# Manufacturing Productivity and High-Tech Investment

## by Charles Steindel

Labor productivity in U.S. manufacturing soared in the 1980s. From 1983 to 1989, output per employee in manufacturing[1] grew at an annual average of 5 percent, compared with 1.1 percent in 1974-82 and the pre-1974 average of 3 percent (Table 1).

No satisfactory explanation for the acceleration in manufacturing productivity has emerged. Net fixed capital per worker in manufacturing showed scant growth in the 1980s. The gross capital-labor ratio was also little changed.[2] Reflecting the lack of capital deepening, multifactor productivity—productivity not accounted for by labor and capital inputs—advanced at a record pace in the 1980s.

The increased growth of productivity in manufacturing is in sharp contrast to its continued weakness in the rest of the economy. Output per employee in the nonfarm, nonmanufacturing sector grew at only a 0.4 percent rate in the 1980s expansion, down from a pre-1974 average of 1.6 percent.

Conceivably, the improvement in manufacturing productivity could have been linked to increased use of high technology. There is a widespread feeling that the manufacturing sector went through significant technological changes in the 1980s. Rather surprisingly, however, data at the simplest level do not suggest any technology surge in manufacturing in the 1980s. "Information-processing" equipment—computers and other office machinery, communication equipment, and technical instruments—accounted for a much smaller share of the capital stock in manufacturing than elsewhere, and per worker growth in the stock of this equipment actually slowed in the 1980s.

Still, despite the rather unimpressive data on capital stock growth, high-tech capital may have made a significant contribution to the improvement in manufacturing productivity. This article explores in more depth some of the issues connected with productivity growth and "high-tech" capital.[3] It finds some evidence of a positive relationship between high-tech capital usage and productivity in manufacturing industries. The relationship is sufficiently large to account for a nontrivial fraction of the growth of productivity in manufacturing industries from the first to the second half of the 1980s, even though other factors played more substantial roles and the bulk of the acceleration in productivity growth remains difficult to explain.

The first section of the article examines how economists conventionally view the possible connections between high-tech capital and output. This conceptual material is followed by an empirical examination of the linkage of high-tech capital stocks and investment flows to the productivity of manufacturing industries.

[1]This measure differs from the commonly reported Bureau of Labor Statistics productivity series because it measures the input of labor as full-time equivalent employment rather than hours worked. The data in this article do not incorporate the recent benchmark revision of the National Income and Product Accounts, since the revised historic data on output by industry are not available.

[2]The net capital stock measures the resource costs of replacing the (straight-line) depreciated value of the equipment and structures currently in service. The gross capital stock measures the same costs without corrections for depreciation.

[3]Throughout this article the terms "high technology" and "computers" will be used interchangeably with the term "information-processing equipment." In the late 1980s spending on computers accounted for about one-third of current-dollar, and two-thirds of constant (1982)-dollar, investment in information-processing equipment by all private firms.

## The contribution of high-tech capital to output

As noted above, the stock of high-tech capital in manufacturing actually grew more slowly in the 1980s than in the previous decade. However, growth in the aggregate productivity of high-tech capital depends not only on changes in the size of the stock but also on trends in the productivity of each item in the stock. The productivity of a high-tech or other capital good is properly measured by the value of what it helps to produce, not by the amount of technology built into the equipment. For example, the productivity of an automated teller machine should be judged by the value of the convenience it affords customers, allowing them to carry around a plastic card rather than cash. The value of this convenience is not necessarily measured by the sophistication of the machine's electronics (a bank could provide essentially the same service by keeping its branches open twenty-four hours a day).

It is usually not possible to measure the productivity of a capital good directly. Many economists calculate the productivity of capital goods by using the techniques of the standard neoclassical model. This approach leads to the finding that the plunging prices of high-tech capital goods imply that the goods' productivity has been falling at a very rapid rate.

Although this result seems suspicious, the logic of the neoclassical model merits some exploration, since it has proven highly useful in many studies of capital formation and growth. The neoclassical model assumes that capital markets are in equilibrium—that the returns from all investments are equalized. In the example above, the return a bank makes from installing an additional automated teller machine would equal the return from investing the same amount in extending branch hours. If the returns were not equal, capital would be redirected to the more productive outlet up to the point where, given diminishing returns, the returns from the different investments were equalized. More significant, the two returns would also equal the return the bank would realize from investing that amount in a financial instrument.

