The new view of growth and business cycles

Jonas D. M. Fisher

Introduction and summary

Two central concerns of economic policy are growth and business cycle stabilization. There is considerable interest in devising government policies and institutions to influence prospects for economic growth and mitigate the distress associated with economic downturns. Proper evaluation of the benefits and costs of a given policy proposal requires knowledge of the determinants of growth and business cycles. This is one reason for the considerable body of research aimed at understanding these phenomena.

The last two decades have seen considerable advances in this research. Recent empirical evidence, however, brings into question two of its basic assumptions—first, that technological change is homogeneous in nature, in that it affects our ability to produce all goods symmetrically, including consumption and investment goods; and second, that business cycles are driven by shocks which affect the demand for investment goods.

In this article, I document the key evidence that challenges the conventional views of growth and business cycles. I then discuss the plausibility of alternative theories that have been advanced to meet the challenge. To date, the evidence seems to support a new view of growth and business cycles, one that is based on technical change biased toward new investment goods like capital equipment.

The key evidence involves two observations on the behavior of the *relative price* of business equipment over the last 40 years. First, in almost every year since the end of the 1950s, business equipment has become cheaper than the previous year in terms of its value in consumption goods. This means that if one had to trade restaurant meals for a piece of equipment that makes the same number and quality of, say, bicycles, one would forgo fewer meals in 1998 than in 1958. Second, this relative price tends to fall the most when the economy, and investment expenditures in particular, are growing at relatively high rates, that is, it is *countercyclical*.

The first piece of evidence is striking because it suggests that much of post-WWII economic growth can be attributed to technological change embodied in new capital equipment. This conflicts with conventional views on what drives economic growth. A piece of capital equipment is a good that is used to produce another good, such as a crane or a computer. An improvement in *capital-embodied technology* is the invention of equipment that takes the same amount of labor and preexisting equipment to produce as the old equipment but that produces more goods when combined with the same amount of labor as before. If a new production process yields the same units of capital equipment with less factor inputs, then this has the same economic implications as if the capital equipment produced were itself more efficient. Hence, an *equivalent* interpretation of what constitutes capital-embodied technical change is that it involves an improvement in the technology that *produces* capital equipment.

To understand the relationship between capital-embodied technical change and the trend in the equipment price, suppose the technology for producing consumption goods is fixed. With improvements in technology embodied in equipment, the supply of (quality-adjusted) investment goods increases relative to consumption goods, so the equipment price falls. Greenwood et al. (1997) build on this insight to show that a large fraction of economic growth can be attributed to *capital-embodied technical change*. This conflicts with the conventional view that most

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growth is due to disembodied technical change, or *multifactor productivity*. Improvements in disembodied technology, usually measured as the Solow (1957) residual, make it possible to produce all kinds of goods, not just capital goods, with less capital and labor.[1] If this were the dominant source of growth, then we should not have seen such a large drop in the price of equipment over the last 40 years.

The second piece of evidence runs counter to standard views of the business cycle. Standard theories hold that the business cycle is driven by shocks which affect the demand for investment goods. For example, consider the *IS–LM* model, which summarizes much of what is often called *Keynesian* macroeconomics. This model is the focus of most textbooks on macroeconomics and underlies much of the discussion of macroeconomic policy in the media.[2] In this model, business cycles are due to shocks to aggregate demand, such as monetary and fiscal disturbances. For example, expansionary monetary policy stimulates demand for investment goods through lower interest rates. If there is an upward sloping supply schedule for investment goods, we would expect the relative price of investment goods to *rise*. The same holds for expansionary fiscal policy, if government spending does not fully crowd out investment. Another view of business cycles, often attributed to Keynes, is that they are primarily investment cycles driven by variation in *animal spirits*, that is, changes in confidence about future growth prospects.[3] With the same assumptions on investment supply, we would expect investment prices to be high when investment is high. In summary, traditional Keynesian views of business cycles imply that investment good prices should be *procyclical*, that is, be high when overall economic activity is relatively high.

In recent years, an alternative view of business cycles, based on "fundamentals" that influence aggregate supply, has gained credence. This *real business cycle* view says that business cycles are driven in large part by disturbances to multifactor productivity. Just as the shocks to aggregate demand which are central to Keynesian theories, these disturbances influence business cycles through their effect on the demand for investment goods.[4] Hence, if there are costs in terms of forgone consumption of expanding investment good production, that is, if the supply schedule of capital is upward sloping, these models also predict the relative price of investment goods to be procyclical (Greenwood and Hercowitz, 1988).

Since the relative price evidence contradicts the major schools of business cycle thought, it poses a challenge to our understanding of business cycles. There are two leading hypotheses that could reconcile the theory and evidence. One, the *embodied technology* view, is built from the real business cycle tradition and takes into account the trend evidence on equipment prices. Falling equipment prices are compelling evidence of capital-embodied technological progress over long horizons. Perhaps changes in the rate of such technological progress occur over shorter horizons as well. Suppose the business cycle were driven, to a large extent, by these disturbances. An increase in the rate of capital-embodied technical change would lead to an outward shift in the supply schedule for investment goods. With stable investment demand, investment would rise and equipment prices would fall. This new view of business cycles, which complements the new view of growth suggested by the long-run evidence on equipment prices, has been explored by Christiano and Fisher (1998), Fisher (1997), and Greenwood et al. (1998).

The other leading theory is more easily understood in the context of traditional Keynesian views of the business cycle. If shocks to aggregate demand occur with a downward sloping investment supply curve, then the price of equipment could fall in a boom. A downward sloping investment supply curve would arise if increasing returns to scale played an important part in the production of capital equipment, so this is called the *increasing returns* view. This view has been advanced by Murphy, Shleifer, and Vishny (1989).

Below, I document the trend and business cycle evidence on equipment prices. There is no reason to expect that capital-embodied technological change is unique to equipment. Equipment is one of many investment good aggregates, that is, types of capital. Moreover, for simplicity most economic models assume only one or two types of capital. Therefore, in addition to equipment prices, I analyze other investment good aggregates. Next, I discuss research that sheds light on the plausibility of the alternative views, including some new evidence. To date, the evidence seems to support the new view of growth and business cycles based on capital-embodied technical change.

If growth and business cycles are originating from changes in capital-embodied technology, then the models we use for policy analysis have to incorporate this and, consequently, policy recommendations could change. For example, to the extent that technological change is embodied in capital equipment, government policies that affect equipment investment could have a dual impact on growth via the quality and quantity of capital goods. This could mean, for example, that investment tax credits directed toward improvements in the efficiency of capital equipment could have a significant impact on growth.

The implications for stabilization policy of the embodied technology view are less obvious. The fact that it seems to supplant the increasing returns view means that the arguments for interventionist stabilization policy that this view lends support to are less compelling. For example, increasing returns could provide scope for policy intervention, as it either involves externalities or is inconsistent with perfect competition. Moreover, it makes models based on animal spirits more plausible, which also has implications for stabilization policy (see Christiano and Harrison, 1999). The embodied technology view is more in line with the real business cycle tradition, in which policy interventions are counterproductive.

Evidence on investment good prices

To study the trend and business cycle properties of investment good prices, we need two things—a way to extract real prices and quantities from data on nominal investment expenditures; and a precise definition of what we mean by the business cycle component of the data. Below, I address these issues. Then, I introduce the data and present the results characterizing the trend and cycle behavior of investment good prices.

Measuring prices and quantities

This section describes how relative prices and real quantities of investment goods are measured. My measures of prices and quantities are based on measures published in the "National income and product accounts" (NIPA) of the U.S. Bureau of Economic Analysis (BEA).

The basis of the BEA procedure is to construct a *price deflator*. To be concrete, a given nominal quantity of expenditures on some good i, X^i_t, is decomposed into a price deflator, P^i_t, (which measures the *nominal* price of the good) multiplied by a quality-adjusted index of the *real* quantity of the good, q^i_t.

The BEA measures P^i_t and q^i_t for different goods using a so-called chain-weighting procedure, which is summarized in box 1. My measure of quantity is simply q^i_t, measured in units of 1992 dollars. My measure of the *real price*, alternatively the *relative price*, of good i at date t, p^i_t, is the real quantity of consumption goods that would need to be sold in order to purchase one unit of good i at time t. It is defined as the price deflator for good i divided by the price deflator for consumption of nondurables and services. The rationale for this measure is described in box 1.

Measuring the business cycle component of the data[5]

In the introduction I described how the price of producer durable equipment (PDE) varies over the business cycle. Below, I provide a brief description of how I measure the business cycle component of the data. A detailed discussion of the procedure is given in Christiano and Fitzgerald (1998).

Figure 1 illustrates the basic idea behind the procedure. The colored line in panel A of figure 1 displays real 1992 dollar chain-weighted gross domestic product (GDP). The reported data are the logarithm of the raw data. The advantage of using the logarithm is that the resulting movements correspond to percent changes in the underlying data. The deviations between the data and the trend line (graphed in panel B) contain the rapidly varying, erratic component, inherited from the choppy portion of the data that is evident in panel A. The colored line in panel B is my measure of the business cycle component of real GDP. This measure excludes both the trend part of the data and the rapidly varying, erratic component. It includes only the component of the data that contains fluctuations in the range of two to eight years. According to this approach, the economy is in recession when the business cycle measure is negative and in prosperity when it is positive.

Figure 1 also compares this measure of the business cycle with the one produced by the National Bureau of Economic Research (NBER). This organization decides, based on an informal examination of many data series by a panel of experts, when the economy has reached a business cycle peak or trough. The start of each shaded area indicates the date when, according to the NBER, the economy reached a business cycle peak. The end of each shaded area indicates a business cycle trough. Note how real GDP falls from peak to trough and then generally grows from trough to peak. An obvious difference in the two business cycle measures is that the measure used in this article is a continuous variable, while the NBER's takes the form of peak and trough dates. As a result, my measure not only indicates when a recession occurs, but also the intensity of the recession. Apart from these differences, the two measures appear reasonably consistent. For example, near the trough of every NBER recession, my measure of the business cycle is always negative. However, the two measures do not always agree. According to my measure, the economy was in recession in 1967 and 1987, while the NBER did not declare a recession then. In part, this is because there must be several quarters of negative GDP growth before the NBER declares a recession. The procedure I use only requires a temporary slowdown.

