pose different risks. Not only might risks differ, so might the timing of income. The measurement of the return on investment probably should not rely entirely on its income during the period in question. Because capital goods to a degree are illiquid, because many investments expand companies' options for future activities, and because many enterprises and innovations take time to realize their full potential, a capital good's current income might misstate its marginal product from its owner's perspective. Furthermore, when companies earn economic rents that change from year to year or their utilization of illiquid investments in capital assets varies from year to year according to the demand for their products, then measures of the supply of capital services can change in ways that do not represent the productivity of the underlying capital goods. Indeed, the returns to capital and rates of capacity utilization have varied substantially over the business cycle and over the decades, suggesting that variations in earnings might reflect more than variations in the fundamental supply of capital services.

The BEA's measure of the stock of capital depends on the prices of capital goods, which poses its own problems (Jorgenson and Landau 1989; Jorgenson 1992; Hulten 1991). The logic behind the BLS's approach reveals that the price of a capital good does not likely reflect its contribution in the production function. Consequently, weighting the various stocks of capital goods by prices might give some very productive assets a relatively low weight and other less productive assets more substantial weights.

Both the BLS's and the BEA's measures of capital change each year partly because of the weights that they apply to the elemental stocks of capital goods change. The BEA, in particular, adopted its chain-weighting technique in order to avoid a difficulty that arises from fixing the weights according to prices of a specific base year. However well current prices represent the contribution of various capital goods to the production function, the prices that prevailed in 1996, for example, provide a less compelling lens for viewing either today's capital stock or that of 1986. Various hedonic adjustments might focus this lens better over the years, but these adjustments become less precise as the technology embedded in these goods changes, as output evolves, and as

[18] The rate of growth of capital is the sum of the rates of growth of the stocks of the elemental capital goods, each multiplied by its share of capital's income (Törnquist aggregation). See Diewert (1976).

[19] For criticisms of these assumptions, see, for example, M. Friedman (1964, 1988), Mankiw (1989), Gordon (1990, 1992), and Morrison (1992). If the employment and remuneration of factors of production adjust comparatively slowly, if the applications of existing capital are not sufficiently flexible, or if companies are oligopolistic competitors, then earnings can misrepresent the contribution of capital in the production function.

the structure of markets changes (Landefeld and Grimm 2000). Although the chain-weight approach might improve comparisons in neighboring years, it does not improve comparisons of the capital stock over more distant years. Furthermore, as is the case for the components of GDP, chain-weight measures of the constant-dollar components of the capital stock do not add to the chain-weight measure of the constant-dollar value of the full capital stock.

This study uses the BEA's measure of stocks of capital goods. In the absence of compelling arguments, Occam's razor recommends the simplest measure, that which invokes the least complex theory.

## Appendix 2

### *Sources of Data*

All data are from the U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts (NIPA) except where otherwise noted. Measures of stocks of assets and flows of goods or services are expressed in real chain-weighted 1996 dollars.

KE, KS: Capital stock of equipment and software, and structures, respectively. Tevlin and Whelan (2000) provided quarterly estimates of the annual published data from the Bureau of Economic Analysis' National Income and Product Accounts that adjusted the interpolation to accommodate the accelerating depreciation of equipment and software during the 1990s.

NFCGDP: Real gross domestic product for nonfinancial corporate business; quarterly data expressed at an annual rate.

RE, RS: User cost of capital for equipment and software, and nonresidential structures.

$$RE = [(CE / CT) (.15 + D)] * [(1-ITC-TAXS * WE) / (1 - TAXE)]$$

$$RS = [(CS / CT) (.05 + D)] * [(1-TAXS * WS) / (1 - TAXE)]$$

CE, CS: Implicit price deflators for nonresidential investment in equipment and software, and structures.

CT is defined as the GDP price deflator. The economic rate of depreciation is estimated at 0.15 for equipment and software, and 0.05 for structures. D is the discount rate for after-tax corporate profits, and equals the Standard & Poor's 500 index of common stocks dividend-price ratio, plus 4 percent, which is the estimated real rate of growth of nonfinancial corporations. This definition of D is inspired by the Gordon growth model for valuing equities.