The return on a dollar investment in an item of high-tech capital is essentially determined by multiplying the productivity of the item by the price of the output it yields, and then dividing the product by the price of the high-tech good. The assumption of the neoclassical analysis is that this return equals the return from a dollar investment in a financial instrument (which may be approximated by some representative interest rate).[4] From the equality of the two returns the productivity of the high-tech capital good can be readily deduced (for

[4]In actual use of the neoclassical model, consideration is given to such matters as the tax implications of physical and financial investment, the useful life and rate of deterioration of the capital good, possible costs and delays in installing the capital good, and the differing productivities of capital installed at different times.

Table 1

**Growth Rates of Productivity and of Labor and Capital Inputs**

| | 1950-73 | 1974-82 | 1983-89 |
|---|---|---|---|
| Manufacturing sector | | | |
| Labor productivity | 3.0 | 1.1 | 5.0 |
| Net capital per employee | 2.6 | 4.4 | 0.2 |
| Gross capital per employee | 2.4 | 4.8 | 1.3 |
| Net high-tech capital per employee | 2.3 | 20.2 | 7.9 |
| Multifactor productivity | 2.2 | 0.0 | 4.7 |
| Memo: Level of net high-tech capital per employee, 1982 dollars | | | |
| 1980: $1567 | | | |
| 1989: $4163 | | | |
| Nonmanufacturing sector | | | |
| Labor productivity | 1.6 | −0.6 | 0.4 |
| Net capital per employee | 1.5 | 1.0 | −0.3 |
| Gross capital per employee | 0.6 | 1.2 | 0.1 |
| Net high-tech capital per employee | 7.2 | 6.7 | 8.8 |
| Memo: Level of net high-tech capital per employee, 1982 dollars | | | |
| 1980: $3719 | | | |
| 1989: $8204 | | | |

convenience, this will be referred to as the "equilibrium" productivity).[5] If the price of high-tech capital falls and the output price is unchanged, one should infer a corresponding decline in the capital good's equilibrium productivity—that is, its economic productivity, not its physical or technical capacity. The reasoning is that an investor can buy a greater quantity of the good for a given dollar amount of investment because the price of the good has dropped; if there is no corresponding drop in its productivity in value terms, the investor will earn an above-market return. Put somewhat differently, the implication of the neoclassical analysis is that if the price of a high-tech good has fallen, market forces will push that good into lower valued uses, thus inviting the conclusion that its productivity in value terms has fallen.

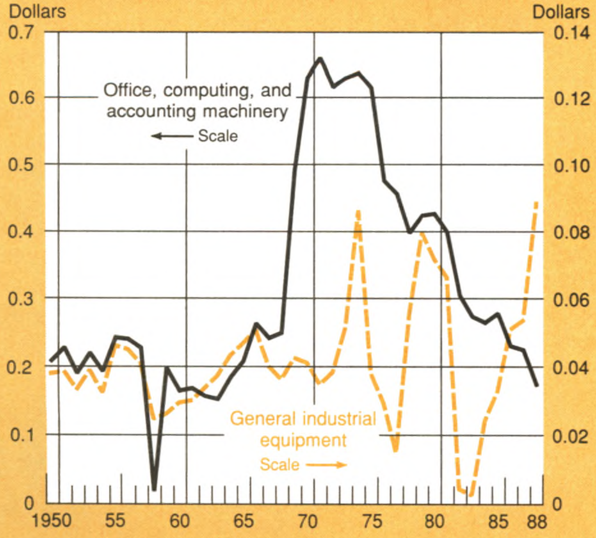
It is generally recognized that the price of high-tech equipment, especially computers, has fallen very sharply. Analysts who use the neoclassical procedure to calculate the equilibrium productivity of high-tech capital therefore find that it has fallen. Charts 1 and 2 illustrate the decline in the equilibrium productivity per dollar of real investment (a dollar of real investment corresponds to a standardized "item"). Chart 1 plots the equilibrium productivity of office, computing, and accounting machinery for the primary metals industry, as calculated by the Bureau of Labor Statistics, and compares it with the productivity of industrial equipment in this industry. Chart 2 compares the productivity of computers for retail trade with that of commercial buildings in that industry. (The computer productivities in retail trade and primary metals differ slightly because the two industries have differing costs of funds.) In both instances the equilibrium productivity of computers—again, as measured in the neoclassical framework—rose through the late 1960s, primarily because the relative cost of computers grew in that period. Over the last generation, however, the equilibrium productivity on computers has plunged, while that on the alternative assets either has been highly volatile (for industrial equipment in primary metals) or has risen substantially (in the case of retail commercial buildings).