The data

I consider a broad variety of investment goods, as outlined in table 1. The broadest measure of investment

BOX 1

Measuring real quantities and prices from nominal expenditure data

The U.S. Bureau of Economic Analysis (BEA) uses the chain-type Fisher index to measure real output and prices. For a thorough discussion of the procedures the BEA uses, see Landefeld and Parker (1997), which this box draws on. This index, developed by Irving Fisher, is a geometric mean of the conventional fixed-weighted Laspeyres index (which uses weights of the first period in a two-period example) and a Paassche index (which uses the weights of the second period). The Laspeyres price index for period t constructed using base year $t-1$, L_t is given by

$$L_t = \frac{\sum_{i=1}^{N} P_t^i \times q_{t-1}^i}{\sum_{i=1}^{N} P_{t-1}^i \times q_{t-1}^i}.$$

The Paassche price index for period t constructed using base year t, S_t is given by

$$S_t = \frac{\sum_{i=1}^{N} P_t^i \times q_t^i}{\sum_{i=1}^{N} P_{t-1}^i \times q_t^i}.$$

Here N is the number of goods whose prices are being summarized by the index, P_t^i is the date t dollar price of the ith quality-adjusted good, and q_t^i is the quality-adjusted quantity of good i purchased at date t. The Fisher price index at date t, F_t is

$$F_t = \sqrt{L_t \times S_t}.$$

From this definition we see that changes in F_t are calculated using the "weights" of adjacent years. These period to period changes are "chained" (multiplied) together to form a time series that allows for the effects of changes in relative prices and in the composition of output over time. Notice that a quantity index can be computed in a manner analogous to the price index. A nice feature of the Fisher index is that the product of these two indexes equals nominal expenditures. Landefeld and Parker (1997) discuss several advantages of this index over previously used fixed weight indexes.

To measure relative prices we need to choose a numeraire. In the introduction the term "value in consumption goods" was used. Implicit in this statement is the assumption that consumption goods, specifically nondurable and services consumption, is the numeraire. Define the price deflator for nondurable and services consumption as P_t^c. Then the relative price of the good i at time t, p_t^i is defined as

$$p_t^i \equiv \frac{P_t^i}{P_t^c} = \frac{\text{time } t \text{ dollars / good } i}{\text{time } t \text{ dollars / consumption good}} = \frac{\text{consumption goods}}{\text{good } i}.$$

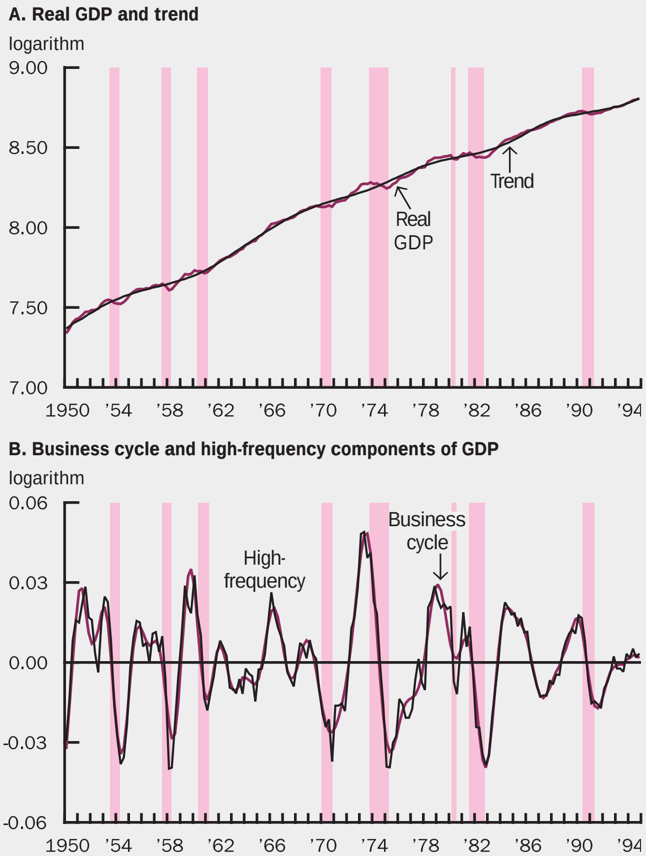
Notice that the units of the price are what we require. The BEA does not provide a measure of price deflator for nondurable and services consumption. To construct the consumption deflator used in this article, I applied the chain-weighting methodology outlined above, treating the NIPA quantity and price indexes for nondurable consumption and service consumption as the prices and quantities in the formulas.

is total private investment (TPI). This measure includes all private expenditures on capital goods and consumer goods designed to last more than three years.[6] This is a broader measure of investment than the conventional NIPA measure of investment, private fixed investment (PFI), which excludes expenditures on consumer goods. Within TPI, I define two main components, nonresidential and residential. Nonresidential has two main subcomponents, structures (NRS, for example, factory buildings and office buildings) and producer durable equipment (PDE, for example, auto-assembly robots and personal computers). Similarly, residential is broken down into residential structures and equipment (RSE, for example, single family homes and refrigerators) and consumer durables (CD, for example, televisions and vacuum cleaners). These four major subcomponents of TPI are then broken down further.[7]

The "Nominal share" and "Real share" data provide information on the relative magnitudes of expenditures on the different measures of investment, as well as a preliminary indication of interesting trends in relative prices. The nominal and real shares for TPI are calculated as the ratio of nominal and real TPI relative to nominal and real GDP, respectively. For example, in 1958 nominal TPI expenditures were 22 percent of nominal GDP and real TPI expenditures were 16 percent of real GDP. The remaining shares are calculated using TPI as the base for the share calculations. For example, PDE expenditures accounted for 24 percent of nominal TPI and 20 percent of real TPI in 1958.[8]

FIGURE 1

The trend and business cycle components of real GDP



Notes: Real GDP in panel A is real 1992 dollar chain-weighted GDP. The reported data are the logarithm of the real data. Shaded areas indicate recessions as determined by the National Bureau of Economic Research.

Source: Author's calculations from U.S. Department of Commerce, Bureau of Economic Analysis, "National income and product accounts," *Survey of Current Business*, extracted from DRI Basic Economics database, 1947–98.

(I explain the last two columns in table 1 in the section on prices of investment goods over the business cycle, which begins on page 40.)

Table 1 reveals several interesting facts about how expenditures on investment have changed since 1958 and underlying trends in relative prices. First, nominal TPI expenditures have been roughly stable (abstracting from short-run movements) as a fraction of nominal GDP since the late 1950s. Yet, the real quantity of this broadest measure has been growing as a fraction of real GDP. In 1958, TPI was 16 percent of 1992 chain-weighted GDP, compared with 26 percent in 1998. The fact that nominal and real shares behave in this way is an indication that the relative price of this bundle of investment goods fell between 1958 and 1998. Notice that there are differences between real and nominal shares for many of the components of investment listed in table 1, suggesting that trends in relative prices are exhibited by many of the subcomponents of TPI. Second, the difference between the real shares of TPI and PFI (the former is a fraction of GDP, while the latter is a fraction of the former) is seen to be due to the increasing quantities of consumer durables being purchased. Third, the much talked about "information age" manifests itself here as the huge increase in the fraction of TPI that has been due to expenditures on information and related equipment since 1960. In 1960 this type of investment accounted for less than 1 percent of real TPI. By 1995, its share had grown to 13 percent. Finally, note that both residential and nonresidential structures account for less of TPI in 1998 than in 1958.

Trends in investment good prices

In this section, I explain two main findings relating to the long-run behavior of relative prices for the various components of investment listed in table 1. First, the relative price of TPI has fallen consistently since the mid-1950s. Second, there is considerable heterogeneity in the long-run behavior of the prices of the subcomponents of TPI. Generally, the behavior of the price of TPI is dominated by dramatic drops in the prices of PDE and CD, which are also evident in the prices of most of the main subcomponents of these investment aggregates. The prices of RSE and NRS and their subcomponents, while exhibiting trends over subsamples of the period studied, have not fallen as consistently and their changes over time are much smaller than those of PDE and CD.

Figure 2 displays the relative price trend evidence. The black lines in figure 2 are measures of the (natural logarithm of the) relative price of each of the investment components listed in table 1 over the period for which data are available.[9] The colored lines are the trends calculated in the same way as the trend of real GDP displayed in figure 1. The first column of panels in figure 2 displays prices and trend lines for the main aggregates. The remaining columns display prices and trends for the four broad categories of TPI and their main subcomponents.

Figure 2 shows that the relative prices of different components of investment have behaved quite

TABLE 1

Measures of investment used in the analysis

	Nominal share			Real share			Business cycle volatility	
	1958	1978	1998	1958	1978	1998	$\sigma_{q^i} / \sigma_{q^y}$	$\sigma_{p^i} / \sigma_{q^y}$
Total private investment	0.2184	0.2641	0.2378	0.1558	0.2154	0.2627	2.97	0.55
Nonresidential	0.4165	0.4496	0.4656	0.4254	0.4356	0.4815	2.83	0.98
Structures	0.1730	0.1510	0.1226	0.2613	0.1674	0.1032	2.66	0.90
Nonresidential buildings	0.0975	0.0821	0.0906	0.1435[a]	0.0982	0.0764	3.63	0.49
Utilities	0.0418[a]	0.0399	0.0238[b]	0.0552[c]	0.0412	0.0226[b]	2.67	0.64
Mining exploration, shafts, & wells	0.0233	0.0255	0.0115	0.0302[a]	0.0207	0.0089	5.49	3.19
Producer durable equipment	0.2438	0.2985	0.3430	0.1981	0.2676	0.3841	3.18	0.85
Information & related	0.0355	0.0690	0.1153	0.0080[c]	0.0327	0.1300[b]	3.05	0.95
Industrial	0.0796	0.0783	0.0734	0.1134[c]	0.0958	0.0747[b]	3.63	0.91
Transportation & related	0.0598	0.0782	0.0871	0.0797[c]	0.0900	0.0762[b]	5.25	0.63
Residential	0.5830	0.5504	0.5344	0.5730	0.5646	0.5200	3.98	0.43
Residential structures & equipment	0.2188	0.2175	0.1782	0.3259	0.2526	0.1546	6.24	0.57
Single family structures	0.1289	0.1203	0.0897	0.2118[a]	0.1350	0.0754	8.89	0.81
Multifamily structures	0.0228	0.0212	0.0122	0.0406[a]	0.0257	0.0109	10.80	0.81
Other structures	0.0627	0.0715	0.0721	0.1028[a]	0.0860	0.0645	3.18	0.34
Consumer durables	0.3643	0.3329	0.3562	0.2835	0.3184	0.3663	2.99	0.61
Motor vehicles & parts	0.1453	0.1539	0.1414	0.1361	0.1629	0.1290	5.16	0.94
Furniture & household equipment	0.1659	0.1223	0.1443	0.0918	0.0933	0.1717	1.94	0.54
Other	0.0534	0.0567	0.0705	0.0551	0.0670	0.0697	1.52	0.59
Private fixed investment	0.6357	0.6671	0.6438	0.7294	0.6812	0.6333	3.09	0.58

[a]1959 data.
[b]1995 data.
[c]1960 data.

Notes: See box 1 for a description of the notation. For total private investment and gross domestic product, *Y*, nominal shares in the first row are $P_t^{TPI} q_t^{TPI} / (P_t^Y q_t^Y)$. Nominal and real shares for investment good *i* in the other rows are given by $P_t^i q_t^i / (P_t^{TPI} q_t^{TPI})$. Real shares for total private investment and gross domestic product are q_t^{TPI} / q_t^Y. Real shares for investment good *i* in the other rows are given by q_t^i / q_t^{TPI}.

