Productivity growth in 'high-tech' manufacturing industries

Among manufacturing industries employing a substantial proportion of research and development and technology-oriented workers, the information technology industries exhibited particularly strong productivity growth over the 1987–99 period

Christopher Kask
and
Edward Sieber

Christopher Kask is an economist in the Office of Productivity and Technology, Bureau of Labor Statistics. Edward Sieber is an economist formerly with that office.

It is widely accepted that the high-technology sector is one of the most dynamic parts of the U.S. economy. High-tech industries are thought of as an important source of employment growth, profits, and innovation in products and production processes. Accordingly, the high-tech sector has been a center of interest, generating numerous analyses and studies. In a 1997 *Monthly Labor Review* study, for example, William Luker, Jr., and Donald Lyons stated that "the continuing attention paid to high-tech industries in recent years seems to be rooted in the widespread belief that the innovations they produce can profoundly alter an economy's mix of firms, industries, and jobs."[1]

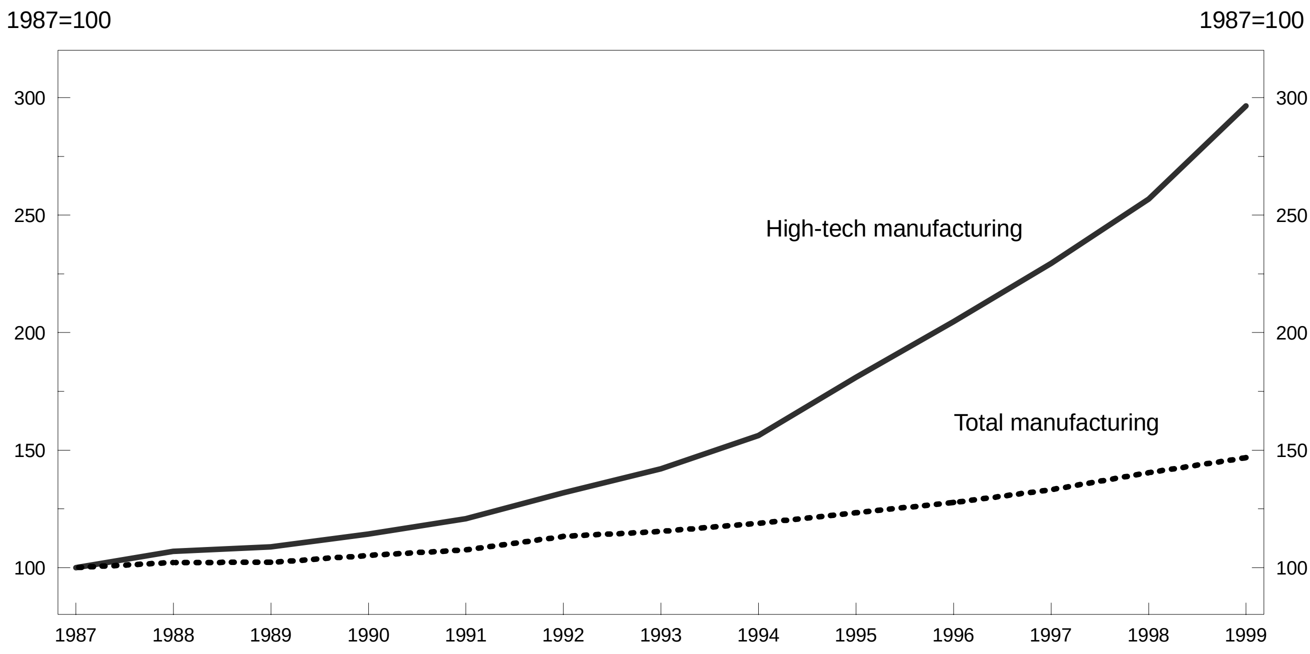
The high-tech manufacturing sector, under alternative definitions, has dominated other manufacturing industries with respect to productivity growth. Between 1987 and 1999, labor productivity—defined as output per hour of labor input—increased 9.5 percent per year in high-tech manufacturing industries.[2] Over the same period, labor productivity in the manufacturing sector as a whole increased 3.2 percent per year. Chart 1 illustrates the dramatic difference between these two growth rates.

Labor productivity relates output to the labor resources used in its production. It is an indicator of the efficiency with which labor is being utilized.[3] High-tech manufacturing's strong performance seems consistent with expectations, but the situation deserves a closer look. Are all the industries in the high-tech sector recording rapid efficiency gains as measured by growth in labor productivity? Would the high-tech efficiency advantage be as large if inputs into the production process other than labor were accounted for? What is happening to costs in the high-tech sector?

This article builds upon earlier BLS work and identifies a set of detailed industries as representing the high-tech manufacturing sector. Productivity developments in these industries were examined, and a set of aggregate measures were developed that permit comparison of the high-tech manufacturing sector with manufacturing as a whole. In addition to labor productivity and related measures such as output, labor hours, employee compensation, and unit labor costs, the analysis includes multifactor productivity, a measure of economic efficiency that relates output to combined inputs of labor hours, capital services, and intermediate purchases.

Economic growth can occur from increases in inputs or from advances in productivity. Increases in inputs impose costs on society, such

Chart 1. Index of output per hour in high-tech manufacturing and total manufacturing, 1987–99



as less leisure time, reduced current consumption, and depletion of resources. Multifactor productivity growth measures changes in output that are not attributed to the changes in combined inputs. While measures of labor productivity provide valuable insights into efficiency, measures of multifactor productivity are more useful in this regard. By accounting for sources of growth from additional inputs—specifically, capital and intermediate purchases—multifactor productivity analysis more closely measures changes in efficiency.[4]

Data sources and limitations

The data used for this analysis are produced by the Office of Productivity and Technology. The analysis of high-tech manufacturing is based on data for industries classified at the three-digit level in the 1987 U.S. Standard Industrial Classification (SIC) system.[5] This data set includes labor productivity and related measures for three- and four-digit SIC industries for the period from 1987 through 1999. For the 140 three-digit SIC manufacturing industries considered here, multifactor productivity and related series are also available for the 1987–99 period.[6]

Data for the manufacturing sector as a whole are from the BLS series on productivity in major sectors of the U.S. economy. This data set contains indexes of labor productivity and related measures for the private business, private nonfarm business, and manufacturing sectors for the 1949–2001 period. Multifactor productivity measures are available for the same sectors for 1949 through 2000, except for manufacturing, which extends through 1999.

Data limitations at the three-digit industry level impose some restrictions on this analysis. Although the aggregate manufacturing data are available from 1947, the need to compare these measures with the industry data restricts the analysis of labor productivity to the 1987–99 period and two subperiods: 1990 to 1995 and 1995 to 1999. Also, it usually is advisable to analyze productivity movements over the course of a full business cycle in order to minimize the effects of cyclical movements on the results. However, the relatively short time span over which the industry data are available does not allow us to follow this approach.[7] In addition, the three-digit level of aggregation may obscure variation in detailed component industries. (Some of this variation is discussed later in this article.) Finally, accurate measurement of price and output series, and therefore productivity, is particularly difficult in industries with rapidly changing products such as those characterized by high-tech manufacturing output (notably computers, semiconductors, and pharmaceuticals).[8]

Defining high-tech manufacturing

What is the high-tech manufacturing sector? Although the term “high tech” is used frequently, there is no consensus on exactly which industries to include in a “high-tech sector," and the appropriate approach to use is not apparent. For example, one early BLS analysis of high-tech employment cites a study in which industry groups were designated as "high tech based on the perceived degree of technical sophistication of the product."[9] A report from the Congressional Office of Technology Assessment identifies high-tech firms as being those involved in introducing new products and processes "through the systematic application of scientific and technical knowledge."[10] The Organization for Economic Cooperation and Development (OECD) identifies high-tech industries largely on the basis of their level of research and development intensity (research and development expenditure in relation to value added).[11] In his 1999 study of high-tech employment, Daniel Hecker notes that high-tech firms "devote a 'high' proportion of expenditures to research and development and employ a 'high' proportion of scientific, technical, and engineering personnel."[12]

The various approaches to classifying high-tech industries fall into two broad classes: A majority of studies classify industries by the extent to which they employ certain types of workers or undertake certain types of expenditures (input-based criteria), while another group of studies focuses on the nature of the industries' products (output-based criteria). Both approaches have certain advantages as well as drawbacks. Input-based approaches have the advantage of resting on easily obtainable, nonsubjective data—for example, the proportion of an industry's workers in technology-oriented professions or the proportion of industry costs devoted to research and development. In the absence of wide agreement on the threshold proportions above which an industry should be considered high tech, however, any such choice must be considered arbitrary. Input-based approaches also suffer from a failure to take account of the products of the industry. Thus, high-tech industries identified solely on the basis of inputs may chiefly manufacture products not commonly thought of as high tech.