What implications should be drawn from the decline in the equilibrium productivity of computers? The proxi-

[5]The calculated productivity is often termed the "real rental rate." The term "rental rate" is used because in full equilibrium the current-dollar amount the owner earns from a capital good each period will equal the amount for which it would be rented out. The "real rental rate" is then the productivity associated with the appropriate current-dollar return. For discussions of the rental rate concept and its measurement, see Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," this *Quarterly Review*, vol. 14 (Summer 1989), pp. 7-28; and James M. Poterba, "Comparing the Cost of Capital in the United States and Japan: A Survey of Methods," this *Quarterly Review*, vol. 15 (Winter 1991), pp. 20-32.

Chart 1

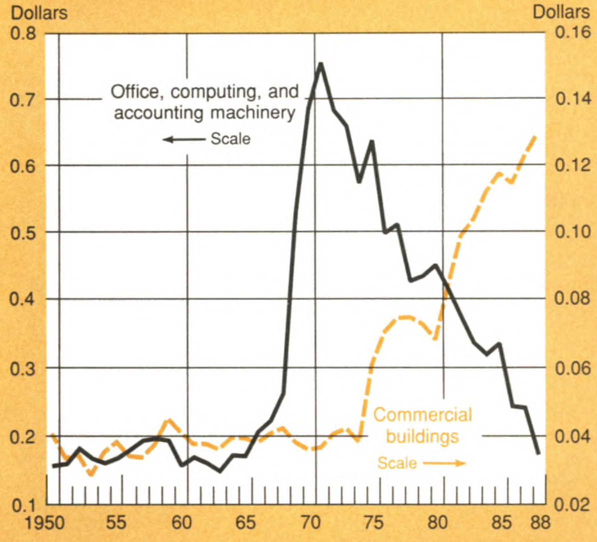
**Equilibrium Productivity per Dollar of Real Investment in Primary Metals**




Source: Bureau of Labor Statistics.

Chart 2

**Equilibrium Productivity per Dollar of Real Investment in Retail Trade**




Source: Bureau of Labor Statistics.

mate causes, of course, have been the tremendous increase in competition and improvements in the production process in the computer industry, developments that together have driven down prices. From the strict neoclassical perspective, however, a key point is the simple fact of the price decline—if the calculation is correctly done, and if markets are in equilibrium, the output gain from an investment in computers has plunged. By this method of reckoning, the decline in the equilibrium productivity of computers has offset much of the increase in their stock; thus, computers did much less to advance growth in the 1980s than the increase in their number would suggest.[6]

Many people would intuitively resist the idea that greater investment in computers has contributed little to productivity growth; similarly, they would question whether rapidly declining computer prices offer any support for this conclusion.[7] Surprisingly, the first objection that they might raise—the obvious increase in the sheer technical sophistication of computers—is not really relevant. The productivity estimates shown in the charts apply to hypothetical computers of standardized processing power, and the price index used in the calculation refers to the prices of such machines. A computer that has five times the processing power of the standardized machine is considered five machines for the purpose of this analysis. Such a machine is obviously more productive than a single standard machine, but the issue is whether it is more or less than five times as productive. Furthermore, as noted above, productivity is defined by the aid an item gives to final production, not by the technology built into it.

[6]The charts do suggest that the equilibrium productivity of computers remained above that of some other capital goods throughout the decade. (Note the different scales for the two types of goods in each chart.) Thus, the shift in the composition of the capital stock to computers could have had a beneficial effect on growth, even if the productivity of computers was falling.

[7]Conceivably, of course, high-tech investment could have indirectly contributed to growth by increasing the rate of technical progress. For instance, computerization could lead to efficiencies in overall operations by speeding up routine clerical work and freeing management time for strategic planning. The problem with this argument from the standard perspective is that the benefit of auxiliary economies should ultimately be reflected in the price of high-tech equipment. If such benefits exist, the demand for the equipment should increase accordingly, putting upward pressure on the price even if there is a lag between the purchase and the benefit. The price of the equipment, however, has declined rapidly for many years, suggesting that the connections between high-tech investment and technical progress are not clearly evident in the marketplace.

Another argument is that high-tech investment in one industry may lead to increased technical progress in other industries through "spillover" effects. A recent study is skeptical that such spillovers are important. See Zvi Griliches, "The Search for R&D Spillovers," National Bureau of Economic Research, Working Paper no. 3768, July 1991.

Even though this class of objections has little merit, the neoclassical analysis is still questionable. Granted, many computers are now being used in low-productivity environments (such as home entertainment), and in all probability, the productivity in value terms of increments to the stock of computers is lower today than in the past. It is hard to believe, however, that the productivity per unit for the installed stock of computers has fallen as rapidly as the charts suggest.