Source: U.S. Department of Commerce, Bureau of Economic Analysis, 1947–98, "National income and product accounts," *Survey of Current Business*, and author's calculations of the business cycle component of the data.

differently in the postwar era. The price of the broadest investment measure, TPI, has been falling consistently since the early 1950s. Since the plot of the relative price of TPI is in natural logarithms, one can take the difference between the prices for two years to calculate the percentage change. This procedure indicates that the price of TPI in terms of consumption goods fell about 42 percent between 1958 and 1998.

Studying the other plots in figure 2, we see that this large drop in the price of TPI can be attributed to strong downward trends in PDE (particularly information and related and transportation equipment) and CD (all three types). The drop in the relative price of information equipment is particularly dramatic, at almost 200 percent since 1961. The prices of NRS and its components were generally rising until the late 1970s, were falling for most of the rest of the sample period, and have started to rise again in the 1990s. RSE and its components display a similar pattern. Generally, the long-run changes in structures prices have been much smaller than in PDE and CD prices. When the investment components are aggregated into nonresidential and residential, the strong downward trends in PDE and CD prices dominate the changing trends in structures.[10]

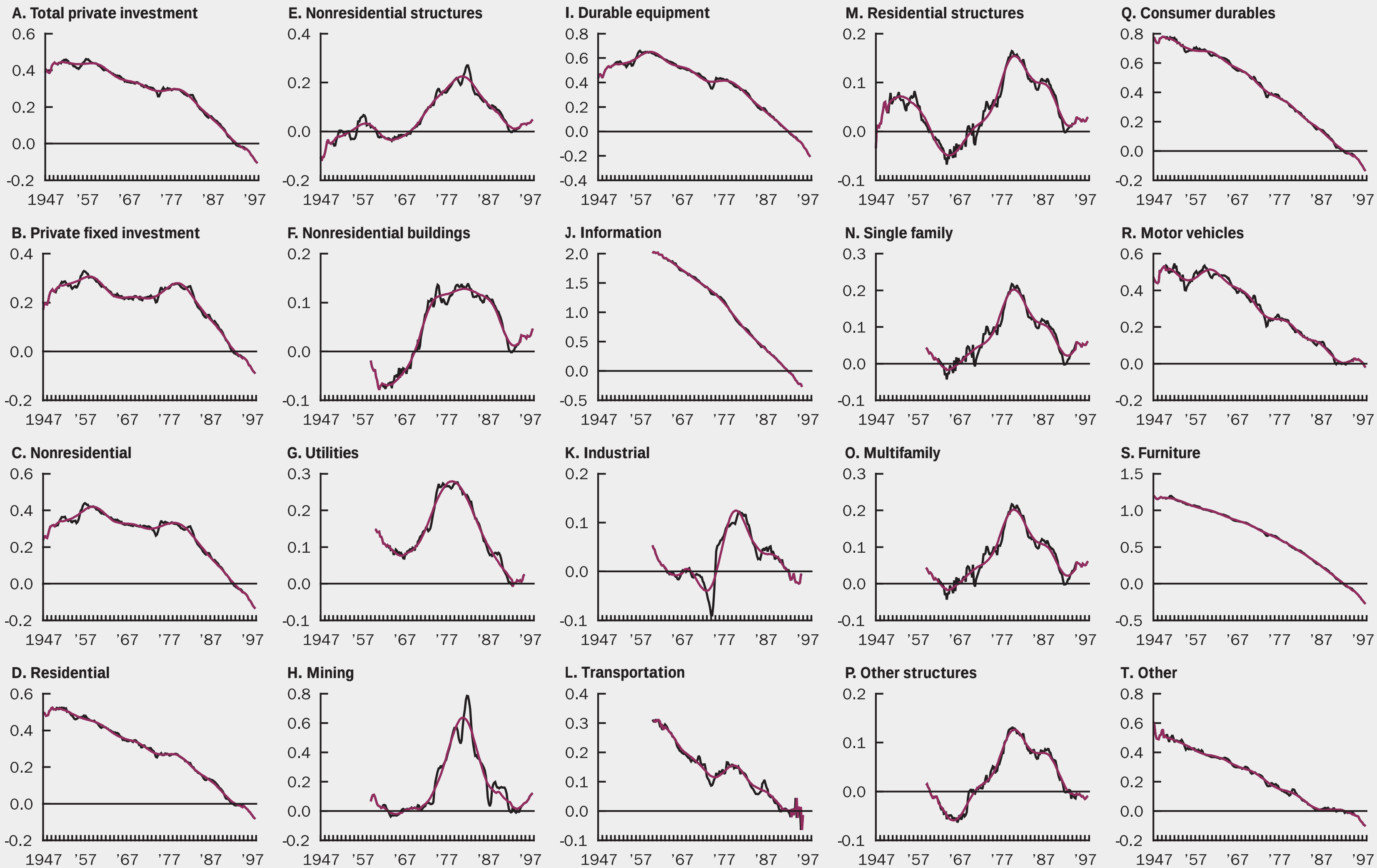
Prices of investment goods over the business cycle

My objective here is to determine the extent to which investment good prices are generally procyclical, countercyclical, or *acyclical* (do not display any distinctive pattern over the business cycle). I find that, generally speaking, prices of PDE, NRS, and their components are countercyclical, prices of RSE and its components are procyclical, and prices of CD and its components are acyclical. There is some sample period sensitivity, as outlined below.

In table 1, the column headed $\sigma_{q^i}/\sigma_{q^y}$, indicates the relative volatility of the different investment components over the business cycle. This is the standard deviation of the business cycle component of the indicated real quantity series divided by the standard deviation of the business cycle component of real GDP. We see that TPI varies almost three times as much as GDP. The most volatile components of

FIGURE 2

Trends in investment good prices, 1947–98 (logarithm)



Notes: Relative price (black line) is a measure of the (natural logarithm of the) relative price of each of the investment components listed in table 1 over the period for which data are available. The trend (colored line) is calculated in the same way as the trend of real GDP displayed in figure 1. Panels A through D show prices and trends for the main aggregates. Panels E through T show prices and trends for the four broad categories of total private investment, along with their main subcomponents.

Source: See figure 1.

investment are single family structures, multifamily structures, and consumer expenditures on motor vehicles and parts. The least volatile components are NRS, furniture and household equipment, and the "other" component of CD. The column headed $\sigma_{p_i}/\sigma_{q_y}$ indicates the relative volatility of the prices of different investment components over the business cycle. This is the standard deviation of the business cycle component of the indicated relative price series divided by the standard deviation of the business cycle component of real GDP. The prices are much less volatile than the quantities. With one exception (mining exploration, shafts, and wells), all the prices are less volatile than real GDP over the business cycle.

As a preliminary look at the cyclicality of investment good prices, figure 3 displays the business cycle components of the prices (colored lines) and quantities (black lines) of seven of the broadest measures listed in table 1, along with the business cycle component of the deflator for consumption of nondurables and services. The latter price is used in the denominator of all the investment relative prices, so its business cycle dynamics will influence all the relative price measures discussed here.[11]

Notice first that the consumption deflator rises in all but one recession, 1981:Q3–82:Q4 (see shaded areas in figure 3). This is a force for procyclicality of investment good prices. For example, if the price deflator for an investment good were constant, then the real price of that good would be procyclical. As expected, the quantities are generally procyclical, although the peaks and troughs do not exactly coincide with the NBER dates. The prices do not display as consistent a pattern as the quantities. For example, sometimes the price of TPI moves with the quantity of TPI (1950s, 1960s, and 1990s) and sometimes it moves in the opposite direction (1970s and 1980s). More distinct patterns emerge when TPI is decomposed into nonresidential and residential. In the 1950s and 1990s, the prices and quantities of nonresidential appear to move closely together. In the 1960s, 1970s, and 1980s, prices and quantities of this investment measure generally move in opposite directions. Prices and quantities of residential show more evidence of moving together. The most striking pattern to emerge among the subcomponents of nonresidential and residential is in PDE. With the exception of the 1950s, almost every time the quantity of PDE moves up, the price of PDE moves down. This suggests countercyclical behavior in the real price of PDE.

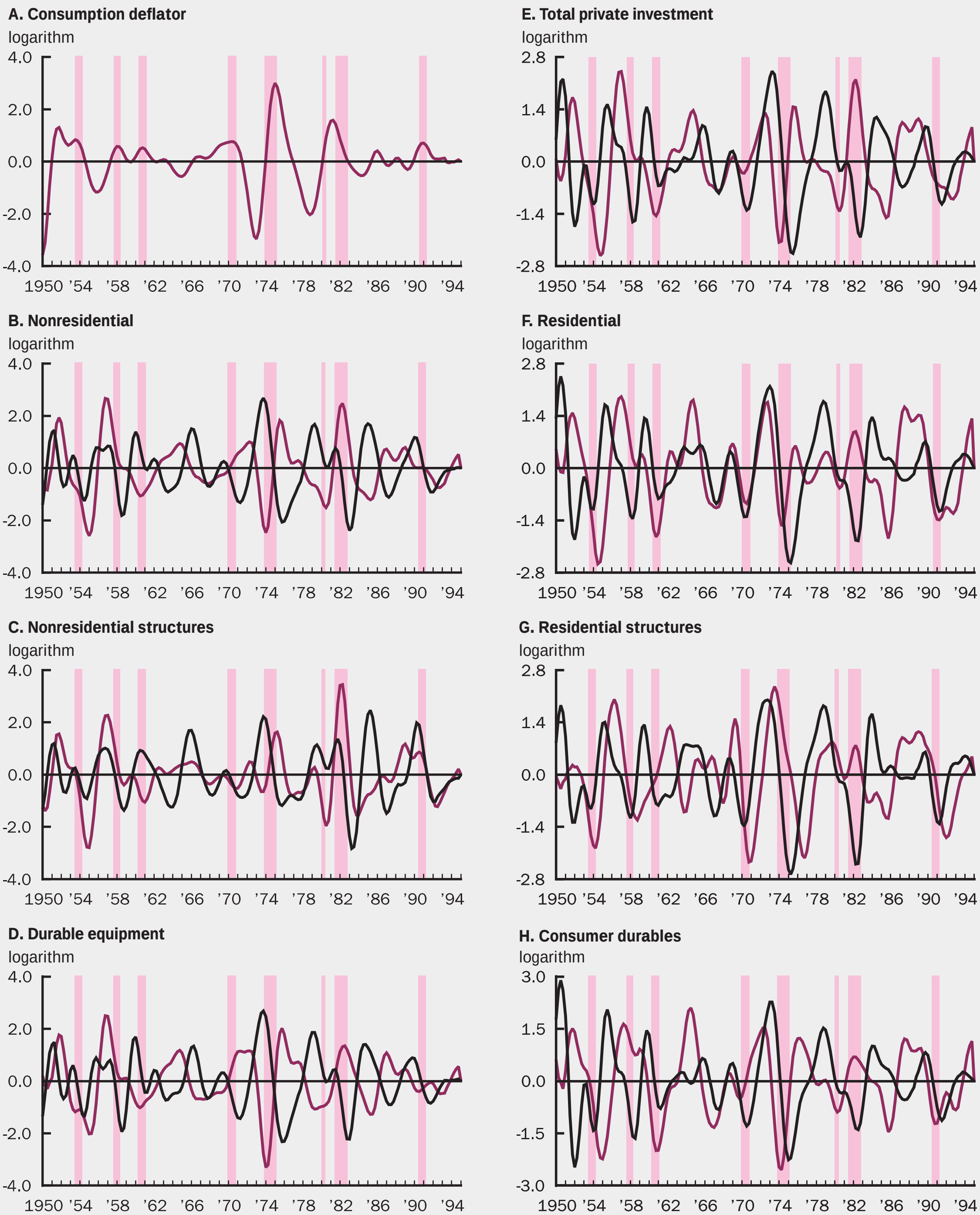
For a more formal examination of how the prices of investment goods vary with the business cycle, I use a *cross-correlogram*. A cross-correlogram is a diagrammatic device for describing how two variables are related dynamically. For example, it provides a measure of whether, say, movements in one variable tend to occur at the same time and in the same direction as movements in another variable. It can also be used to measure whether, for example, positive movements in a variable tend to occur several quarters ahead of positive movements in another variable.