Output-based approaches generally rely on some determination of the level of technical sophistication embodied in an industry's products or the extent to which these products have undergone rapid change. Although following this approach makes it more likely that the products of the designated industries will match popular conceptions of high tech, the judgements about product sophistication or rapid change on which these studies rely tend to be subjective.

Considerable research interest has been directed at "information technology" industries. Three of the manufacturing industries studied here—computer and office equipment (SIC 357), communications equipment (SIC 366), and electronic components and accessories (SIC 367)—fall into this category. Much of the research, however, has used more aggregated data and focused on SIC 35, industrial and commercial machinery and equipment and computer equipment, and SIC 36, electronic and other electrical equipment and components.[13]

BLS data show that productivity gains in these two industries accounted for a large share—0.5 percentage points per year—of the 1.9-percent annual average rise in nonfarm business output per hour from 1990 to 1999. Further, information processing equipment and software represents a portion of capital, and growth in such capital accounted for another 0.6 percentage points per year of the growth in labor productivity. As a result, the production of these information technology goods and the use of information processing equipment and software accounted for more than half of nonfarm business labor productivity growth over this period.[14]

The results reported in this article show that, at the three-digit SIC level, productivity growth in the information technology industries far surpassed that in the other high-tech industries studied. Why not, then, specify the high-tech manufacturing sector to include only the information technology industries? For purposes of this analysis, criteria were desired that are independent of the industry growth and productivity measures we wish to evaluate. This, coupled with a view that high-tech manufacturing industries may include those with advanced production processes even though their products may not be considered high tech, led us to favor an input-based approach to designate high-tech industries.

Previous *Monthly Labor Review* articles on the high-tech sector have generally focused on employment in high-tech industries.[15] These studies have all considered the question of how to define the high-tech sector and have examined alternative criteria for this purpose. In these studies and in the work of outside researchers, the use of research and development data is a common criterion for classifying high-tech industries. Indeed, the National Science Foundation notes that "industries that rely heavily on research and development . . . are often referred to as high-technology industries."[16]

To arrive at a workable definition of high-tech manufacturing industries, we draw heavily from the Hecker analysis of high-tech employment.[17] In that article, the fundamental criterion for including an industry in the high-tech sector is the existence of a high proportion of research and development employment and "technology-oriented workers." Technology-oriented workers include engineers; life and physical scientists; mathematical specialists; and engineering, scientific, and computer managers. In Hecker's study, the high-tech sector contains 29 three-digit-level industries, including a subset of 10 "high-tech intensive" industries. Of the 29 industries, 25 are classified in manufacturing and 4 are in services; of the 10 high-tech intensive industries, 2 are in services. High-tech intensive industries are those that have at least 15 research and development workers per thousand workers and 190 technology-oriented workers per thousand workers. These ratios are at least 5 times the average for all industries. Although the criteria are objective, the cut-off proportions are necessarily somewhat arbitrary.

In this article, we adopt Hecker's subset of high-tech intensive manufacturing industries. Because this study focuses on manufacturing industries only, we exclude the two service-producing industries in Hecker's group—computer and data processing services (SIC 737) and research, development, and testing services (SIC 873).[18] Over the 1987–99 period, employment in our group of high-tech manufacturing industries averaged about 16 percent of total manufacturing employment.

Table 1 shows the makeup of the high-tech manufacturing sector in terms of both employment and value of production. Among these industries, the electronic components and accessories industry and the aircraft and parts industry (SIC 372) have the highest employment levels, each accounting for nearly 20 percent of average employment in this sector over the period. When combined with the computer and office equipment industry, which has an average employment share of 13.3 percent, these three industries make up more than 52 percent of high-tech manufacturing employment. Not surprisingly, the same three industries account for the largest shares of average total production in the high-tech manufacturing sector, each generating 13 to 16 percent of the sector total.

The research and development and technology-oriented employment criteria used to designate high-tech industries, applied at the three-digit SIC level of detail, capture industries with outputs that are commonly thought of as high-tech, such as electronic computers (SIC 3571) and semiconductors (SIC 3674). The criteria also capture industries in which the production processes are high-tech even though the outputs themselves are not often thought of as high tech, such as industrial inorganic and industrial organic chemicals (SICs 281 and 286). In addition, high-tech output includes components of three-digit industries that do not produce items normally thought of as high tech, nor do they use high-tech processes; such industries include laboratory apparatus and furniture (SIC 3821) or office machines, not elsewhere classified (SIC 3579).

Although the measures for high-tech industries and total manufacturing are drawn from different data sets, they are very similar in concept. In most cases, discrepancies arising from the use of different data sources or computation methods are not likely to significantly alter the comparisons.[19]

Table 1. Composition of the high-tech manufacturing sector, 1987–99 average

SIC	Industry	Percent of sector total based on: Value of production	Percent of sector total based on: Employment
281	Industrial inorganic chemicals	4.0	2.9
283	Drugs	11.8	8.5
286	Industrial organic chemicals	11.6	4.9
357	Computer and office equipment	13.5	13.3
366	Communications equipment	10.3	8.8
367	Electronic components and accessories	16.0	19.9
372	Aircraft and parts	14.6	19.4
376	Guided missiles, space vehicles, and parts	4.6	4.6
381	Search and navigation equipment	6.7	7.5
382	Measuring and controlling devices	7.0	10.1

Labor productivity

Labor productivity, as measured by output per hour, is an important indicator of economic progress. Growth in labor productivity measures the growth in output that is not attributed to growth in the number of hours worked. Improvements in the well being of average workers rest largely on the growth of labor productivity. The benefits for workers from growth in labor productivity are reflected in rising real wages and other compensation. Over time, trends in real labor compensation tend to parallel trends in labor productivity. There is an expectation that the recent acceleration in productivity growth in the high-tech sector will be a source of rising compensation and more rapid growth in standards of living. Labor productivity growth is also credited with contributing to price stability. Changes in output prices may be influenced by changes in compensation per unit of output (unit labor costs). With rising productivity, higher worker compensation need not translate into higher output prices. Increases in output per hour offset the growth in hourly compensation and tend to moderate price growth.

On average, labor productivity in the high-tech sector grew 9.5 percent per year from 1987 to 1999. (See table 2.) This exceeded the labor productivity growth rate for overall manufacturing by 6.3 percentage points. While output grew by 8.0 percent annually, on average, hours actually declined by 1.4 percent per year from 1987 to 1999. Output in total manufacturing, by contrast, grew by 3.3 percent per year, on average, and hours were unchanged.