In fact, the productivity of computers may have remained much stronger throughout the 1980s than the neoclassical equilibrium productivity calculations would suggest. First, the rapidity of the computer price decline may be questioned. The computer price index essentially estimates the cost of a standardized unit of processing power. The measure is potentially subject to pure statistical error. Furthermore, the index may not capture trends in the costs associated with the purchase of a computer, such as expenditures for software, installation, and training. These costs may well have increased relative to hardware costs. Thus, the true cost of acquiring a computer, while surely reduced, may have fallen less than suggested by the official price index.

In addition, the assumption that the markets for computers and other high-tech equipment are in equilibrium may not hold. If a market for a capital good is to be in a true equilibrium, both buyers and sellers must be fully aware of the good's technical characteristics (such as its useful life and rate of physical decay) and productive potential (such as the products it helps to make). Given the remarkable changes over the last decade in both the design and use of computers, it is hard to believe that the market for computers has achieved that sort of equilibrium. The actual productivity trend for computers in service could well have been stronger than the equilibrium productivity calculation implies.

Other problems with the equilibrium productivity measure emerge when we look carefully at explanations for the continued rapid growth of investment in high-tech equipment. The common sense notion is that this type of investment has been growing because for many businesses, the productivity of the equipment remains high relative to its costs. Analysts using the neoclassical model emphasize instead that the price decline is even more pronounced than the decline in productivity.[8]

[8]The price effect is emphasized in Yolanda K. Henderson and Jeffrey B. Liebman, "Capital Costs, Industrial Mix, and the Composition of Business Investment," Federal Reserve Bank of Boston *New England Economic Review*, January-February 1992, pp. 67-92.

A recent analysis using the neoclassical approach finds that in most manufacturing industries the benefits attributable to investment in high-tech capital are smaller than the costs, even when a possible feedback from high-tech investment to technical progress is taken into account. This finding raises the question why high-tech investment continues to grow rapidly (Catherine J.

Although this emphasis may be logical at a formal level, one finds it hard intuitively to justify rapid growth in spending on goods whose productivity is falling as rapidly as the neoclassical calculation suggests.

On the whole, the conventional neoclassical result that high-tech capital has had little to do with growth appears to rest on some strong and questionable assumptions. Studies less wedded to the strict neoclassical approach are more supportive of the notion that investment in high-tech capital has contributed importantly to economic growth. In particular, some studies have presented evidence that investment in computers has helped manufacturing firms achieve significant cost savings and faster productivity growth—to a greater extent, perhaps, than in the case of nonmanufacturing firms.[9] The findings of these studies make it advisable to assess the statistical connection between manufacturing industry productivity, overall capital intensity, high-tech capital intensity, and investment in high-tech capital. The next section, then, is designed to quantify the role of high-tech capital formation in accelerating manufacturing productivity during the 1980s.

### The linkage of industry productivity and high-tech capital: framework and statistical evidence

Empirical studies of the link between productivity and computerization in the neoclassical tradition rely upon formal and well-articulated models of the connections between inputs and outputs. Essentially, the neoclassical method employs several restrictive assumptions (for example, a known rate of decline in the physical productivity of the asset) to calculate a complex measure of high-tech capital use. As noted earlier, such methods may not be appropriate to apply to new and rapidly changing capital such as high-tech equipment.

An analyst seeking an alternative to the more rigorous and formal neoclassical approach might look for significant correlations between output—or, alternatively, labor productivity, the ratio of output to labor—and simple measures of high-tech capital use. The strategy employed in this article is to test whether measures of high-tech capital use that do not incorporate all the neoclassical assumptions help explain industry labor productivity trends.

Economists generally hold that labor productivity is positively related to overall capital intensity (and to factors such as the state of the business cycle and trends in the state of technical knowledge). The question addressed in this analysis is whether different degrees of high-tech equipment use help explain differences in labor productivity levels across industries at one point in time, and whether differing trends in the use of high-tech equipment help to explain differing trends in labor productivity growth. Accordingly, this section reports the results of several pooled time-series/cross-section regressions of the form

$$ln(\frac{Y_{it}}{L_{it}}) = a ln(\frac{K_{it}}{L_{it}}) + b ln(\frac{HK_{it}}{L_{it}}) + c + d_i t + e ln(CUR_t),$$

where

$Y_{it}$ = real gross output in industry $i$ in year $t$

$L_{it}$ = full-time equivalent employment in industry $i$ in year $t$

$K_{it}$ = a measure of the aggregate capital used in industry $i$ in year $t$

$HK_{it}$ = a measure of the use of high-tech equipment in industry $i$ in year $t$

$CUR_t$ = the overall capacity utilization rate in manufacturing in year $t$.