The basis for the cross-correlogram is the *correlation coefficient*, or correlation. A correlation is a measure of the degree to which two variables move together and always takes on values between –1 and 1. If a correlation is positive, then the two variables are said to be positively correlated. Similarly, if a correlation is negative, the variables are said to be negatively correlated. Larger absolute values in a correlation indicate a stronger pattern of moving together. A correlation for two variables measured contemporaneously is a measure of how much two variables move together *at the same time*. A correlation can be computed for two variables measured at different times. For example, we can measure the correlation between variable x at time t and variable y at time $t-k$, where k is a positive integer. This would measure the degree to which variations in y occur before movements in x. A cross-correlogram plots these correlations for various values of k.

Figure 4 displays cross-correlograms (along with a two-standard-deviation confidence interval, a measure of how precisely the correlations are estimated) for various business cycle components of real investment and GDP, $-6 \leq k \leq 6$. For example, panel A of figure 4 displays the correlations of real nonresidential investment at date t and real GDP at date $t-k$ for the various values of k. The fact that the correlation for $k = 0$ is positive and close to 1 for all the plots in figure 4 shows that all the components of investment displayed are strongly positively correlated with GDP contemporaneously. This confirms the impression given by figure 3 that real expenditures on these investment goods are strongly procyclical. Notice that the largest correlations for nonresidential and its two main subcomponents, NRS and PDE, are for $k > 0$. This says that these components of investment tend to *lag* GDP over the business cycle. Another way of saying this is that movements above trend in GDP tend to occur *before* movements above trend in these measures of investment. On the other hand, the largest correlations for residential and its main subcomponents, RSE and CD, are all for $k < 0$. This says that these components of investment *lead* output over the business cycle. Because the correlations in figure 4 are mostly positive, this figure shows that the main components of investment are generally procyclical. (If they had been mostly

FIGURE 3

Business cycle components of investment good prices and quantities



Notes: Each business cycle component has been scaled by its standard deviation, and all data are quarterly. The colored lines represent the business cycle component of the price series for the indicated variable and the black lines represent the business cycle component of the quantity series for the indicated variable. Shaded areas indicate recessions as determined by the National Bureau of Economic Research.

Source: See figure 1.

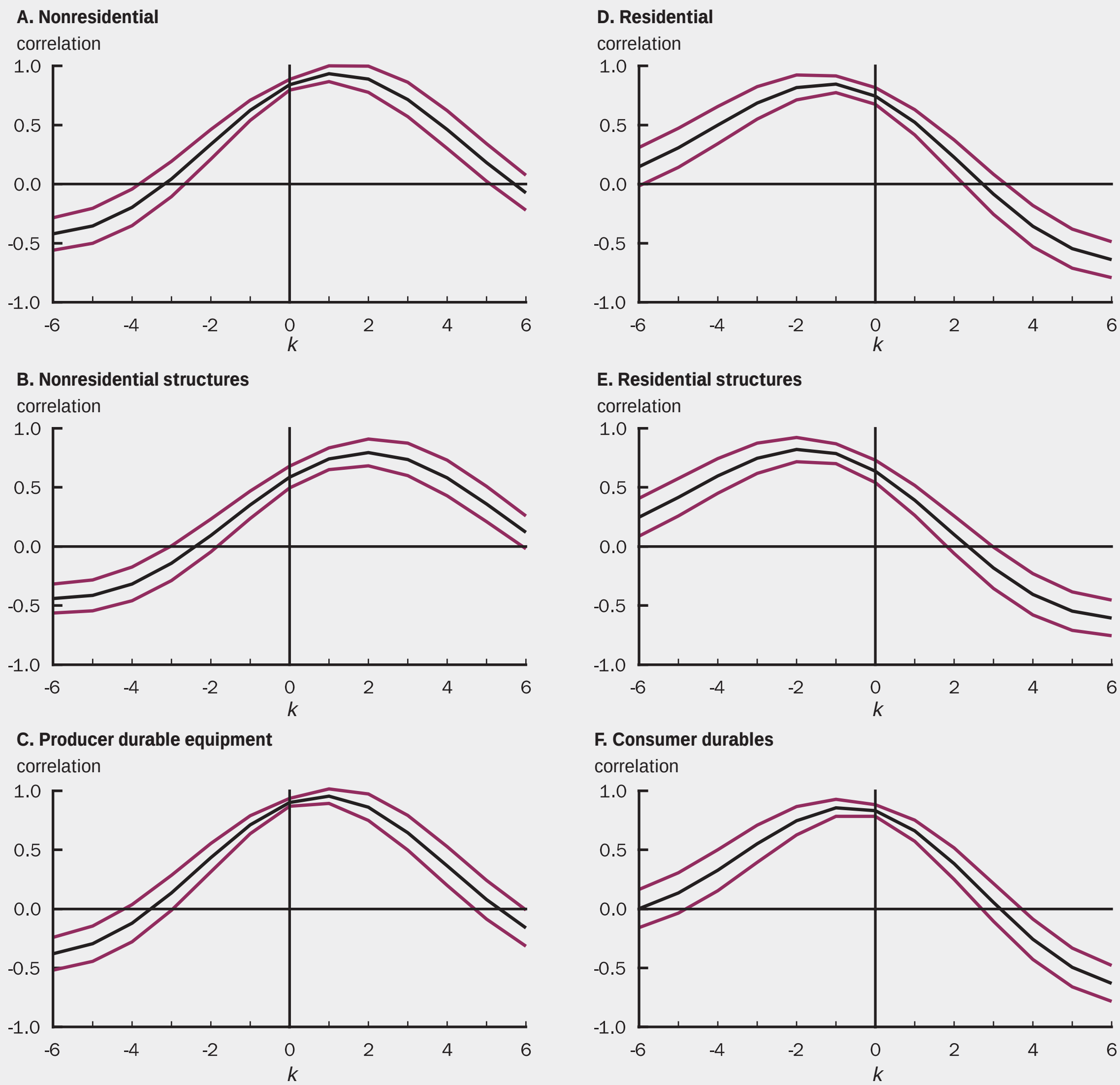
negative, then this would have been evidence of countercyclicality. If the correlations were mostly close to zero, this would have been evidence of acyclicality.)

Figure 5 displays cross-correlograms (with standard errors) for the prices of the broadest measures of investment and real GDP. The plots in figure 3 indicate that there may be some sample period sensitivity in the estimation of the underlying correlations, so figure 5 displays cross-correlograms based on two sample periods. The first column of panels in figure 5 is based on the sample period 1947:Q1–98:Q3 and the second column is based on 1959:Q1–98:Q3. Notice that none of the correlations for the TPI price based on the longer sample are significantly different from zero. This means that the price of the broadest measure of investment is essentially acyclical. There is some evidence of countercyclical movements in this price for the shorter sample, although the correlations in this case are generally not very large in absolute value or statistically significant.

The cyclical behavior of prices for the narrower investment aggregates displayed in figure 5 reveals

FIGURE 4

Business cycle correlations between investment quantities (*t*) and output (*t–k*)



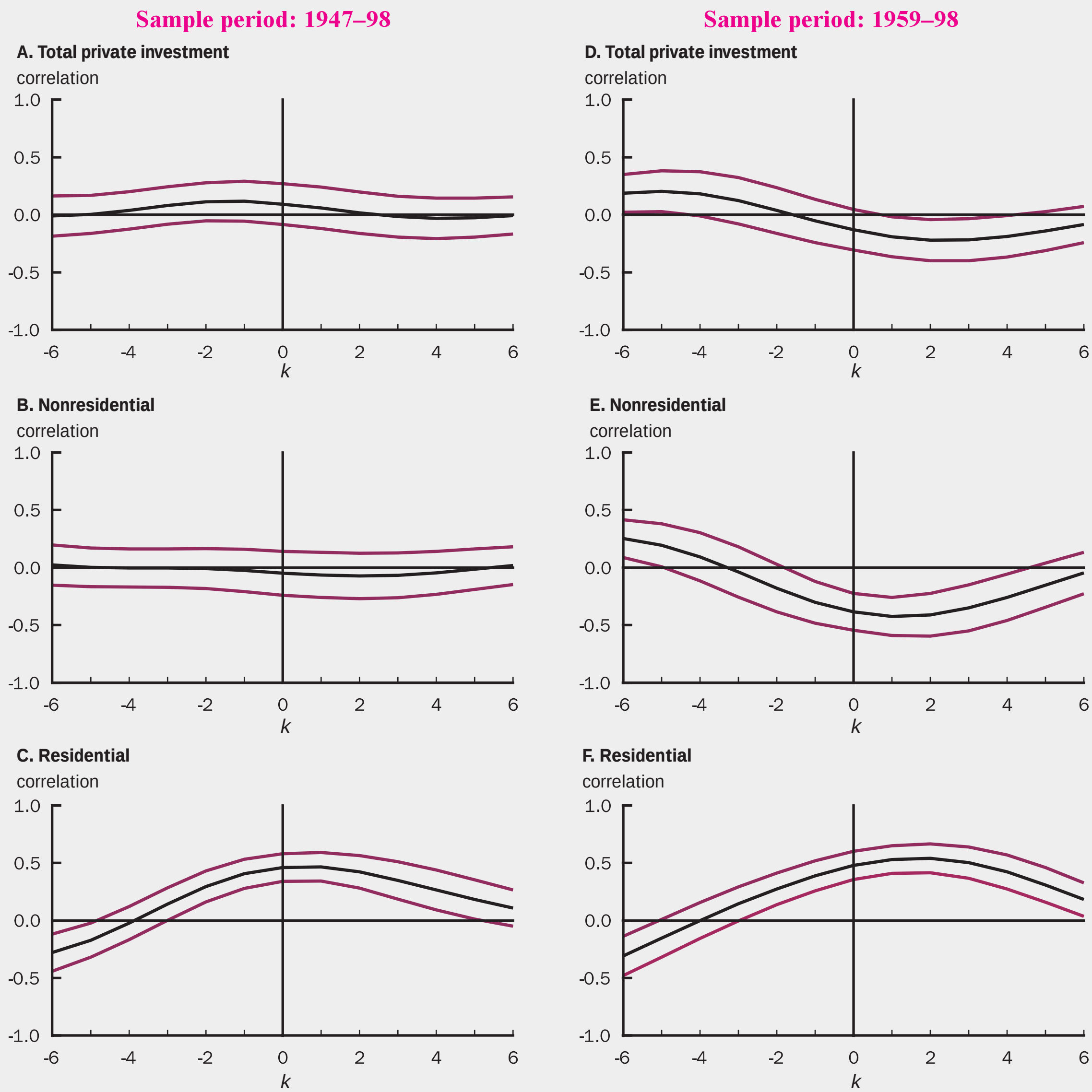
Note: Black lines are point estimates of correlations for the indicated series; colored lines are a two-standard-error confidence band.
Source: See figure 1.

that the lack of any distinct cyclical pattern for the price of TPI masks interesting differences between the prices of nonresidential and residential goods. Over the longer sample, the nonresidential price is estimated to be essentially acyclical, but the residential price is clearly procyclical. Over the shorter sample the nonresidential investment price is clearly countercyclical and the residential price remains procyclical. The difference in the estimated cross-correlogram for nonresidential over the two sample periods turns out to be due to differences in the behavior of the price of PDE in the 1950s compared with the later sample period (see figure 3).