Although the high-tech sector experienced rapid growth in output per hour throughout the 1990s, the rate of growth accelerated in the latter half of the decade. From 1990 to 1995, labor productivity growth averaged 9.6 percent per year. The strong growth was due to a rapid decline in employee hours of 3.8 percent per year combined with output growth of 5.5 percent. The decline in hours in the high-tech sector reversed

Table 2. Labor productivity, multifactor productivity and related measures for high-tech industries and manufacturing

[1987=100]

Year	Output per hour	Output	Total hours	Employ-ment	Average hours	Unit labor costs	Multifactor product-ivity	Com-bined inputs	Capital	Inter-mediate pur-chases	Output per unit of capital	Output per unit of inter-mediate pur-chases
						High-tech manufacturing						
1987	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1988	107.0	107.6	100.6	100.8	99.8	99.0	103.2	104.3	104.9	106.3	102.6	101.3
1989	108.9	109.6	100.6	100.8	99.9	100.2	104.2	105.2	109.7	106.2	100.0	103.2
1990	114.4	112.6	98.5	98.4	100.0	101.4	105.3	106.9	114.1	109.3	98.7	103.0
1991	120.9	112.9	93.4	93.7	99.7	101.3	105.6	107.0	117.9	111.4	95.8	101.4
1992	131.8	116.4	88.3	88.4	99.9	98.3	109.9	106.0	121.5	111.4	95.8	104.5
1993	142.1	119.4	84.0	83.9	100.1	93.8	113.3	105.4	125.2	111.7	95.4	106.8
1994	156.3	127.4	81.5	81.0	100.6	86.8	119.9	106.2	129.9	113.4	98.1	112.3
1995	181.0	147.1	81.3	80.7	100.7	76.8	131.4	111.9	138.0	122.4	106.6	120.2
1996	204.8	169.8	82.9	82.4	100.6	69.2	140.4	121.0	149.4	135.9	113.7	125.0
1997	229.5	199.2	86.8	85.6	101.4	62.7	152.0	131.1	161.4	149.7	123.4	133.1
1998	256.9	226.3	88.1	87.3	100.9	57.3	164.5	137.6	173.8	157.2	130.2	143.9
1999	296.5	251.2	84.7	84.5	100.3	52.1	179.7	139.8	183.0	160.4	137.3	156.6
						Average annual percent change						
1987–99 ..	9.5	8.0	–1.4	–1.4	0.0	–5.3	5.0	2.8	5.2	4.0	2.7	3.8
1990–95 ..	9.6	5.5	–3.8	–3.9	.1	–5.4	4.5	.9	3.9	2.3	1.6	3.1
1995–99 ..	13.1	14.3	1.0	1.2	–.1	–9.2	8.1	5.7	7.3	7.0	6.5	6.8
						Manufacturing						
1987	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1988	102.2	104.9	102.7	101.8	100.9	101.9	101.8	103.1	101.7	103.9	103.1	100.9
1989	102.3	105.4	103.1	102.2	100.9	105.0	99.9	105.5	103.7	108.7	101.7	96.9
1990	105.2	106.2	101.0	100.7	100.3	107.0	99.8	106.4	106.2	112.0	100.0	94.7
1991	107.6	104.1	96.8	97.2	99.5	110.1	98.8	105.4	108.4	112.8	96.0	92.2
1992	113.3	109.1	96.3	95.5	100.9	109.4	100.5	108.6	110.8	120.6	98.5	90.4
1993	115.4	112.7	97.7	95.6	102.2	110.3	101.5	111.1	113.3	124.6	99.6	90.4
1994	118.9	118.6	99.8	96.8	103.1	110.2	104.1	114.1	115.8	128.7	102.5	92.2
1995	123.4	123.7	100.2	97.9	102.4	108.3	106.1	116.6	119.6	133.0	103.4	93.0
1996	127.7	127.6	99.9	97.6	102.3	106.0	107.0	119.3	124.1	138.7	102.9	92.0
1997	133.2	135.4	101.6	98.6	103.1	103.6	110.7	122.3	129.3	141.9	104.7	95.4
1998	140.4	142.3	101.4	99.3	102.1	103.6	113.7	125.2	135.2	147.4	105.2	96.5
1999	146.8	147.5	100.5	97.8	102.8	103.2	117.0	126.1	142.2	147.3	103.7	100.1
						Average annual percent change						
1987–99 ..	3.2	3.3	0.0	–.2	0.2	0.3	1.3	2.0	3.0	3.3	0.3	0.0
1990–95 ..	3.2	3.1	–.1	–.6	.4	.2	1.2	1.8	2.4	3.5	.7	–.4
1995–99 ..	4.4	4.5	.1	.0	.1	–1.2	2.5	2.0	4.4	2.6	.1	1.9

after 1995, and hours grew at 1.0 percent per year through 1999. Despite this reversal in hours growth, labor productivity growth accelerated to 13.1 percent per year as output growth raced ahead to 14.3 percent per year from 1995 to 1999. While output per hour in the manufacturing sector also grew more rapidly in the second half of the 1990s, the 4.4-percent rate (up from the 1990–95 rate of 3.2 percent) was still only about one-third of the growth rate in the high-tech sector.

This rapid growth in high-tech labor productivity masks considerable variation in the growth rates of labor productivity for the individual industries within the group. Of the 10 industries identified as high tech, only the 3 information technology industries had labor productivity growth rates in excess of the average for the group. (See table 3.) Output per hour in the computer and office equipment industry grew 27.5 percent per year over the 1987–99 period, while in the electronic components and accessories industry, the rate of growth was 21.8 percent per year, and in communications equipment, it was 10.4 percent. In addition, the rate of labor productivity growth in three other high-tech industries exceeded the total manufacturing rate, while the rate in four high-tech in-

Table 3. Sector and industry average annual growth rates: labor productivity, multifactor productivity, and related measures, 1987–99

SIC	Industry	Output per hour	Output	Hours	Employ-ment	Total Compen-sation	Unit labor costs	Multi-factor product-ivity	Combined Inputs	Capital	Inter-mediate purchases
	Manufacturing	3.2	3.3	0.0	–0.2	3.6	0.3	1.3	2.0	3.0	3.3
	High-tech sector	9.5	8.0	–1.4	–1.4	2.3	–5.3	5.0	2.8	5.2	4.0
281	Industrial inorganic chemicals	4.6	2.8	–1.7	–1.8	2.4	–.4	2.0	.7	–.6	2.0
283	Drugs	.4	3.1	2.7	2.7	7.2	4.0	–2.7	6.0	6.0	7.3
286	Industrial organic chemicals	.9	–.2	–1.1	–1.3	3.2	3.4	–1.9	1.7	3.1	1.8
357	Computer and office equipment	27.5	25.0	–1.9	–1.8	1.2	–19.0	18.8	5.2	6.2	7.4
366	Communications equipment	10.4	9.9	–.4	–.4	5.4	–4.1	3.9	5.8	5.3	9.6
367	Electronic components and accessories	21.8	22.5	.5	.5	5.0	–14.3	16.6	5.1	9.0	5.3
372	Aircraft and parts	2.8	.2	–2.5	–2.6	.6	.4	.8	–.6	2.5	–.1
376	Guided missiles, space vehicles, & parts	3.9	–3.3	–6.9	–6.8	–3.9	–.7	.0	–3.2	–.3	–1.8
381	Search and navigation equipment	2.8	–3.0	–5.7	–5.7	–1.8	1.2	.3	–3.3	–1.3	–1.7
382	Measuring and controlling devices	3.6	3.1	–.5	–.4	3.2	.1	.2	2.9	3.9	5.2

dustries was less than the rate for total manufacturing.