The first coefficient, $a$, will measure the percentage increase in an industry's labor productivity from a 1 percentage point increase in the industry's ratio of capital to labor, irrespective of what type of capital is purchased. The normal expectation is that this coefficient will be somewhere around .25, or at least in a range between 0 and .5.

Coefficient $b$ measures the percentage increase in labor productivity arising from a 1 percentage point increase in the ratio of high-tech equipment use to labor when the industry's capital stock is held constant. The total effect of high-tech equipment on output combines coefficients $a$ and $b$ in a rather complex way: the combination will not be in simple additive form both because

*Footnote 8 continued*
Morrison and Ernst R. Berndt, "Assessing the Productivity of Information Technology Equipment in U.S. Manufacturing Industries," National Bureau of Economic Research, Working Paper no. 3582, January 1991; see also Berndt, Morrison, and Larry S. Rosenblum, "High-Tech Capital Formation and Labor Composition in U.S. Manufacturing Industries: An Exploratory Analysis," National Bureau of Economic Analysis, Working Paper no. 4010, March 1992).

[9]For example, see Stephen S. Roach, "Pitfalls on the New Assembly Line: Can Services Learn from Manufacturing?" Morgan Stanley and Company, Special Economic Study, June 22, 1989, and the same author's comment on "Recent Trends in Capital Formation," by Charles Steindel, in Charls E. Walker, Mark Bloomfield, and Margo Thorning, eds., *U.S. Investment Trends: Impact on Productivity, Competitiveness, and Growth* (Washington: D.C.: American Council for Capital Formation Center for Policy Research, 1991), pp. 53-60; Martin N. Baily and Robert J. Gordon, "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power," *Brookings Papers on Economic Activity*, 1988:1, pp. 347-420; and Donald Siegel and Zvi Griliches, "Purchased Services, Outsourcing, Computers, and Productivity in Manufacturing," National Bureau of Economic Research, Working Paper no. 3678, April 1991.

the equation involves logarithms and because the measure of high-tech equipment use in the second term may not be the same as that counted in the capital stock data.

Coefficient $c$ is a constant term designed to capture the effects of omitted common factors affecting productivity in all industries. Coefficient $d_i$ measures the effect of the passage of time on productivity in industry $i$; this term is intended to measure the effects of technical progress and knowledge (which are typically assumed to grow smoothly over time) on an industry's productivity. In more sophisticated models, technical progress has been explained by the growth of factors such as research and development expenditures, patents, and the skill levels of an industry's work force.

Coefficient $e$ measures the effect of aggregate demand relative to potential on productivity. The overall index of capacity utilization in manufacturing, $CUR_t$, would be an appropriate index of the status of aggregate demand as it affects manufacturing. This coefficient would be expected to be positive: productivity is known to be highly procyclical, as is capacity utilization.[10]

Variations of the proposed model were estimated for the manufacturing sector, including all industries for which data were available in the National Income and Product Accounts.[11] The reported regressions use the start-of-year real net capital stock as the measure of the aggregate industry capital input.[12]

The high-tech capital effects—the $HK_{it}$ terms—were modeled by a number of different variables. The first and most obvious one was the start-of-year net stock of high-tech capital (that is, the stock of computers and other office machines, communication equipment, and instruments). If high-tech capital is "inherently" more productive than other types, the coefficient on this variable is likely to be positive—in other words, industries with a capital mix more geared toward high-tech equipment will show higher levels of labor productivity.

Table 2 presents the results of this regression for three time periods often considered to have differing aggregate productivity trends: 1949-73, 1974-79, and 1980-89.[13] The constant and industry time trends are not reported. In all three periods the coefficient on the high-tech capital stock term is positive (although it is not statistically significant in the 1980s). This finding implies that a 1 percentage point increase in a manufacturing industry's capital stock in the form of high-tech capital adds more to productivity than does an increase in an alternative asset.

The differential coefficient on high-tech capital appears small relative to that on the overall capital stock—especially in the 1980s. However, given the relatively small size of the high-tech stock, the small differential coefficient disguises a large overall

[10]Equations reported in Charles Steindel, "Industry Productivity and High-Tech Investment," Federal Reserve Bank of New York, Research Paper no. 9202, January 1992, use separate dummy variables for each year (rather than the capacity utilization rate) in order to capture cyclical effects. The coefficients on the capital stock and high-tech capital use variables reported in that paper are very similar to those in this article.