The evidence in figure 5 suggests two things. First, the cyclical behavior of investment good prices depends to some extent on the sample period examined. Second, considering a broad investment aggregate masks potentially interesting cyclical characteristics of more narrowly defined investment good prices. Figures 6 and 7 try to uncover whether the cyclical behavior of nonresidential and residential prices also masks different cyclical behavior among the subcomponents

FIGURE 5

Business cycle correlations between investment prices (*t*) and output (*t–k*)



Note: Black lines are point estimates of correlations for the indicated series; colored lines are a two-standard-error confidence band.
Source: See figure 1.

of these broad investment aggregates. These figures display price–output cross-correlograms for the main subcomponents of nonresidential and residential. Due to data availability, the sample period for estimating the correlations is 1959:Q1–98:Q3.

The first column in figure 6 pertains to NRS and its main subcomponents, nonresidential buildings, utilities, and mining. The price of NRS is significantly countercyclical. This appears to be mainly driven by the price of utilities and mining. The second column of figure 6 pertains to PDE and its main subcomponents, information and related equipment, industrial equipment, and transportation equipment. There are two observations to make here. First, the price of PDE is strongly and significantly countercyclical. The contemporaneous ($k = 0$) correlation is –0.63 with a standard error of 0.03. The largest correlation in absolute value is for $k = 2$, indicating that this price lags output by about two quarters, about the same as the quantity of PDE (see figure 4). The second observation is that the prices of the main components of PDE behave almost identically: They are strongly and significantly negatively correlated with output and lag output by about two quarters. The behavior of the industrial equipment price is particularly striking, given that the long-run behavior of this price is so different from that of the other two subcomponents of PDE (see figure 2).

Figure 7 is constructed similarly to figure 6, with RSE and its subcomponents in the first column and CD and its subcomponents in the second column. This figure shows that prices of RSE are generally procyclical and prices of CD goods are mostly acyclical. The behavior of RSE is driven mostly by the cyclicality of single and multifamily structures. Interestingly, despite the fact that investment in RSE tends to lead output over the business cycle, the real price of RSE and its components lags output. The real price of CD is driven mostly by motor vehicles and other. Of the subcomponents of CD, only the furniture price displays significant countercyclicality.

Summary of the evidence

The key features of the evidence presented in this section can be summarized as follows. First, there is strong evidence of a downward trend in the price of investment goods in terms of consumption goods. This downward trend is concentrated among components of PDE and CD. Second, the broadest category of investment, TPI, displays little distinct cyclical variation over the sample period 1947:Q1–98:Q3, but is moderately countercyclical in the later period, 1959:Q1–98:Q3. If we are willing to abstract from the 1950s, say because of the dominating influence of the Korean war, then it seems reasonable to say that the price of the broadest component of investment is weakly countercyclical. Certainly it is difficult to make the case that this price is procyclical, regardless of the sample period considered.

Many components of TPI display distinct cyclical characteristics, even if we include the 1950s. The prices of the two main components, nonresidential and residential, behave differently. The former is significantly countercyclical and the latter is significantly procyclical. The behavior of the nonresidential price is dominated by the PDE price. The PDE price is strongly countercyclical, as are the prices of all its subcomponents. The price of NRS is mildly countercyclical, but this pattern is not shared by all its subcomponents. The behavior of the residential price is dominated by RSE prices, which are strongly procyclical. CD prices are acyclical or weakly countercyclical.

Implications for growth and the business cycle

How does the trend and cycle behavior of investment goods prices presented above challenge conventional views about growth and business cycles? Next, I discuss various attempts to reconcile theory with the evidence and some empirical work that sheds light on the plausibility of competing theories.

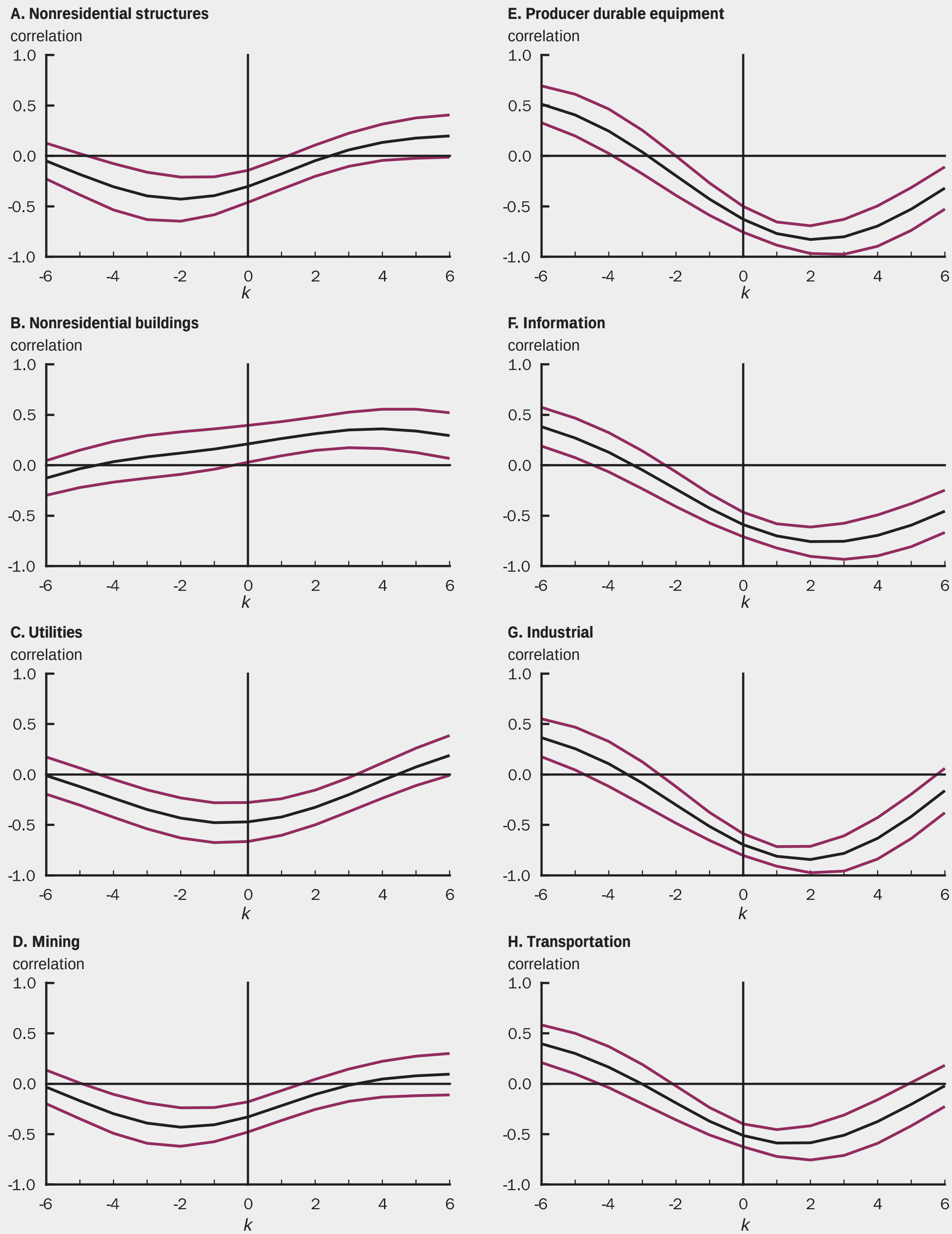
Growth theory

Recent years have seen an explosion of theoretical and empirical research into economic growth.[12] On the theoretical side, two leading classes of models of the determinants of economic growth have emerged. The first is based on the accumulation of *human capital* and follows from the work of Lucas (1988). Human capital consists of the abilities, skills, and knowledge of particular workers. The basic idea behind this view of economic growth is that it is fundamentally based on improvements in the stock of human capital of workers over time. This view of growth holds that, other things being equal, the larger is the stock of human capital of workers, the more productive they are. This means that one expects an improvement in the stock of human capital to increase the amount of output of *any* good that can be produced for a fixed quantity of workers and capital. In this sense, growth due to the accumulation of human capital has a homogeneous impact on the economy's ability to produce goods.

The second leading class of models focuses on research and development. Pioneering work along these lines includes Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). One of the key insights of this literature is that growth can emerge if there are nondecreasing returns to produced