By decomposing labor productivity in the high-tech sector, we can quantify the contributions made by the individual industries to the sector's productivity growth. The sum of the industry contributions approximately equals the labor productivity growth rate for the high-tech sector.[20] Table 4 illustrates that, as might be expected, the computer and office equipment and the electronic components and accessories industries contributed the most to the sector's productivity growth over the 1987–99 period. Combined, these two industries accounted for nearly three-quarters of the high-tech sector's labor productivity growth of 9.5 percent per year. The computer and office equipment industry contributed 3.4 percentage points, and the electronic components and accessories industry contributed 3.3 percentage points. A much smaller but nonetheless strong contribution was made by the communications equipment industry, which accounted for 1.0 percentage point of the sector's average annual growth. These three industries also are responsible for much of the high-tech acceleration in the second half of the 1990s. From 1990 to 1995, they accounted for more than 80 percent of the sector's labor productivity growth. In the second half of the 1990s, the contributions made by these three industries to labor productivity growth in the sector all increased. Together, the three industries were responsible for nearly 90 percent of the high-tech sector's growth in labor productivity from 1995 to 1999.

Output

Real output in the high-tech manufacturing sector more than doubled over the 1987–99 period, while in overall manufacturing, output increased by 48 percent. The average annual growth rate for the period was 8.0 percent in the high-tech sector, compared with 3.3 percent in manufacturing as a whole.

Output growth in total manufacturing and in the high-tech sector accelerated during the second half of the 1990s, compared with the first half. In manufacturing, the average annual growth rate of 4.5 percent from 1995 to 1999 was much faster than the rate of 3.1 percent experienced in the earlier part of the decade. In the high-tech sector, the acceleration was even greater, with the rate of output growth increasing from 5.5 percent per year in the early 1990s to 14.3 percent in the latter half of the decade.

Industry output growth varied greatly within the high-tech sector. The three information technology industries grew at rates substantially faster than the rate for overall manufacturing. In contrast, the remaining seven high-tech industries grew slower than overall manufacturing, with three of the seven actually declining over the 1987–99 period. Output in computers and office equipment grew the fastest, averaging 25.0 percent per year and contributing 3.1 percentage points to high-tech output growth. Electronic components and accessories grew somewhat more slowly (22.5 percent), but its contribution to overall growth in the sector was greater (3.5 percentage points). Finally, in the communications equipment industry, growth in output was much slower than in the other two information technology industries, but quite strong nonetheless—9.9 percent per year, which accounted for 1.0 percentage point of the growth in high-tech output.

Generally, when combining industry data to form an aggregate (sectoral) output measure, industry outputs that are used as inputs by establishments within the same industry—intrasectoral transactions—are subtracted from the aggregate's overall output (and intermediate inputs) in order to avoid double counting.[21] Intrasectoral transactions have been removed from the aggregate manufacturing sector data used here and from the data for each of the three-digit industries we classify as high tech, but they have not been re-

Table 4. Sector growth rates and industry contributions to high-tech sector: labor productivity, multifactor productivity, and related measures, 1987–99

SIC	Industry	Output per hour	Output	Hours	Multifactor productivity	Combined inputs
	Manufacturing	3.2	3.3	0.0	1.3	2.0
	High-tech sector	9.5	8.0	–1.4	5.0	2.8
281	Industrial inorganic chemicals	.2	.1	–.1	.1	.0
283	Drugs	.1	.3	.2	–.3	.7
286	Industrial organic chemicals	.0	.0	–.1	–.2	.2
357	Computer and office equipment	3.4	3.1	–.3	2.4	.7
366	Communications equipment	1.0	1.0	.0	.4	.6
367	Electronic components and accessories	3.3	3.5	.2	2.6	.8
372	Aircraft and parts	.5	.0	–.5	.1	–.1
376	Guided missiles, space vehicles, & parts	.1	–.2	–.3	–.1	–.1
381	Search and navigation equipment	.2	–.2	–.5	.0	–.2
382	Measuring and controlling devices	.3	.2	.0	.0	.2

moved from the high-tech sector aggregate. This means that the output growth rates cited here and the intermediate purchases input growth rates cited later in the article are slightly different than adjusted measures would show. Also, not removing the double-counted output tends to artificially reduce the multifactor productivity growth rates for the high-tech sector aggregate because the double-counted transactions are in both the numerator and the denominator of the productivity formula.[22]

Labor input

Changes in labor input, as measured by total employee hours, reflect movements in employment and average hours per employee.[23] Because average hours in high-tech manufacturing were unchanged over the 1987–99 period, shifts in labor hours in this sector were largely the result of changes in employment levels. Employment in high-tech manufacturing declined 15.5 percent over the period, while hours dropped 15.3 percent.[24] Thus, by 1999, the high-tech manufacturing workforce had shrunk by more than 500,000 workers since 1987, and labor input had fallen by more than one billion hours.

The rates of decline in high-tech manufacturing labor input varied throughout the period, with employment and labor hours dropping sharply toward the middle portion of the period, before reversing direction and regaining some lost ground in the latter part of the period. These fluctuations are reflected in the data for the 1990–95 and 1995–99 subperiods. In the manufacturing sector as a whole, a slight decline in employment combined with a small increase in average hours resulted in essentially no change in the level of total labor hours from 1987 to 1999.[25]

Employment and total labor hours declined in most of the industries in the high-tech manufacturing sector over the 1987–99 period. The largest declines (50 to 58 percent) occurred in the search and navigation equipment (SIC 381) and guided missiles, space vehicles, and parts (SIC 376) industries. More modest declines (20 to 27 percent) occurred in two of the largest industries in the high-tech sector—aircraft and parts and computer and office equipment. The smallest high-tech industry, industrial inorganic chemicals, recorded employment and hours declines of 19 percent.

Employment and labor hours increased in only two high-tech manufacturing industries over the 1987–99 period. In the larger of the two, electronic components and accessories, employment increased by 5.6 percent and labor hours increased by 6.8 percent. In the much smaller drug industry (SIC 283), both employment and hours increased by about 37 percent over the period.

Unit labor costs

Total compensation costs in the high-tech industries rose more slowly over the period than in manufacturing as a whole. However, when labor costs are compared on a per-unit-of-output basis (unit labor costs), the high-tech manufacturing sector emerges with an even stronger advantage. While unit labor costs in the manufacturing sector as a whole increased slightly from 1987 to 1999 (0.3 percent per year), they declined in the high-tech industries at an average annual rate of 5.3 percent.

Unit labor costs are calculated either by dividing an index of labor compensation by an index of real output, or by dividing an index of compensation per hour by an index of output per hour (labor productivity). Changes in unit labor costs show how much labor productivity growth offsets increases in employee compensation per hour. Thus, the strong labor productivity gains found in high-tech manufacturing outweigh hourly compensation increases in that sector, and result in a substantial decline in unit labor costs over the period.

Unit labor cost performance varied substantially over the period among the high-tech industries. Not surprisingly, the industries with the largest increases in labor productivity, such as computers and office equipment and electronic components and accessories, tended to have the largest unit labor cost declines. Unit labor costs dropped by 19.0 percent per year in computers and office equipment and 14.3 percent per year in electronic components and accessories over the 1987–99 period. Communications equipment recorded a much more modest unit labor cost decline of 4.1 percent per year. The remaining high-tech manufacturing industries had changes in unit labor costs ranging from slight declines to moderate increases. The largest increases occurred in drugs, where unit labor costs increased 4.0 percent per year, and industrial organic chemicals, which saw an average annual increase of 3.4 percent.

Multifactor productivity

The amount and complexity of the data calculations required for multifactor productivity measures are much greater than those for labor productivity. The growth rate of multifactor productivity can be expressed as the growth rate of output less the growth rate of combined inputs. The combined inputs measure is a weighted average of labor hours, capital services, and intermediate purchases, with weights being the input's share in the cost of output. In this section, we calculate multifactor productivity for the high-tech sector within manufacturing.