[11]The industries are essentially all those identified by two digits in the Standard Industrial Classification, with the addition of the three-digit motor vehicle industry and other transportation equipment industry.

[12]For estimates of similar equations for the nonmanufacturing sector, together with some further variations for the manufacturing sector, see Steindel, "Industry Productivity."

[13]The methods used to calculate gross output by industry differ between the periods before and after 1977. See Frank de Leeuw, Michael Mohr, and Robert P. Parker, "Gross Product by Industry, 1977-88: A Progress Report on Improving the Estimates," *Survey of Current Business*, vol. 71 (January 1991), pp. 23-38.

Table 2
**Factors Explaining Productivity in Manufacturing Industries**

| | Period | Ratio of Capital to Labor | Ratio of High-Tech Capital to Labor | Capacity Utilization | $\bar{R}^2$ |
|---|---|---|---|---|---|
| Equation 2.1 | 1949-73 | .224<br>(.039) | .055<br>(.021) | .610<br>(.212) | .823 |
| Equation 2.2 | 1974-79 | .447<br>(.068) | .086<br>(.044) | .471<br>(.406) | .854 |
| Equation 2.3 | 1980-89 | .408<br>(.050) | .026<br>(.031) | .745<br>(.417) | .866 |

Notes: Standard errors are in parentheses. All data are in logs. Capital stock data are start of year. Constant and industry time trend coefficients are not reported.

impact. According to equation 2.3, a 1 percent increase in the capital stock in each manufacturing industry would increase productivity by .408 percent if there were no associated change in the high-tech stock. (This result roughly squares with the assumption that this coefficient should be somewhere in the neighborhood of .25.) At the end of the 1980s high-tech capital accounted for about 10 percent of the manufacturing capital stock; in other words, a 10 percent increase in the high-tech capital stock would have increased the overall stock by 1 percent. If a 1 percent increase in the overall capital stock were purely in high-tech forms, the associated increase in productivity would be about .65 percent (1 x .408 + 10 x .026 = .668)—more than 50 percent larger than if the increase were in conventional forms of capital.

The size and statistical significance of the high-tech capital term did shrink in the 1980s. It is possible, however, that compositional effects within high-tech capital need to be taken into account. For example, given the dramatic changes in computers in the 1980s, newly purchased high-tech equipment may have been significantly more productive than older vintages during that decade. Accordingly, Table 3 replaces the high-tech capital stock term of the Table 2 model with a five-year distributed lag on gross investment.[14] Conceptually, this substitution is legitimate because capital stocks are, by construction, weighted sums of current and past investment.[15]

The results show a clear vintage effect: investment in high-tech capital has consistently had a big short-term payoff. These results can be fleshed out in much the same manner as those of Table 2. A 1 percent increase in a manufacturing industry's capital stock in the 1980s would increase productivity by .425 percent if the increase were in conventional forms of capital (equation 3.3). If the increase were in high-tech forms, however, data from the late 1980s suggest that the 1 percent increase in the capital stock of a typical manufacturing industry would be equivalent to roughly a 60 percent increase in its high-tech investment.[16] The initial coefficient on high-tech investment in equation 3.3 is a high .107; this indicates that a 1 percent capital stock increase concentrated in high-tech equipment would, after a one-year lag, raise the industry's productivity by nearly 7 percent (1 x .425 + 60 x .107 = 6.845).

Although equation 3.3 credits high-tech investment with giving a large initial surge to productivity, the results suggest a quick fade after the first year. In fact, the sum of the coefficients on high-tech investment for all years is only .020. In other words, the long-run effect

[14] In a sense these equations assume that the flow of investment is superior to the stock of capital as an indicator of the input of capital. This assumption may seem unusual, but severe changes in the composition of the aggregate capital stock have led some economists to argue that in the absence of direct observations, aggregate investment is likely to dominate standard measures of the gross and net capital stock as a gauge of the aggregate capital input. See Frank de Leeuw, "Interpreting Investment-to-Output Ratios," in Allan Meltzer, ed., *Unit Roots, Investment Measures, and Other Essays*, Carnegie-Rochester Conference Series on Public Policy, vol. 32 (1990), pp. 83-120. A. Steven Englander and Charles Steindel, "Evaluating Recent Trends in

*Footnote 14 continued*
Capital Formation," this *Quarterly Review*, vol. 14 (Autumn 1989), pp. 7-19, produce evidence against this hypothesis on an aggregate level. Nonetheless, the superiority of investment could well be valid for individual components of the capital stock.