FIGURE 6

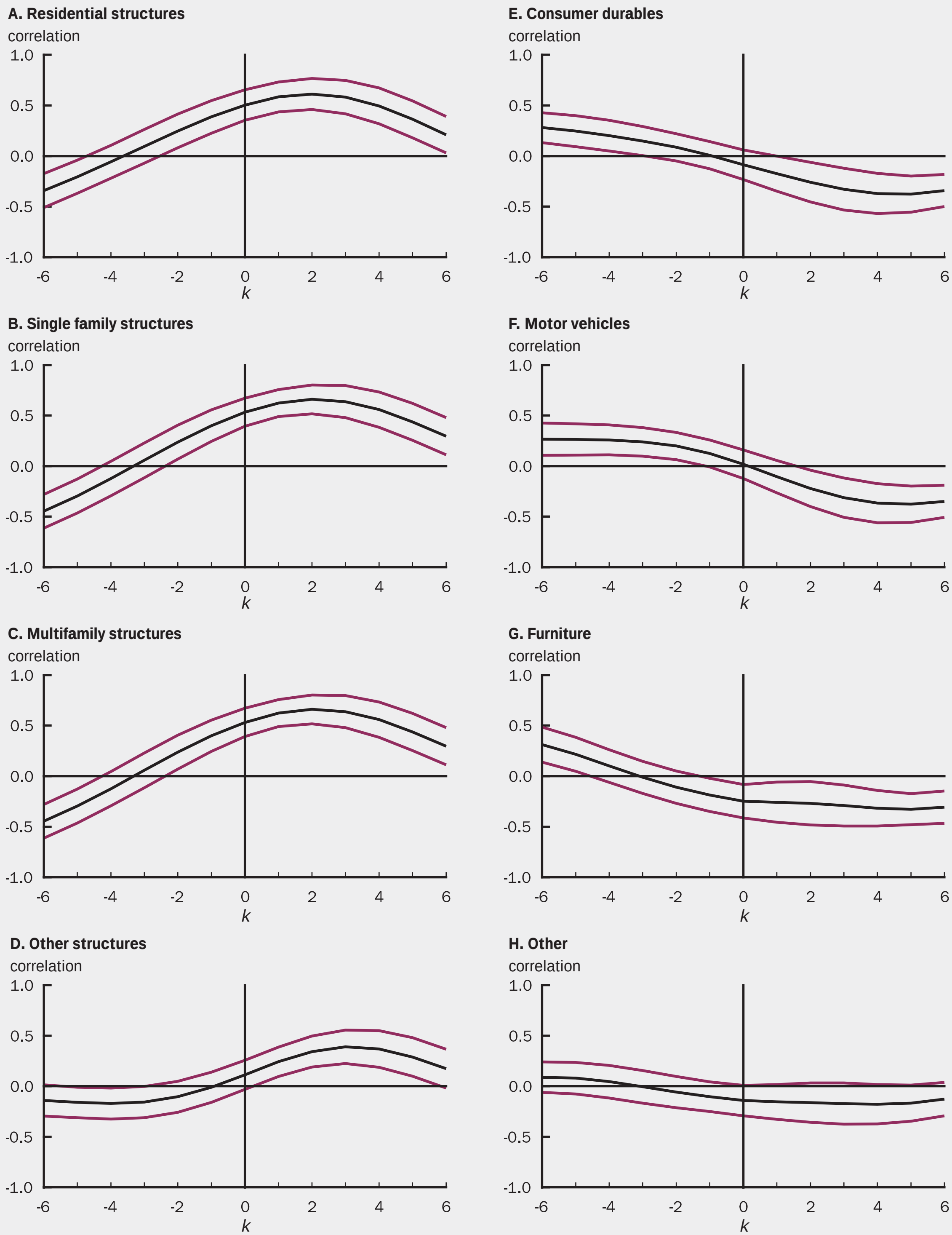
Business cycle correlations between nonresidential prices (*t*) and output (*t–k*)



Note: Black lines are point estimates of correlations for the indicated series; colored lines are a two-standard-error confidence band.
Source: See figure 1.

FIGURE 7

Business cycle correlations between residential prices (*t*) and output (*t–k*)



Note: Black lines are point estimates of correlations for the indicated series; colored lines are a two-standard-error confidence band.
Source: See figure 1.

factors of production (such as knowledge or capital, but not labor).[13] The bottom line of this theory is similar to that of the human capital models. Improvements in technology due to research and development usually increase the productivity of all factors of production. Consequently, if there is such an improvement in technology, more of all goods can be produced with a fixed quantity of capital and labor. Again, technological change is assumed to have a homogeneous impact on produced goods.

The evidence on trends in investment good prices, particularly the trend in the price of PDE, challenges these views of growth, because it strongly suggests that there have been substantial improvements in technology that have affected one kind of good but not another. Specifically, the data suggest that the quality and technology of capital goods production have advanced almost nonstop since the end of World War II. Why do the data suggest this? Assuming that the prices and quantities of PDE are correctly measured, the real price of PDE measures how many (constant quality) consumption goods need to be sold in order to raise the funds to purchase one (constant quality) unit of PDE. If this price has been falling, then fewer and fewer consumption goods are needed to buy a unit of PDE. This suggests that the supply of PDE has grown relative to the supply of consumption goods. One way the supply of PDE can rise in this way is if the technology for producing capital goods improves at a faster rate than that for producing consumption goods. In this case, the same amount of capital and labor applied to producing PDE or consumption goods will yield more PDE than consumption as time passes. That is, the supply of PDE will grow relative to consumption goods. The basic logic of supply and demand then dictates that the price of PDE in terms of consumption goods must fall. Greenwood et al. (1997) build on this intuition to show how the trend in the relative price of PDE and the associated increase in the share of PDE in aggregate output (see table 1) can be accounted for in a growth model in which most growth is due to capital-embodied technical change. In addition, the authors argue that other potential explanations for the price and quantity trends are implausible or boil down to essentially the same explanation.[14]

Greenwood et al. (1997) apply their model of growth to reevaluate conventional estimates of the importance of technological change in improving standards of living. This line of research is called growth accounting. The effects of technical change using standard models, like the ones briefly described above, can be summarized by multifactor productivity, which is also called the Solow residual. Multifactor productivity is an index of the quantity of aggregate output that can be produced using a fixed quantity of (quality-adjusted) capital and labor. The higher the multifactor productivity, the more output can be produced. Traditionally, most of growth is viewed as being due to improvements in multifactor productivity. Greenwood et al. (1997) use their model to show that approximately 60 percent of all improvements in productivity can be attributed to capital-embodied technical change, while the multifactor productivity index accounts for the rest. This says that capital-embodied technical change is a fundamental part of growth.

Business cycle theory

To assess the cyclical evidence on relative prices, we need to understand how various shocks to the economy might influence the cost of investment goods compared with consumption goods. Figure 8 displays a production possibilities frontier (PPF) for consumption and investment goods. The PPF depicts the various quantities of consumption and investment goods that can be produced if capital and labor are fully employed and used efficiently. The shape of the frontier reflects the fact that, holding fixed the quantity of labor and capital employed in producing goods, it is costly to shift production toward either producing more consumption goods or more investment goods.[15] This is reflected in the figure by the increase in the (absolute value of the) slope of the frontier as one moves from the upper left to the lower right. In a competitive equilibrium, the slope of the frontier equals the relative price of the goods. Hence, as more investment goods are produced, the relative price of investment goods rises.

The PPF summarizes the supply side of the economy. The actual price in a competitive equilibrium is determined by the interaction of the demand for consumption and investment goods with the supply. Suppose that the demand for consumption and investment goods dictates that the quantity of consumption goods and investment goods actually produced is given by C_0 and I_0 in figure 8. Now, suppose a Keynesian demand shock—for example, an increase in the money supply which lowers interest rates—increases the demand for investment goods relative to consumption goods. Since this is a demand shock, the PPF in figure 8 does not change. The change in demand leads to a movement down the frontier, say to a point where consumption and investment are given by C_1 and I_1. Since the slope of the frontier is steeper at this point, the relative price of investment goods must rise. If aggregate output is driven by shocks to investment demand, then the price of investment goods is predicted to be procyclical.

An aggregate supply shock has a similar implication. The conventional assumption about these kinds of shocks is that they raise multifactor productivity and influence all produced goods symmetrically. This is shown in figure 9 as a proportional shift out in the solid line PPF to the dashed line PPF. The dashed line PPF has been drawn so that its slope is identical to the slope of the solid line PPF along a straight line from the origin. This means that if the ratio of consumption to investment goods produced before and after the technology shock is constant, then the relative price of investment goods will be unchanged. However, this is not what is predicted in standard models. These models say that when a good technology shock arrives, which raises the productivity of all factors of production, the optimal response of individuals is to smooth consumption. That is, not have consumption change too much in the short run. The result of this is that investment rises more than consumption. In figure 9, this is represented by consumption and investment changing from C_0 and I_0 before the productivity shock to C_1 and I_1 after the shock. It follows that the price of investment goods must rise in this case as well. Since output also rises with a positive technology shock, the price of investment goods is predicted to be procyclical.[16]

In view of the cyclical evidence presented earlier, these model predictions are problematic. They are consistent with the behavior of residential investment, but inconsistent with the behavior of the other major components of investment and the broadest measure, TPI. Why are investment goods prices not procyclical? The two leading explanations involve assumptions about the technology for producing investment goods. One is based on *increasing returns* to scale in the production of investment goods (but not consumption goods). The other is based on a variation in the rate of capital-embodied technical change. The increasing returns view assumes that the more investment goods that are produced, the less costly it is to produce a unit of investment goods. One way to represent this is shown in figure 10, which displays a pseudo-PPF.[17] Notice that the shape is different from figures 8 and 9. Now when more investment goods are produced relative to consumption goods, the price of investment goods falls. In this case, both aggregate technology shocks and Keynesian demand shocks can lead to countercyclical relative prices.

To understand the embodied technology view, consider an increase in the productivity of producing investment goods that has no direct impact on the production of consumption goods. This could take the form of improvements in the efficiency of producing investment goods. It could also take the form of an improvement in the quality of investment goods produced so that a given quantity of capital and labor can produce a higher quantity of quality-adjusted goods. Either way, we can represent the change in technology as in figure 11. The improvement in technology is shown by the shift from the solid to the dashed frontier. Along the dashed frontier, for each quantity of consumption goods produced, more investment goods can be produced. Moreover, along any straight line from the origin, the slope of the dashed frontier is flatter than the solid frontier. That is, for any fixed ratio of consumption to investment goods, the investment goods are cheaper in terms of consumption goods after the change in technology. Now, after the increase in technology, there will be a shift in favor

FIGURE 8

Effect of increase in demand for investment goods

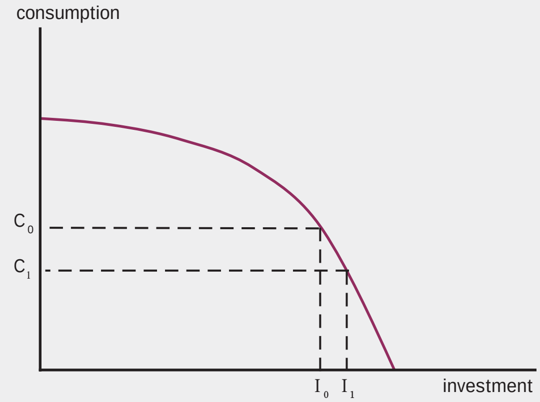
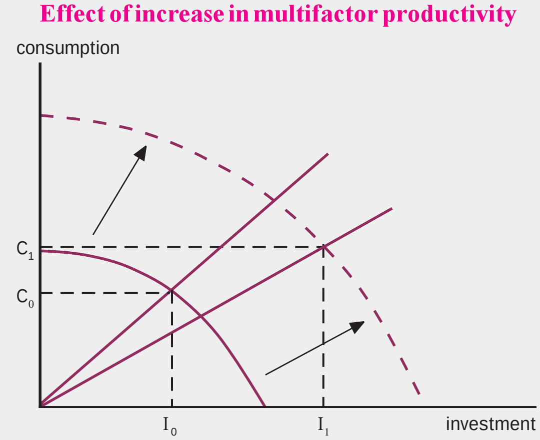


FIGURE 9

Effect of increase in multifactor productivity



of the production of investment goods. If this shift is strong enough, the movement along the dashed frontier could in principle raise the investment good price. In practice, this does not happen. Since aggregate output rises after this kind of technology shock, if business cycles are in part driven by this kind of disturbance, then investment good prices could be countercyclical.