As noted earlier, intrasectoral transactions have not been removed from the high-tech manufacturing sector aggregate. In order to quantify the possible bias arising from our inclusion of the intrasectoral transactions, we independently estimated multifactor productivity growth for the high-tech sector by aggregating industry level productivity data.[26] The results indicate that the high-tech sector's adjusted multifactor productivity growth rate may be somewhat higher than the rate reported in this article.[27]

During the 1987–99 period, multifactor productivity in overall manufacturing grew 1.3 percent per year, on average. (See table 2.) Over the same period, the multifactor productivity growth rate in high-tech manufacturing was 5.0 percent per year. Although combined inputs grew somewhat faster in the high-tech industries than in manufacturing as a whole, output grew more than twice as rapidly in the high-tech sector than it did in overall manufacturing.

Multifactor productivity growth accounted for more than 60 percent of the 8.0 percent per year growth in high-tech output. (See table 3.) Combined inputs grew 2.8 percent per year and accounted for somewhat less than 40 percent of output growth. In contrast, input growth was responsible for the majority of output growth in manufacturing as a whole. Combined inputs growth contributed 60 percent of the 3.3-percent annual growth rate in manufacturing output, while 40 percent of output growth resulted from increases in multifactor productivity.

The more rapid input growth in the high-tech sector relative to manufacturing was due to faster growth in capital services and intermediate purchases. Capital services in high-tech industries grew 5.2 percent per year, compared with 3.0 percent in total manufacturing. Intermediate purchases rose 4.0 percent per year in high-tech manufacturing, compared with 3.3 percent in manufacturing as a whole. Hours fell in the high-tech sector—slightly offsetting the effect of more rapid increases in capital and intermediate purchases on combined inputs—while hours in the total manufacturing sector were unchanged. In both sectors, intermediate purchases' share in the cost of output (the value of intermediate purchases as a percentage of the total value of output) remained about constant, while labor's cost share fell and capital's cost share increased. The decline in labor's share and the increase in capital's share of costs, however, were more pronounced in the high-tech sector than in manufacturing as a whole.

The pattern of multifactor productivity growth in the high-tech manufacturing sector during the 1990s parallels that of high-tech labor productivity—a strong increase in multifactor productivity during the first half of the decade was followed by an acceleration, led by extremely rapid output growth, in the second half. From 1990 to 1995, strong capital growth and moderate intermediate purchases growth in the high-tech manufacturing sector were partially offset by a substantial decline in labor hours of 3.8 percent per year. The resulting slow growth in combined inputs, coupled with output growth of 5.5 percent per year, yielded an average high-tech multifactor productivity growth rate of 4.5 percent per year over the subperiod.

In the second half of the decade, rapid increases in capital and intermediate purchases in the high-tech sector and a modest increase in labor hours led to a dramatic increase in the average annual growth rate of combined inputs, from 0.9 percent to 5.7 percent. Despite the rapid acceleration in combined inputs, much faster growth in high-tech manufacturing output led to an increase in the high-tech multifactor productivity growth rate to 8.1 percent per year over the 1995–99 period.

The overall manufacturing sector also experienced a substantial acceleration in multifactor productivity growth during the second half of the 1990s. Following an average increase of 1.2 percent per year from 1990 to 1995, multifactor productivity growth in manufacturing more than doubled in the latter portion of the decade—to 2.5 percent. The 1995–99 rate in manufacturing, however, was less than a third of the 8.1-percent rate in the high-tech sector over the same subperiod.

The magnitude of the acceleration in high-tech manufacturing output and multifactor productivity growth that began in the mid-1990s works to obscure a more subtle difference between the early and late halves of the decade—a marked contrast in the sources of high-tech output growth in each period. From 1990 to 1995, for example, with combined input growth depressed by declines in labor hours, more than 80 percent of output growth resulted from increases in multifactor productivity, and less than 20 percent was due to increases in inputs. Over the 1995–99 period, by contrast, the share of high-tech manufacturing output growth attributable to multifactor productivity growth dropped to less than 60 percent, with combined inputs accounting for more than 40 percent of output growth over the period. These proportions for the high-tech sector in the second half of the 1990s are very similar to those found in the manufacturing sector as a whole for the subperiod.

As with labor productivity growth, multifactor productivity growth in the high-tech industries varied greatly within the sector. In computer and office equipment and electronic components and accessories, multifactor productivity growth rates far exceeded the overall high-tech sector rate. Six industries had rates of multifactor productivity growth that were less than the rate for total manufacturing. Two of the six industries experienced declines in multifactor productivity over the period, and in one industry it was unchanged.

Although most high-tech industries made some positive contribution to the high-tech sector labor productivity growth rate (the contribution of the industrial organic chemicals industry was so small it was negligible), this was not true for multifactor productivity. Table 4 shows that only the three information technology industries made significant positive contributions to high-tech multifactor productivity growth. Two industries had small positive effects on the sector's multifactor productivity growth, two had no effect, and three industries lowered the sector's overall growth rate. The electronic components and accessories industry had a multifactor productivity growth rate of 16.6 percent per year and contributed 2.6 percentage points to high-tech sector multifactor productivity growth from 1987 to 1999. The computer and office equipment industry had growth of 18.8 percent per year and contributed 2.4 percentage points to the sector multifactor productivity growth rate. Communications equipment contributed an additional 0.4 percentage points to the high-tech sector multifactor productivity growth rate.

It is interesting to note that while the high-tech multifactor productivity growth rate for the 1987–99 period was nearly 4 times the comparable rate for total manufacturing, it was more than 12 times the rate for the non-high-tech manufacturing industries. Chart 2 illustrates this point, showing multifactor productivity growth rates of 0.4 percent per year for non-high-tech manufacturing, 1.3 percent per year for total manufacturing, and 5.0 percent per year for high-tech manufacturing.[28]

Capital services

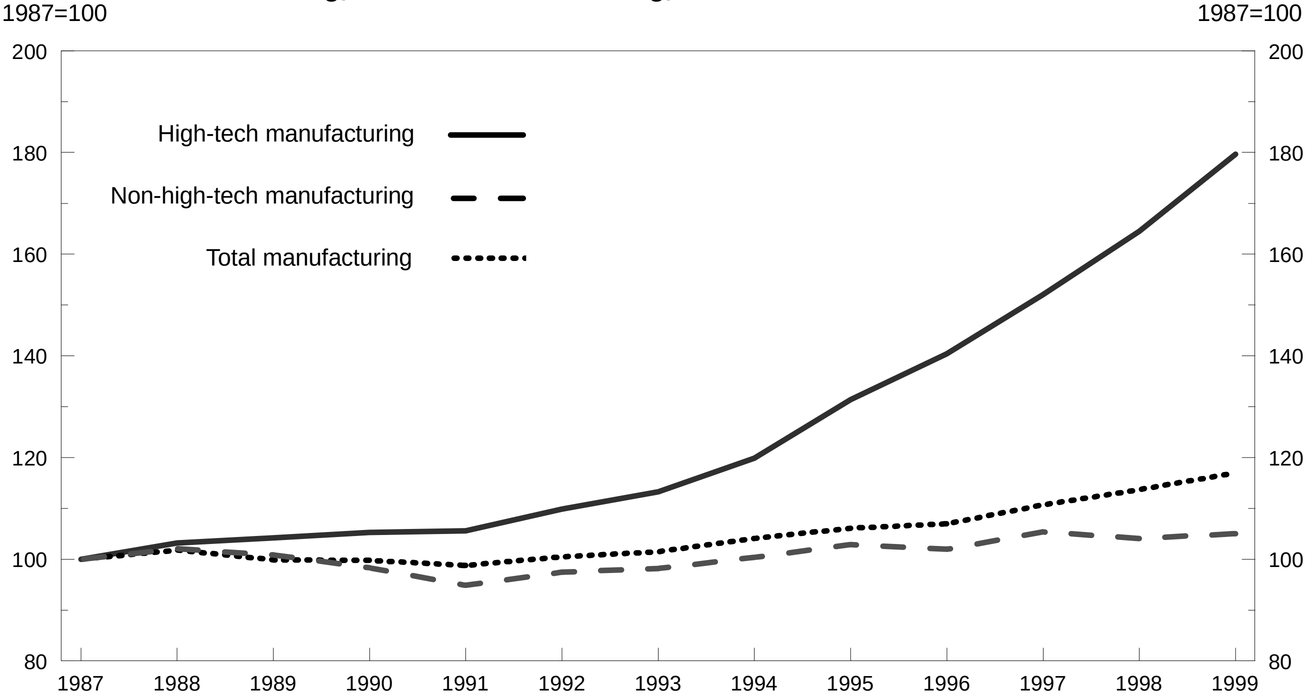
Capital is defined as the flow of services derived from the assets used in the production of an industry's or a sector's output. Capital increased at an average annual rate of 5.2 percent per year in the high-tech manufacturing sector from 1987 to 1999. In the manufacturing sector as a whole, capital increased at a rate of 3.0 percent per year over the period. The higher growth rate of capital input in high-tech manufacturing is consistent with the strong output growth found in that sector. Each of the four broad categories of capital assets—equipment, structures, inventories, and land—advanced more rapidly in the high-tech sector than in aggregate manufacturing over the study period.[29]