ITC, the investment tax credit for equipment, TAXS, the statutory, and TAXE, the effective, tax rates paid by U.S. corporations, are taken from the DRI Model of the U.S. Economy. ITC is the weighted average of investment tax credits for autos, office equipment, and other equipment.

WE, WS: The present value of one dollar of depreciation, allowances for nonresidential capital equipment and corporate structures, taken from the DRI Model of the U.S. Economy.

q: The ratio of the market value of nonfinancial corporations to the replacement value of their net assets.

Market value equals new equity issuance net of financial assets (total financial assets less trade receivables, mutual fund shares, and miscellaneous assets) plus net interest-bearing debt (the sum of bank loans, commercial paper, acceptances, finance company loans, U.S. government loans, and adjusted bonds (AB)).

$$AB = 0.5 * MTG + NYSEBOND * (0.5 * MTG + TEB + CB)$$

MTG = commercial mortgages
TEB = tax-exempt bonds
CB = corporate bonds

NYSEBOND: Market value as a percent of par value for all New York Stock Exchange listed bonds. Annual data come from the NYSE *Fact Book* for various years. Quarterly data were derived using a nonlinear interpolation based on the pattern of 5-year Treasury note yields.

The replacement value of net nonfarm nonfinancial corporate assets is the sum of total corporate real estate, equipment and software, and inventories at year-end prices. Except for NYSEBOND, all data used to construct the q series are taken from the *Flow of Funds Accounts of the United States,* Board of Governors of the Federal Reserve System.

F: Cash flow for businesses, using data from the Board of Governors, *Flow of Funds Accounts,* for the nonfarm nonfinancial corporate business sector. Cash flow is defined as profits less taxes and dividends, including the consumption of fixed capital and the inventory valuation adjustment.

All regressions were estimated using ordinary least squares with no allowance for autocorrelation of the errors. The period of fit was 1960:I to 1990:IV, and forecast was 1991:I to 1999:IV. Polynomial distributed lags were used in all of the models except the time series and some of the modified neoclassical terms. During the past decade, the uncharacteristically large increase in equipment spending, intensified by the boom in the information processing and software component, made it difficult to fit models regressed on the level of investment or the ratio of investment to the stock of capital. Similarly, the decline in new building and real estate expenditures in the early 1990s was not an event models could predict based on past investment trends. Running regressions on the growth of the capital stock improved the fit, but varying the length of lags, degree of polynomials, and endpoint constraints as described below was also necessary to generate results that better described the recent investment and capital stock trends. The relatively strong performance of the time series model is, therefore, the result of statistical and not actual explanatory economic effects.

## Quarterly Models of Investment in Equipment and Structures

### *Time Series*

$$KE/KE_{t-1}-1 = -.00081 + b_1(KE_{t-1}/KE_{t-2}-1) + b_2(KE_{t-2}/KE_{t-3}-1) + b_3(KE_{t-3}/KE_{t-4}-1) + b_4(KE_{t-4}/KE_{t-5}-1) + c_1 NFCGDP/KE_{t-1} + c_2 NFCGDP/KE_{t-2} + c_3 NFCGDP/KE_{t-3} + c_4 NFCGDP/KE_{t-4} + c_5 NFCGDP/KE_{t-5}$$

$b_1 = 1.0564$
$b_2 = .2042$
$b_3 = -.2915$
$b_4 = .0613$
Sum = 1.0304
$c_1 = .0274$
$c_2 = -.0148$
$c_3 = -.0090$
$c_4 = .0012$
$c_5 = -.0045$
Sum = .0003

$$KS/KS_{t-1}-1 = .00015 + b_1(KS_{t-1}/KS_{t-2}-1) + b_2(KS_{t-2}/KS_{t-3}-1) + b_3(KS_{t-3}/KS_{t-4}-1) + b_4(KS_{t-4}/KS_{t-5}-1) + c_1 NFCGDP/KS_{t-1} + c_2 NFCGDP/KS_{t-2} + c_3 NFCGDP/KS_{t-3} + c_4 NFCGDP/KS_{t-4} + c_5 NFCGDP/KS_{t-5}$$