Evaluating the theories

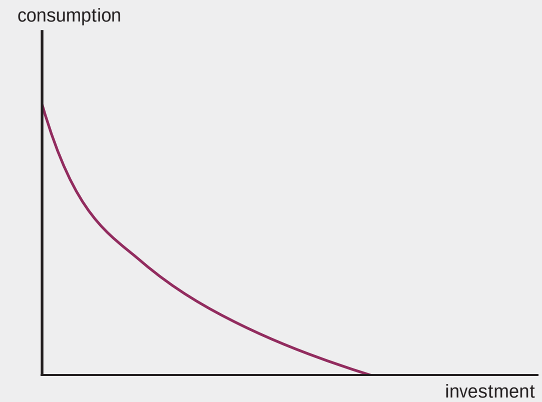
Beyond the work of Greenwood et al. (1997), little has been done to evaluate the plausibility of the capital-embodied technological change theory of the trend evidence on investment prices. However, more work has been done to evaluate the differing views on the cyclicality of investment good prices.

Generally, the empirical evidence seems to go against the increasing returns interpretation of the cyclical evidence on prices. Harrison (1998) examines annual data on capital, labor, and value added in various industries in the consumption good sector and the investment good sector. She finds some empirical support for increasing returns associated with capital and labor in the production of investment goods. However, she does not find a sufficient degree of increasing returns to generate increasing returns in the factor of production, labor, that is variable in the short run. Consequently, the work does not support the increasing returns view. Other research on measuring increasing returns focuses on the manufacturing sector. Basu and Fernald (1997), Burnside (1996), and Burnside, Eichenbaum, and Rebelo (1995) have overturned previous empirical claims of increasing returns in the manufacturing sector, including capital equipment industries.

Other empirical work attempts to address a key implication of the increasing returns view—that the supply curve for investment goods slopes down. That is, holding other things constant, the cost of investment goods is diminishing in the quantity of investment goods produced. Shea (1993), in a study of many sectors of the economy, uses instrumental variables econometric techniques to distinguish *supply* shocks from *demand* shocks to trace out the slope of supply curves. The author's main conclusion is that, broadly speaking, supply curves slope up. Goolsbee (1998) focuses specifically on the supply of capital goods and uses a series of "natural experiments" (involving periodic changes in federal laws providing for investment tax credits) to identify a disturbance that affects the demand for investment goods but not the supply. He finds clear evidence of an upward sloping investment supply curve. To summarize, empirical work on the sign of the slope of the investment good supply schedule finds that it is positive.

FIGURE 10

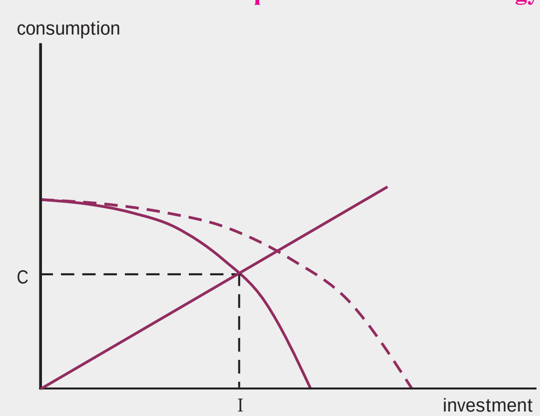
Increasing returns to scale case



Other research assesses the plausibility of the embodied technology view. Christiano and Fisher (1998) and Greenwood et al. (1998) evaluate business cycle models in which a major driving force for fluctuations is variations in capital-embodied technical change. They test the embodied technology view by examining the ability of their models to account for various business cycle phenomena. Both studies find that their models do about as well as other business cycle models in accounting for business cycle phenomena. As a measure of the importance of capital-embodied technical change as a driving force for business cycles, Greenwood et al. (1998) find that about 30 percent of business cycle variation in output can be attributed to this kind of shock. Christiano and Fisher (1998), in a very different model, find that about three-quarters of output fluctuations are due to this shock. Either way, the evidence suggests that variation in the rate

FIGURE 11

Effect of increase in capital-embodied technology



of technical change embodied in capital equipment accounts for a significant proportion of business cycle variation in output.

New evidence

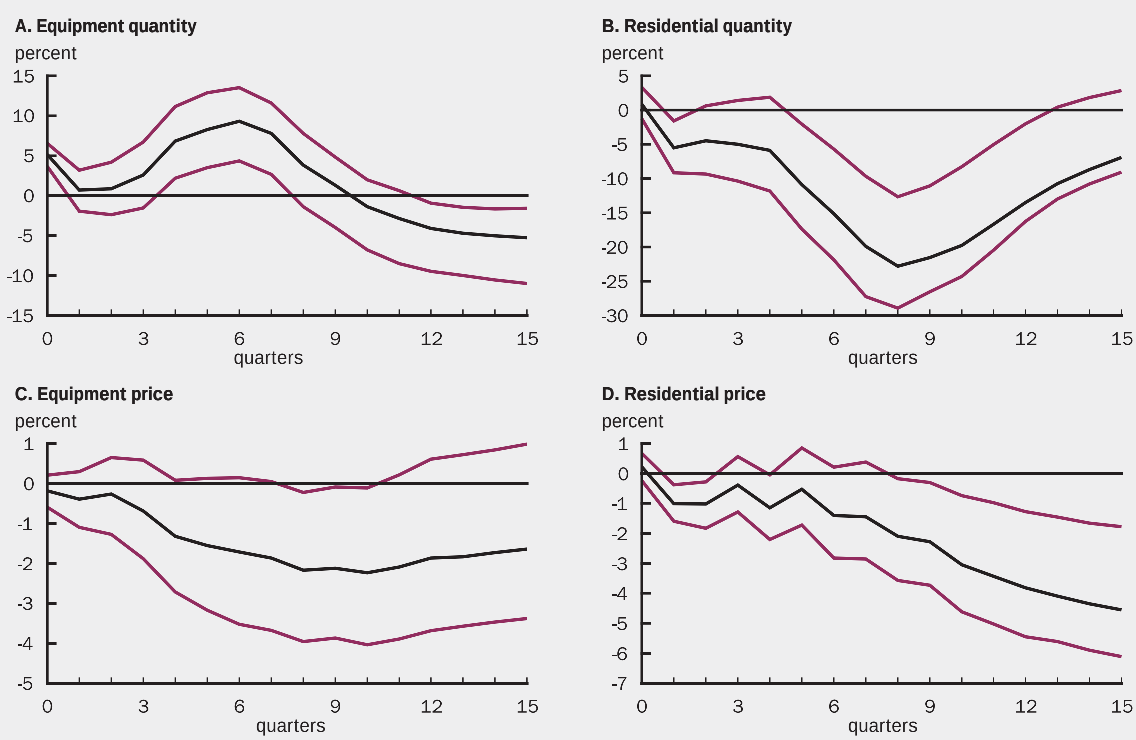
Some new research attempts to distinguish the increasing returns view from the embodied technology view of the cyclical behavior of investment good prices. This evidence is based on two econometric procedures designed to identify disturbances to the aggregate economy that influence the demand for investment goods, but leave supply unchanged. The specific shocks considered are an exogenous increase in government purchases (that is an increase in government purchases that is unrelated to developments in the economy) and an exogenous monetary contraction.

In the government spending case, the idea is to investigate how particular investment quantities and prices respond to an exogenous increase in government purchases. The exogenous increase in government spending takes the form of a large military buildup (specifically the Korean war, the Vietnam war, and the Carter–Reagan buildup.) The methodology is identical to that employed by Eichenbaum and Fisher (1998).[18] Figure 12 displays the estimates, which are based on quarterly data for 1947:Q1–98:Q3. The first row of figure 12 plots the response to an exogenous increase in government purchases of real investment in PDE and RSE (solid lines) along with a 68 percent confidence band (colored lines). The second row plots the corresponding relative price responses. Interestingly, PDE investment rises and RSE investment falls.[19] Under the increasing returns view, we would expect the PDE price to fall and the RSE price to rise. The second row of plots indicates that the RSE price response is inconsistent with the increasing returns view, while the PDE price response seems to confirm it.

The monetary shocks case examines how quantities and prices of PDE and RSE respond to an estimate of a contractionary monetary disturbance. The methodology is standard[20] and has been summarized by Christiano (1996) (see also Christiano, Eichenbaum, and Evans, 1999). The estimated responses (along with a 95 percent confidence interval) are presented in figure 13. Looking at the quantities in the first row of plots, notice that both PDE and RSE fall after an

FIGURE 12

Response of investment quantities and prices to exogenous increase in government purchases



Notes: Black lines are point estimates of the responses; the colored lines are a symmetric 68 percent confidence band.
Source: Author's calculations from data extracted from DRI Basic Economics database, 1959–98.

exogenous monetary contraction. Under the increasing returns view, one would expect the prices of both investment goods to rise. Studying the second row of plots, we see that the PDE price response is not significantly different from zero and the RSE price drops significantly.

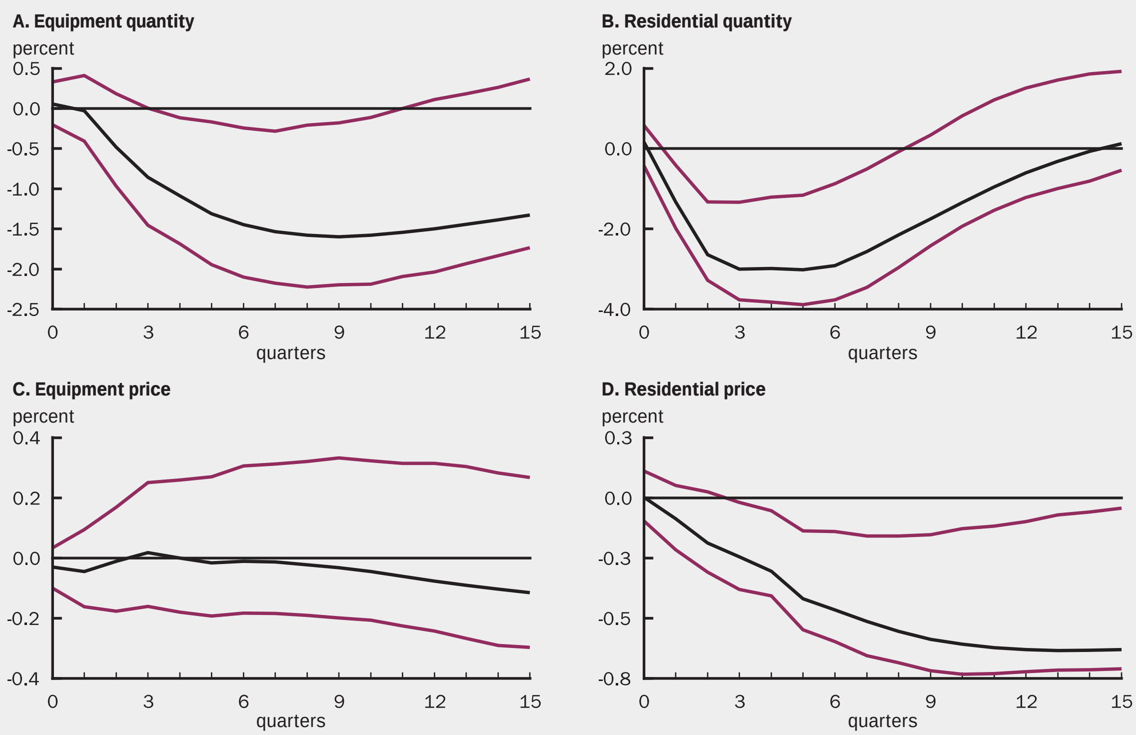
Taken together, the evidence on the responses of RSE prices and quantities to government spending and monetary shocks goes against the increasing returns view. It conforms to a standard neoclassical view of investment, in the sense that it is consistent with the discussion of the production possibilities frontier in figure 8. Of course, the increasing returns view is really intended to apply to PDE investment. The responses of PDE prices and quantities provide mixed signals. The responses to a monetary shock provide evidence neither for nor against increasing returns, since the quantity falls but the price response is not very precisely estimated and could be either positive, negative, or zero. The responses to a government spending shock might be viewed as evidence in favor of increasing returns. However, one interpretation of the PDE price response in this case is that it is dominated by the Korean war military buildup. This occurred just after World War II, when military spending had fallen from very high levels. The increasing returns that could support a lower price with higher investment might conceivably be due to the resumption of large-scale production at facilities that had been operating far below minimum efficient scale. If this is true, it seems more like a special case than an enduring feature of the U.S. economy.