Capital services account for a larger share of total costs in the high-tech manufacturing sector than in manufacturing as a whole. Over the 1987–99 period, costs of capital services averaged 24 percent of total costs in high-tech manufacturing, compared with 19 percent in aggregate manufacturing. Capital services have become increasingly important in both high-tech and total manufacturing. In the high-tech sector, capital services rose from 21 percent of total costs in 1987 to 29 percent in 1999; in the aggregate manufacturing sector, the capital cost share rose from 17 percent to 21 percent over the period.

Capital growth in both the high-tech manufacturing and all-manufacturing sectors accelerated through the 1990s. From 1990 to 1995, capital in high-tech manufacturing increased at an average rate of 3.9 percent per year, while in the second half of the decade, it increased at a rate of 7.3 percent per year. Similarly, the rate of capital growth in overall manufacturing nearly doubled from the earlier to the later subperiod, increasing from an average annual rate of 2.4 percent during the first half of the decade to 4.4 percent per year during the second half.

Growth in capital services varied greatly among the high-tech industries. Five high-tech industries had increases in capital services that exceeded the increase in overall manufacturing, and one recorded an increase that about matched the all-manufacturing rate. The information technology industries, where output grew most rapidly, also had some of the largest increases in capital over the period. Electronic components and accessories recorded growth in capital of 9.0 percent per year, the highest rate of increase among all the manufacturing industries for which data were available.

Chart 2. **Index of multifactor productivity in high-tech manufacturing, non-high-tech manufacturing, and total manufacturing, 1987–99**



The remaining two information technology industries, communications equipment and computer and office equipment, had capital growth rates of 5.3 and 6.2 percent per year, respectively. Capital also increased at a rapid rate in the drug industry (6.0 percent), despite only moderate output growth that about equaled the average for total manufacturing. Although they essentially had flat output growth over the period, industrial organic chemicals and aircraft and parts had increases in capital near the all-manufacturing average. Capital declined in industrial inorganic chemicals; guided missiles, space vehicles and parts; and search and navigation equipment. The latter two industries also had substantial declines in output over the period.

Average annual output growth in the high-tech manufacturing sector exceeded the rate of capital growth over the period (8.0 percent versus 5.2 percent). As a result, capital productivity—output per unit of capital—rose 2.7 percent per year over the period. In the aggregate manufacturing sector, output growth of 3.3 percent per year and capital growth of 3.0 percent produced an increase in capital productivity of just 0.3 percent per year.

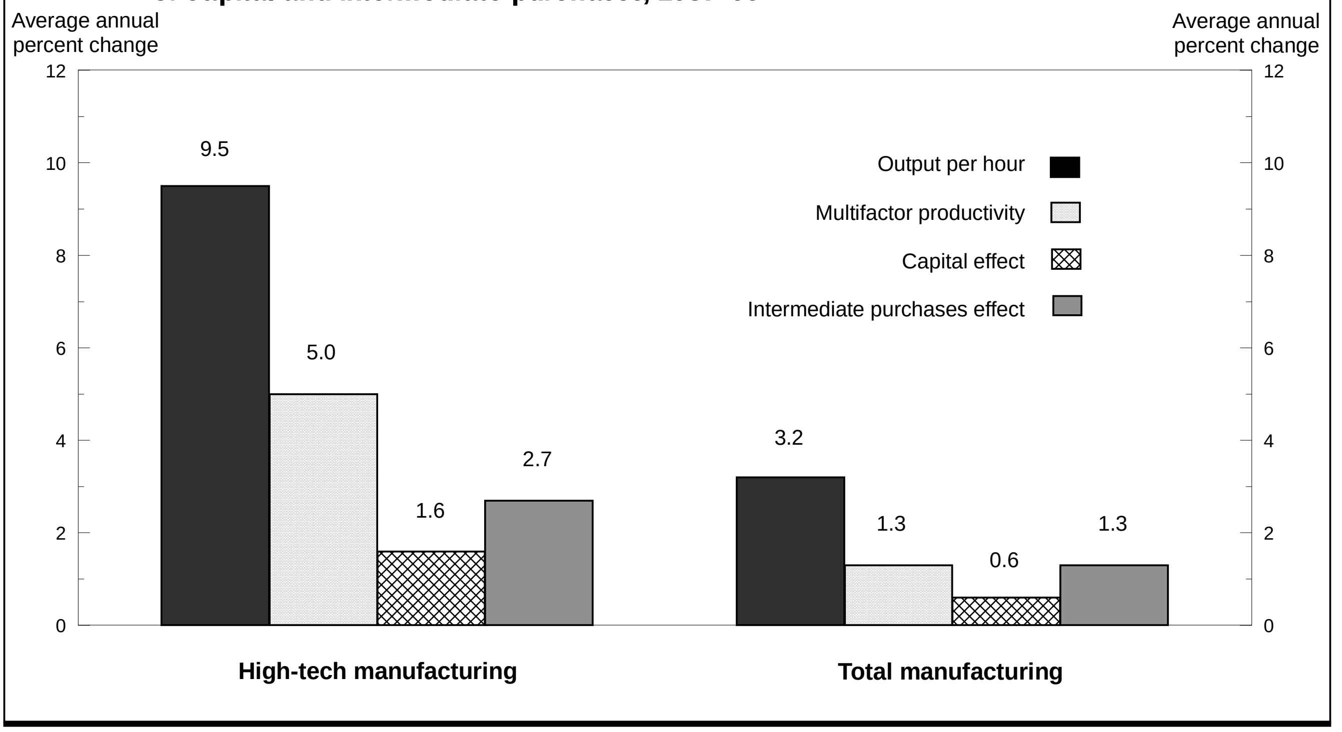
The better performance of capital productivity in high-tech manufacturing developed entirely in the second half of the 1990s. Capital productivity in both the high-tech and aggregate manufacturing sectors dipped toward the middle of the period and then rose again. From 1987 to 1994, average capital productivity growth in aggregate manufacturing exceeded that in the high-tech manufacturing sector. From 1994 to 1999, however, capital productivity in the high-tech sector increased rapidly, while in the aggregate manufacturing sector it stagnated.

Intermediate purchases

Intermediate purchases include the materials, purchased services, fuels, and electricity used in the production process. To support production in the high-tech manufacturing sector, intermediate purchases inputs increased at an average rate of 4.0 percent per year from 1987 to 1999. In manufacturing as a whole, intermediate purchases inputs rose an average of 3.3 percent per year.