$b_1 = 1.1724$
$b_2 = -.0841$
$b_3 = -.0482$
$b_4 = -.0776$
Sum = .9625
$c_1 = .0125$
$c_2 = -.0031$
$c_3 = -.0121$
$c_4 = .0084$
$c_5 = -.0056$
Sum = .0001

### *Accelerator*

$$KE/KE_{t-1}-1 = -.0118 + \sum_{i=0}^{12} b_i NFCGDP/KE_{t-1}$$

$b_1 = .0039$
$b_2 = .0034$
$b_3 = .0030$
$b_4 = .0025$
$b_5 = .0021$
$b_6 = .0016$
$b_7 = .0012$
$b_8 = .0007$
$b_9 = .0003$
$b_{10} = -.0002$
$b_{11} = -.0007$
$b_{12} = -.0011$
Sum = .0167

Polynomial distributed lag, 2nd order, 12-period lag length, no endpoint constraint.

$$KS/KS_{t-1}-1 = -.0095 + \sum_{i=0}^{12} b_i NFCGDP/KE_{t-1}$$

$b_1 = .0013$
$b_2 = .0007$
$b_3 = .0002$
$b_4 = -.0002$
$b_5 = -.0005$
$b_6 = -.0008$
$b_7 = -.0009$
$b_8 = -.0010$
$b_9 = -.0010$
$b_{10} = -.0008$
$b_{11} = -.0006$
$b_{12} = -.0004$
Sum = –.0040

Polynomial distributed lag, 3rd order, 12-period lag length, far endpoint constraint.

### *Neoclassical*

$$KE/KE_{t-1}-1 = -.0055 + \sum_{i=0}^{12} b_i NFCGDP/KE_{t-1} + \sum_{i=0}^{12} c_i NFCGDP/RE_{t-1}/KE_{t-1}$$

$b_1 = .0008$
$b_2 = .0015$
$b_3 = .0020$
$b_4 = .0025$
$b_5 = .0027$
$b_6 = .0029$
$b_7 = .0029$
$b_8 = .0027$
$b_9 = .0025$
$b_{10} = .0020$
$b_{11} = .0015$
$b_{12} = .0008$
Sum = .0248

First polynomial distributed lag term, 3rd order, 12-period log length, both endpoint constraints.

$c_1 = -.0005$
$c_2 = -.0011$
$c_3 = -.0017$
$c_4 = -.0021$
$c_5 = -.0023$
$c_6 = -.0025$
$c_7 = -.0025$
$c_8 = -.0024$
$c_9 = -.0022$
$c_{10} = -.0018$
$c_{11} = -.0014$
$c_{12} = -.0007$
Sum = –.0212

Second polynomial distributed lag term, 3rd order, 12-period log length, far endpoint constraint.

$$KS/KS_{t-1}-1 = -.0044 + \sum_{i=0}^{12} b_i NFCGDP/RS/KS_{t-1} + \sum_{i=0}^{12} c_i NFCGDP/RS_{t-1}/KS_{t-1}$$

$b_1 = .0005$
$b_2 = .0005$
$b_3 = .0004$
$b_4 = .0004$
$b_5 = .0004$
$b_6 = .0003$
$b_7 = .0002$
$b_8 = .00006$
$b_9 = -.00008$
$b_{10} = -.0002$
$b_{11} = -.0004$
$b_{12} = -.0006$
Sum = .0015
$c_1 = -.0006$
$c_2 = -.0004$
$c_3 = -.0003$
$c_4 = -.0001$
$c_5 = -.00002$
$c_6 = .00007$
$c_7 = .0001$
$c_8 = .0002$
$c_9 = .0002$
$c_{10} = .0002$
$c_{11} = .0001$
$c_{12} = .00004$
Sum = –.0005

Polynomial distributed lags, 3rd order, 12-period lag lengths, no endpoint constraints.