[15] The Commerce Department assumes that high-tech capital has an eight-year life. Given this assumption, a five-year distributed lag on high-tech investment seems ample to pick up any differential productivity effects.

[16] At the end of 1989 the real aggregate net capital stock of the manufacturing sector was $780 billion; the sector's high-tech stock was $82 billion and its gross high-tech investment for the year was $12.5 billion.

Table 3
**Vintage Effects of High-Tech Investment on Productivity in Manufacturing Industries**

| | Period | Ratio of Capital to Labor | Ratio of High-Tech Investment to Labor: Prior Year | Ratio of High-Tech Investment to Labor: Sum over Prior Five Years | Capacity Utilization | $\bar{R}^2$ |
|---|---|---|---|---|---|---|
| Equation 3.1 | 1953-73 | .184 (.039) | .080 (.041) | .107 | .664 (.223) | .850 |
| Equation 3.2 | 1974-79 | .420 (.071) | .120 (.108) | .087 | .698 (.512) | .855 |
| Equation 3.3 | 1980-89 | .425 (.051) | .107 (.060) | .020 | .977 (.435) | .871 |

Notes: Standard errors are in parentheses. All data are in logs. Capital stock data are start of year. Constant and industry time trend coefficients are not reported.

of a 1 percent increase in gross high-tech investment on productivity is an increase of .020 percent, over and above its effect on the overall capital stock. A 1 percent increase in gross high-tech investment, however, will in the long run be associated with a 1 percent increase in the high-tech capital stock. Equation 2.3 shows that the effect of a 1 percent increase in the high-tech capital stock on productivity is a rise of .026 percent. It is reassuring that equation 3.3 has essentially the same long-run properties as equation 2.3. Basically, equation 3.3 gives some of the short-term dynamics missing from 2.3.

Table 4 presents estimates of the gains manufacturing industries made from high-tech capital stock growth in the late 1980s and compares them with the gains made from overall capital formation. The estimates were prepared by calculating, for each manufacturing industry, the percentage increases in overall capital per worker and high-tech capital per worker from 1980-84 to 1985-89, multiplying these percentage changes by the relevant coefficients in equation 2.3, and reporting the average result. Thus, the reported number is an estimate of the productivity gains realized by a typical manufacturing industry over the course of the 1980s from overall capital formation and the incremental effect credited to the high-tech component.

Table 4

**Factors Influencing Productivity Growth in Manufacturing Industries in the Second Half of the 1980s**

In Percent

| | |
|---|---|
| Average industry productivity change, 1980-84 to 1985-89 | 18.7 |
| Influences computed from equation 2.3 | |
| Overall capital growth | 3.2 |
| Additional effect of high-tech capital growth | 1.7 |
| Changes in capacity utilization | 4.0 |
| Other factors† | 8.7 |

†Industry time trends and unexplained statistical error. This figure is calculated as the residual change after accounting for the other influences.

For the typical industry, labor productivity levels were on average 18.7 percent higher in the second half of the 1980s than in the first half. According to equation 2.3, about one-sixth of this increase—3.2 percentage points—was due to an increased ratio of capital to labor.

The high-tech capital and investment effects significantly boost the overall effect of capital. Equation 2.3 suggests that the increase in high-tech capital per worker in the late 1980s contributed an additional 1.7 percentage points to overall labor productivity, over and above its effect on capital stock growth. Thus, the incremental effect of high-tech capital formation on manufacturing industry labor productivity was about one-half the impact of overall capital formation. Summing these two estimates yields the combined effect of overall capital stock growth and high-tech growth; this total accounts for about 25 percent of the increase in labor productivity in a typical manufacturing industry. Cyclical factors as measured by changes in capacity utilization account for a bit less. This reckoning still

Table 5

**Effects of Machinery Stocks on Productivity in Manufacturing Industries, 1980-89**

| | Ratio of High-Tech Machinery to Labor | Ratio of Standard Machinery to Labor | Ratio of All Machinery to Labor | $\bar{R}^2$ |
|---|---|---|---|---|
| Equation 5.1 | .026<br>(.031) | | | .866 |
| Equation 5.2 | | −.085<br>(.095) | | .870 |
| Equation 5.3 | .014<br>(.126) | −.057<br>(.041) | | .870 |
| Equation 5.4 | | | −.191<br>(.121) | .872 |