Although the growth of intermediate purchases over the entire study period (1987–99) was similar in both high-tech and total manufacturing, the two sectors exhibited very different patterns in this measure during the 1990s. Intermediate purchases in high-tech manufacturing increased only 2.3 percent per year during the first half of the 1990s, but the rate more than tripled during the second half (7.0 percent). Intermediate purchases growth in overall manufacturing, by contrast, dropped from a rate of 3.5 percent per year in the first part of the decade to 2.6 percent per year during the second part.

Chart 3. Output per hour (labor productivity) equals multifactor productivity plus the effects of capital and intermediate purchases, 1987–99



Within the high-tech sector, there is a great deal of variation with respect to intermediate purchases among the component industries. In the five high-tech industries in which the rate of output growth matched or exceeded that of overall manufacturing—the three information technology industries, drugs, and measuring and controlling devices (SIC 382)—intermediate purchases grew rapidly over the 1987–99 period, at rates ranging from about 5 percent to nearly 10 percent per year. The remaining high-tech industries had increases in intermediate purchases below the manufacturing sector average, and intermediate purchases declined in the two industries with significant output declines over the period: guided missiles, space vehicles and parts; and search and navigation equipment.

Because high-tech manufacturing output increased more rapidly than inputs of intermediate purchases in that sector, intermediate purchases productivity rose 3.8 percent per year from 1987 to 1999. However, within the high-tech sector, only computer and office equipment and electronic components and accessories had substantial increases in intermediate purchases productivity, averaging 16.5 percent and 16.3 percent per year, respectively. Among the remaining high-tech manufacturing industries, three had small increases (less than 1 percent per year) in intermediate purchases productivity over the period, while five had small declines (1 to 2 percent per year).

Relating multifactor and labor productivity

Multifactor productivity analysis provides additional insights into the sources of growth in labor productivity. Changes in the quantity of capital services per hour and changes in intermediate purchases per hour are important sources of growth in labor productivity. The influence of capital per hour on labor productivity is known as the *capital effect*. Similarly, the effect of changes in the ratio of intermediate purchases to labor hours on labor productivity is known as the *intermediate purchases effect*. The capital effect is measured as the change in the ratio of capital to labor hours multiplied by capital's share in the value of output, and the intermediate purchases effect is equal to the change in the ratio of intermediate purchases to labor hours multiplied by the intermediate purchases share in the value of output. The sum of the capital effect, the intermediate purchases effect, and multifactor productivity growth approximately equals the growth in labor productivity.[30]

As can be seen in chart 3, among the three components of labor productivity change, the largest contributor in the high-tech sector was multifactor productivity, which accounted for more than half (5.0 percentage points) of the 9.5-percent average annual growth rate in labor productivity. The second most important contributor was the intermediate purchases effect, which accounted for nearly a third (2.7 percentage

Table 5. High-tech manufacturing industry performance relative to all manufacturing industries, 1987–99

Quintile	Output	Hours	Output per hour	Unit labor costs	Multi-factor product-ivity	Combined Inputs	Inter-mediate purchases per hour	Capital per hour
1	3	1	6	2	4	5	7	8
2	3	1	2	0	1	0	1	1
3	0	2	0	1	1	1	2	1
4	0	3	0	2	2	1	0	0
5	4	3	2	5	2	3	0	0

NOTE: For each column-head variable, the set of all 140 three-digit SIC manufacturing industries was ranked according to each industry's average annual percent change for the 1987–99 period. The rankings were then divided into quintiles, each containing about 28 industries. The first quntile represents the most rapid growth, and the fifth quintile the slowest growth. The number of high-tech industries in each quntile is shown in the columns.

points) of the growth in labor productivity over the period.

In contrast, the intermediate purchases effect and multifactor productivity growth each contributed about equally to the growth of labor productivity in the manufacturing sector as a whole. The intermediate purchases effect and multifactor productivity each contributed 1.3 percentage points (2.6 points combined) to the labor productivity growth rate of 3.2 percent per year in manufacturing.

In both manufacturing and high-tech manufacturing, the capital effect made the smallest contribution to labor productivity growth, in each case accounting for just 15 to 20 percent of the labor productivity increase. In manufacturing, the capital effect contributed 0.6 percentage points of the average labor productivity growth of 3.2 percent per year. In the high-tech sector, the capital effect contributed 1.6 percentage points to the average labor productivity growth of 9.5 percent per year. In the high-tech sector, growth in the capital-labor ratio exceeded growth in the ratio of intermediate purchases to labor. However, the intermediate purchases' share in output was twice that of capital and therefore resulted in a much larger intermediate purchases effect.

High-tech industry characteristics

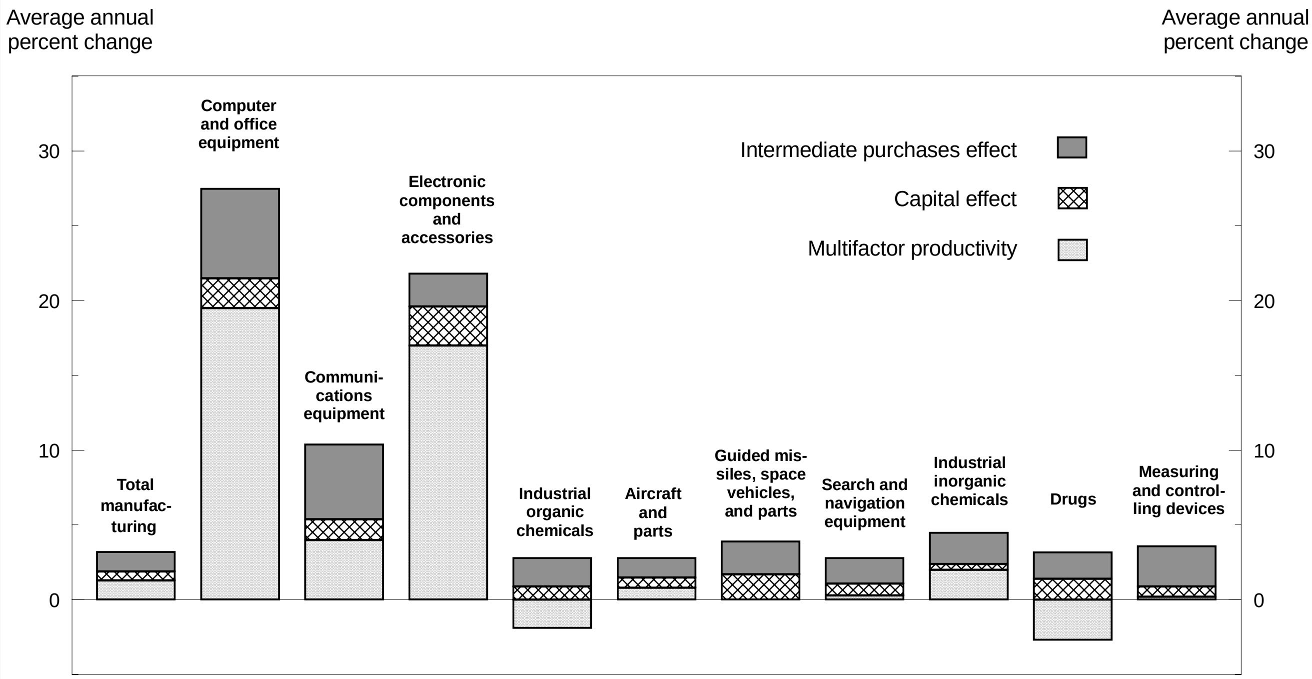
The high-tech manufacturing sector analyzed in this article is made up of industries with a high proportion of workers engaged in research and development activities and in technology-oriented occupations. It has been demonstrated that the high-tech manufacturing sector contrasts sharply with overall manufacturing in virtually all measures. Yet, the high-tech sector analyzed here is made up of industries that are far from uniform and vary widely in their characteristics and performance. In fact, the performance of some of the high-tech manufacturing industries appears to be closer to the non-high-tech industries than it is to other high-tech industries.