Conclusion

In this article, I have presented evidence on trends and business cycle variation in the prices of investment goods relative to nondurables and services consumption. This evidence seems to go against conventional views of both business cycles and growth. How can one reconcile theory with the evidence? The leading views include one based on increasing returns to scale in the production of investment goods and another based on capital-embodied technical change. While some of the evidence I presented could be viewed as supporting the increasing returns view, generally, there is little empirical support

FIGURE 13

Response of investment quantities and prices to an exogenous monetary contraction



Notes: Black lines are point estimates of the responses; the colored lines are a symmetric 95 percent confidence band.
Source: See figure 1.

for increasing returns. At this point, then, the leading candidate to reconcile theory with the data appears to be the one based on capital-embodied technical change, that is, the embodied technology view.

This conclusion has implications for our understanding of growth and business cycles, future research on these subjects, and policy. The prospect of a comprehensive theory of growth and business cycles is appealing because of its simplicity. Disembodied technical change has gained credence for its supposed ability to account for growth and business cycles. Yet, the theory of business cycles based on disembodied technology has always been problematic because the shocks are hard to interpret. The growth accounting results of Greenwood et al. (1997) bring into question the growth implications of this theory as well. In the search for a comprehensive theory of growth and business cycles, then, advances in capital-embodied technology seem to offer a promising alternative. In addition, they provide a much more tangible notion of growth. These considerations suggest that future research on growth and business cycles that emphasizes capital-embodied technical change may be fruitful.

If growth and business cycles are originating from changes in capital-embodied technology, then the models we use for policy analysis have to incorporate this and, consequently, policy recommendations could change. To the extent that technological change is embodied in capital equipment, government policies that affect equipment investment could have a dual impact on growth via the quality and the quantity of capital goods. This could mean, for example, that investment tax credits directed toward improvements in the efficiency of capital equipment could have a significant impact on growth. More research is required to uncover the full implications of this.

The implications for stabilization policy of the embodied technology view are less obvious. The fact that it seems to supplant the increasing returns view means that the arguments for interventionist stabilization policy that this view supports are less compelling. For example, increasing returns could provide scope for policy intervention, because it either involves externalities or is inconsistent with perfect competition. Moreover, it makes animal spirits models more plausible, which also has implications for stabilization policy (see, for example, Christiano and Harrison, 1999). The embodied technology view is more in line with the real business cycle tradition, in which policy interventions are counterproductive. Real business cycle theory says that the business cycle is largely the result of optimal behavior by individuals in the economy interacting, for the most part, in perfectly competitive markets. Any policy interventions in such an environment tend to reduce overall welfare. To the extent that the embodied technology view is more compelling than previous incarnations of real business cycle models, it lends greater support to the argument that interventionist stabilization policy cannot improve the well-being of any individual in the U.S. economy without hurting some other individual. Of course, this still leaves open the possibility that equity considerations might be used to defend interventionist stabilization policy.

NOTES

[1]Equivalently, higher quality goods of all kinds can be produced with the same amount of capital and labor. As described in more detail below, new models of endogenous growth have reduced forms, which have similar implications for growth accounting to those of models written in terms of exogenous disembodied technical change.

[2]Examples of textbooks that emphasize the IS–LM model are Abel and Bernanke (1997), Gordon (1998), Hall and Taylor (1997), and Mankiw (1997).

[3]For a survey of theories based on animal spirits, see Farmer (1993).

[4]A good summary of this view is Prescott (1986). For a discussion of how this view can be used to explain the 1990–91 recession, see Hansen and Prescott (1993).

[5]This section relies heavily on Christiano and Fitzgerald (1998, pp. 58–59).

[6]This is the empirical counterpart to investment as it is usually defined in the real business cycle literature.

[7]The aggregation in this table is identical to the aggregation used by the BEA, except for "residential," which is calculated as the chain-weighted aggregate of "residential structures and equipment" and "consumer durable." See box 1 for the chain-weighting procedure.

[8]For TPI and GDP, y, the nominal shares in the first row are $P_t^{TPI} q_t^{TPI}/(P_t^y q_t^y)$ and the real shares are q_t^{TPI}/q_t^y. Nominal and real shares for investment good i in the other rows are given by $P_t^i q_t^i/(P_t^{TPI} q_t^{TPI})$ and the real shares are q_t^i/q_t^{TPI}.

[9]In the notation used above, the black lines are (the natural logarithm of) p_t^i for i corresponding to the 20 types of investment listed in table 1 over the period for which data are available.

[10]Many of the trends evident in figure 2 are not apparent in the NIPA fixed-weighted constant 1982 dollar and earlier NIPA data. In a very influential book, Gordon (1989) argued that the conventional BEA treatment of investment good quality severely underestimated the degree of quality change in investment goods. His analysis was the first to show that there is a substantial downward trend in the prices of PDE and CD. The BEA now incorporates many of the adjustments for quality change advocated by Gordon (1989).

[11]The procedure used to extract the business cycle component of the relative price data involves the application of a linear filter. This, combined with the fact that this filter is applied to the natural logarithm of the relative prices, implies that the business cycle component of each relative price is the business cycle component of the relevant investment deflator minus the business cycle component of the consumption deflator.

[12]For a comprehensive review of this literature, see Barro and Sala-i-Martin (1995).

[13]The assumption of constant returns to scale is usually based on a replication argument. A fixed quantity of capital and labor applied to produce *x* amount of some good can always be applied again to produce another *x* of the good. That is, increasing the quantity of factors of production by some proportion changes the amount produced by the same proportion. This argument seems harder to apply in the case of technology. For example, suppose a group of researchers have discovered a new process for making steel. If another group of researchers make the same discovery, there is no net improvement in knowledge. In this case, there would be decreasing returns. On the other hand, fixed costs or advantages to having many researchers working on similar projects may mean that increasing returns to scale are important in the process of knowledge creation.

[14]Greenwood et al. (1997) show how the research and development and human capital classes of models can be used to account for the evidence, if these activities have a disproportionate impact on the production of equipment compared with consumption goods. Two explanations they consider differ fundamentally from their basic story. They both involve a two-sector interpretation of the evidence, in which equipment and consumption goods are produced in separate sectors (using separate production functions). In one case, the production functions have different factor shares, that is, the different goods require capital and labor in different proportions to produce a unit of the good. The authors conclude that the "prospect for explaining the relative price decline with a two-sector model based on differences in share parameters looks bleak, given the implausibly large differences required in the structure of production across sectors (p. 358)." The other explanation involves an externality in the production of investment goods. Specifically, the productivity of factors in the investment good sector is increasing in the quantity of investment goods along the lines described in Romer (1986). Greenwood et al. (1997) show that this explanation can, in principle, account for the trend evidence. However, this theory relies on an externality which is difficult to identify empirically. Some evidence on increasing returns to scale, which the production externality implies, is discussed below. Generally, there is little empirical support for this view.

[15]The shape of the frontier can be justified by standard neoclassical assumptions about how goods are produced, in particular that they are produced using constant returns to scale production functions in labor and capital and that it is costly to transfer labor and/or capital across sectors producing consumption goods and sectors producing investment goods. Note that adjustment costs in the installation of investment goods affect the relative price of installed capacity, ***not*** the relative price of investment goods.

[16]This discussion assumes that the shares of factors in production are identical in producing consumption and investment goods and/or that there are costs of adjusting factors of production across sectors. It is possible for the price of investment goods to be countercyclical in this type of model if the share of labor in production is greater in the consumption sector than in the investment goods sector. As long as factors of production are perfectly mobile across sectors (that is, there are no costs to shifting factors across sectors), an increase in technology lowers the price of investment goods in this case. Factor shares are difficult to measure, so assessing the plausibility of this possibility is difficult. However, the Greenwood et al. (1997) results for long-run trends suggest that the differences in factor shares required to reconcile the empirical evidence on prices with this explanation may be implausible. Also, it is implausible to assume that there are no costs of shifting factors of production across sectors.

[17]This frontier does not necessarily reflect true technological possibilities, but takes into account the restrictions on individual decisionmaking, such as individuals not internalizing a production externality, such that the points on the frontier are consistent with optimizing behavior of producers.

[18]The methodology is identical to that employed by Eichenbaum and Fisher (1998). This methodology uses four variables, in addition to the investment good quantity and price variables, in a vector autoregression, along with a dummy variable which takes on the value zero at all dates except 1950:Q3, 1965:Q1 and 1980:Q1, in which cases the variable equals unity. These dates correspond to the beginning of three large military buildups. The key identifying assumption is that these buildups were exogenous events. For further discussion, see Edelberg, Eichenbaum, and Fisher (1999). The four variables are the log level of time t real *GDP*, the net three-month Treasury bill rate, the log of the Producer Price Index of crude fuel, and the log level of real defense purchases, g_t. Six lags were used. The plotted responses in figure 12 correspond to the average response of the indicated variable across the three military buildup episodes, taking into account the endogenous variation in the variable.

[19]See Edelberg, Eichenbaum, and Fisher (1999) for a discussion of how this evidence can be explained within the context of a standard neoclassical model.

[20]Technically, I estimate a vector autoregression in the deflator for nondurables and services, real GDP, an index of changes in sensitive materials prices, the federal funds rate, plus the investment price and quantity I am interested in. All variables except the federal funds rate are first logged. The impulse response functions in figure 13 correspond to an orthoganalized innovation in the federal funds rate. The orthoganalization procedure assumes the order of the vector autoregression is the same as listed in the text and a triangular decomposition. Ordering is not important for the investment responses as long as standard assumptions are made about the variables that precede the federal funds rate in the ordering (see Christiano, Eichenbaum, and Evans, 1999). Finally, the standard errors are computed using the procedure described by Christiano, Eichenbaum, and Evans (1999).

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