Notes: Standard errors are in parentheses. All data are in logs. Capital stock, capacity utilization, constant and industry time trend coefficients are not reported. "Standard" machinery is metalworking, general industrial, and special industry machinery. "All machinery" is the sum of standard and high-tech machinery.

leaves a very large portion of the increase in productivity unexplained except in a purely statistical way by time trends. Hence, much of the acceleration in output per worker remains a mystery. In any event, these results suggest that the role of high-tech capital growth in manufacturing industry productivity trends in the 1980s was economically significant and substantial in comparison with that of capital formation in general.[17]

These results do not detail how increased manufacturing investment in high-tech equipment increased productivity. It may be that intensified foreign competition encouraged manufacturers to seek economies, and computerization of back-office operations was a relatively simple way to reduce expenditures. Alternatively, common reports that manufacturers profited from breakthroughs in the use of computer-managed design and control of production may be correct.[18]

Since high-tech equipment is still a relatively small part of the overall manufacturing capital stock, it is conceivable that the calculated relationship between productivity and high-tech capital could be merely a proxy for a relationship between productivity and some larger category of capital—for example, traditional forms of machinery. It is possible that in the 1980s the productivity of traditional machinery was higher than that of capital in general, as a result of improvements in technology that were also associated with increased spending on high-tech equipment. Table 5 summarizes a number of regressions, similar in structure to those of Table 2, relating productivity to capital holdings in high-tech and more traditional types of manufacturing machinery—the sum of metalworking, general industrial, and special industry machinery. The table reports only the individual coefficients for machinery types. As in Table 2, a positive coefficient suggests that the machinery type is more productive than overall capital. There is no evidence that traditional machinery contributed more to productivity in the 1980s than did capital in general.[19]

## Conclusions

Growth in the stock of high-tech equipment appears to have played a meaningful role in the recent acceleration in manufacturing productivity growth. This conclusion is in contrast to the more skeptical assessment offered by the standard neoclassical analysis. The results suggest that the neoclassical assumption that financial returns and asset prices provide accurate information about the productivity of capital may not be valid for high-tech investment by all industries.

The statistical analysis of this article indicates that about one-sixth of the growth in productivity in a typical manufacturing industry over the second half of the 1980s may be attributed to growth in its capital stock, and an additional one-tenth to growth in the industry's stock of high-tech capital. Because of the imprecise estimate of the productivity impact of high-tech capital in equation 2.3, the attribution to high-tech capital is subject to a considerable margin of error. Nevertheless, the results in Table 3 suggest that even if the cumulative impact of high-tech capital formation is small, the initial effect of increased investment in the area may be substantial.

On the whole, it appears that overall capital formation, including the differential impact of the high-tech component, accounted for about 25 percent of productivity growth in manufacturing industries in the late 1980s. The cyclical improvement in the economy from the first to the second half of the decade, as gauged by increased capacity utilization, was apparently associated with a slightly smaller share of the increase. The remainder of productivity growth—about one-half the total—was probably associated with the normal growth of technology as well as extraordinary factors such as the drop in energy prices and moves to improve 'efficiency in the face of foreign competition.

The evidence produced in this article does not show that high technology was a decisive element in the improvement in manufacturing productivity in the 1980s. Nevertheless, the results suggest that high-tech equipment may have made a larger contribution than the traditional analysis implies.

[17]A similar calculation for equation 3.3 results in an estimated contribution of high-tech investment to productivity equal to zero for a typical manufacturing industry in the second half of the 1980s. This result is due to modest declines in high-tech investment by manufacturers in the late 1980s; the calculation indicates that high-tech investment made its greatest contribution to productivity levels in the middle years of the decade.

[18]In "Pitfalls on the New Assembly Line" Roach argues that computers aided back-office economies in manufacturing. Others have advanced different explanations for the surge in manufacturing productivity. For instance, a recent study suggests that manufacturers that implemented new training programs in the 1980s saw unusually rapid productivity gains. See Ann P. Bartel, "Productivity Gains from the Implementation of Employee Training Programs," National Bureau of Economic Research, Working Paper no. 3893, November 1991.

[19]When these equations were estimated with the same specification as those of Table 3, vintage effects were evident for traditional as well as high-tech machinery. This finding is consistent with the results obtained for an international cross section in J. Bradford De Long and Lawrence H. Summers, "Equipment Investment and Economic Growth," *Quarterly Journal of Economics*, vol. 106 (May 1991), pp. 445-502; and De Long, "Productivity and Machinery Investment: A Long-Run Look, 1870-1970," National Bureau of Economic Research, Working Paper no. 3903, November 1991.