***Modified Neoclassical***

$$KE/KE_{t-1}-1 = -.0280 + \sum_{i=0}^{4} b_i LOG(NFCGDP) + \sum_{i=0}^{8} c_i LOG(RE) + d_1 LOG(KE)$$

$b_1 = .0172$
$b_2 = .0129$
$b_3 = .0086$
$b_4 = .0043$
Sum = .0430

First polynomial distributed lag term, 2nd order, 4-period lag length, far endpoint constraint.

$c_1 = -.0041$
$c_2 = -.0036$
$c_3 = -.0030$
$c_4 = -.0025$
$c_5 = -.0020$
$c_6 = -.0015$
$c_7 = -.0010$
$c_8 = -.0005$
Sum = -.0182
$d_1 = -.0425$

Second polynomial distributed lag term, 2nd order, 8-period lag length, far endpoint constraint.

$$KS/KS_{t-1}-1 = -.0656 + \sum_{i=0}^{6} b_i LOG(NFCGDP) + c_1 LOG(RS) + c_2 LOG(RS_{t-1}) + c_3 LOG(RS_{t-2}) + c_4 LOG(RS_{t-3}) + d_1 LOG(KS)$$

$b_1 = .0046$
$b_2 = .0038$
$b_3 = .0031$
$b_4 = .0023$
$b_5 = .0015$
$b_6 = .0008$
Sum = .0161
$c_1 = -.0039$
$c_2 = -.0005$
$c_3 = -.0005$
$c_4 = .0036$
Sum = –.0013
$d_1 = -.0228$

Polynomial distributed lag, 2nd order, 6-period lag length, far endpoint constraint.

***Q Model***

$$KE/KE_{t-1}-1 = -.0152 + \sum_{i=0}^{12} b_i((q-1)*(KE_{t-1}))$$

$b_1 = .00000020$
$b_2 = .00000037$
$b_3 = .00000051$
$b_4 = .00000061$
$b_5 = .00000068$
$b_6 = .00000072$
$b_7 = .00000072$
$b_8 = .00000068$
$b_9 = .00000061$
$b_{10} = .00000051$
$b_{11} = .00000037$
$b_{12} = .00000020$
Sum = .0000068

Polynomial distributed lag, 3rd order, 12-period lag length, both endpoints constrained.

$$KS/KS_{t-1}-1 = -.0014 + \sum_{i=0}^{12} b_i((q-1)*(KS_{t-1}))$$

$b_1 = .0013$
$b_2 = .0007$
$b_3 = .0002$
$b_4 = -.0002$
$b_5 = -.0005$
$b_6 = -.0008$
$b_7 = -.0009$
$b_8 = -.0010$
$b_9 = -.0010$
$b_{10} = -.0008$
$b_{11} = -.0006$
$b_{12} = -.0004$
Sum = –.0040

Polynomial distributed lag, 3rd order, 12-period lag length, far endpoint constraint.

***Cash Flow***

$$KE/KE_{t-1}-1 = -.0018 + \sum_{i=0}^{12} b_i(F/CE/KE_{t-1})$$

$b_1 = -.0170$
$b_2 = -.0034$
$b_3 = .0074$
$b_4 = .0153$
$b_5 = .0204$
$b_6 = .0228$
$b_7 = .0222$
$b_8 = .0189$
$b_9 = .0127$
$b_{10} = .0037$
$b_{11} = -.0081$
$b_{12} = -.0228$
Sum = .0721

Polynomial distributed lag, 3rd order, 12-period lag length, no endpoints constrained.

$$KS/KS_{t-1}-1 = -.0014 + \sum_{i=0}^{12} b_i(F/CS/KS_{t-1})$$

$b_1 = .0083$
$b_2 = .0076$
$b_3 = .0069$
$b_4 = .0062$
$b_5 = .0056$
$b_6 = .0049$
$b_7 = .0042$
$b_8 = .0035$
$b_9 = .0028$
$b_{10} = .0021$
$b_{11} = .0014$
$b_{12} = 00007$
Sum = .0542

Polynomial distributed lag, 2nd order, 12-period lag length, far endpoint constraint.

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