This raises the question of whether or not the high-tech industries have any commonalities beyond the research and development and technology-oriented employment criteria used to classify them as such. Prompted by this question, we ranked all of the manufacturing industries according to their performance on each of the key measures analyzed in this article and divided the ranked industries into quintiles. The results of this analysis are shown in table 5, and they illustrate that high-tech manufacturing industries do indeed share several key characteristics and tendencies.

The most striking commonality is the tendency of high-tech industries to have more rapid rates of growth in the ratios of intermediate purchases to labor and capital to labor than do the non-high-tech industries. Conversely, hours in the high-tech industries tended to decline more rapidly than (or not to grow as quickly as) hours in the non-high-tech industries. Another feature of high-tech industries is their tendency to outperform non-high-tech manufacturing industries in output per hour and unit labor costs. Output per hour is more likely to grow more rapidly, and unit labor costs are more likely to grow more slowly (or decline more rapidly) in high-tech industries than in other manufacturing industries.

Still, the mediocre (or sometimes poor) productivity performance of some high-tech manufacturing industries is puzzling. It is not clear why some manufacturing industries

Chart 4. Components of labor productivity (output per hour) growth in total manufacturing and in high-tech manufacturing industries over the 1987–99 period



NOTE: Output per hour equals multifactor productivity plus the effects of capital and intermediate purchases.

that employ such high proportions of research and development workers and highly skilled, technology-oriented workers should be experiencing such unremarkable productivity performance over an extended period. One possible explanation involves the difficulty of accurately measuring price and output movements in rapidly-changing industries, a problem we mentioned earlier.

BLS and others have devoted particular attention to the measurement of prices for information technology. It is possible that changes in price and/or quality are not captured as well for some high-tech industries as others. Medical care prices generally and pharmaceutical prices in particular have generated a lot of concern, both at BLS and among outside researchers. Research has addressed instances where there may have been biases in producer price indexes (PPIs) for particular drugs or classes of drugs.[31] During the 1990s, BLS made some changes in the way these prices are handled in the indexes, but these changes were not incorporated into the data for earlier years.[32] Such biases in the PPIs would affect the productivity measures reported here because in many cases PPIs are used to deflate output measures when calculating industry productivity growth.[33]

Another possible explanation is that, in some cases, the skills of research and development and technology-oriented employees may be directed toward the marketing of products or development of superficially differentiated existing products rather than on the development of new products or production processes. A third possible explanation for the poor performance of some high-tech industries is that the returns from the high-tech workers they employ and the research and development they undertake are not yet evident, but will appear in the future.

It also should be noted that two of these high-tech industries experienced substantial output declines over the period (guided missiles, space vehicles, and parts; and search and navigation equipment); one experienced a very small decline (industrial organic chemicals); and one experienced a very small increase (aircraft and parts). It can be difficult for industries to maintain productivity growth in the face of flat or declining output. BLS data show that industries with long-term declines in output are more likely to record productivity declines than are industries in which output is growing. Despite this disadvantage, all four of these high-tech manufacturing industries recorded labor productivity increases, although their performance with respect to multifactor productivity was much less positive—only one had even a modest increase in multifactor productivity over the period, and one had a substantial decline. It also is worth mentioning that in three of these industries—aircraft and parts; guided missiles, space vehicles, and parts; and search and navigation equipment—a major underlying cause of the output decline was unrelated to industry performance. Following the end of the Cold War in the late 1980s, real defense spending fell sharply. Because these three industries are significantly tied to defense-related purchases, the retrenchment in spending contributed to substantial contractions in their output over the period of this study.[34]

Among the 10 high-tech manufacturing industries analyzed in this study, the dramatic differences in performance between the 3 information technology industries and the remaining 7 industries are illustrated by chart 4, which shows the components of labor productivity growth for the manufacturing sector and the 10 high-tech manufacturing industries. The chart depicts the three information technology industries, followed by the four industries with negative or weak output growth, and finally, the remaining three industries. For each industry, labor productivity growth is equal to the sum of multifactor productivity growth, the capital effect, and the intermediate purchases effect. When all three components of labor productivity growth are positive, the level of the labor productivity growth rate is shown by the total of the bar. For the two industries with negative multifactor productivity growth rates, the labor productivity growth rate falls below the top of the bar because the negative multifactor productivity component offsets the combined intermediate purchases and capital effects.

The chart shows that the information technology industries had extremely rapid labor productivity and multifactor productivity growth, well above the average for manufacturing. The seven remaining industries, however, present a much more mixed picture with respect to productivity performance. While all had positive labor productivity growth, only three exceeded the productivity growth rate for the overall manufacturing sector. In addition, only one had multifactor productivity growth above the all-manufacturing average, and two actually had substantial multifactor productivity declines.

Among the seven non-information-technology industries in the high-tech sector, the four with weak or negative output growth achieved positive labor productivity growth by virtue of reductions in labor input. The other three industries—industrial inorganic chemicals, drugs, and measuring and controlling devices—all had healthy output growth (about 3 percent per year). Two of these, industrial inorganic chemicals and measuring and controlling devices, combined output increases with reductions in labor input, and their resulting labor productivity growth rates exceeded the average rate for the manufacturing sector. In contrast, the drug industry was the only high-tech industry to have a substantial increase in labor input, and it also had among the most rapid growth in capital and intermediate purchases. Consequently, drugs recorded the most rapid increase in combined inputs in the high-tech manufacturing sector. Because this rapid increase in inputs occurred in combination with output growth about equal to the manufacturing-sector average, however, labor productivity growth in this industry was below the average for the manufacturing sector as a whole, and multifactor productivity declined over the period. Perhaps this poor productivity performance can be tied to the output price measurement problem discussed previously.

IN SUM, labor and multifactor productivity growth in the high-tech manufacturing sector were dominated by trends in three information technology industries: computer and office equipment; electronic components and accessories; and communications equipment. Three of the remaining seven high-tech manufacturing industries performed somewhat better than total manufacturing with respect to growth in labor productivity and unit labor costs. At the same time, there was a markedly different use of resources in high-tech manufacturing industries than in total manufacturing. Capital services and intermediate purchases in the high-tech sector grew more rapidly relative to labor input than was the case in total manufacturing. Despite strong output growth in high-tech manufacturing, employment in the high-tech sector declined over the period, while employment in the manufacturing sector as a whole remained essentially flat.

It should be emphasized that the results presented in this study are sensitive to the period analyzed. Because data for the measures analyzed are not yet available for a full business cycle, the results reported may reflect some cyclical influences. On the other hand, 1987 and 1999 both were years well into the business expansions of the 1980s and 1990s, respectively, so cyclical influences are likely to be small. Future analyses along these lines will benefit from updated measures as they become available. □

Notes

[1] William Luker, Jr. and Donald Lyons, “Employment shifts in high-technology industries,” *Monthly Labor Review*, June 1997, pp. 12–25.

[2] This growth rate refers to high-tech manufacturing industries classified on the basis of employment of certain types of workers. The criteria for identifying high-tech industries will be discussed in detail later in this article.

[3] Labor productivity measures should not be interpreted as representing the contribution of labor to production. Changes over time in labor productivity reflect a number of factors, including substitution of other inputs, such as capital and intermediate purchases, for labor in the production process; changes in the organization of production; changes in the allocation of resources between sectors; the direct and indirect effects of research and development; and the development of new technology.

[4] Several factors may affect the multifactor productivity residual, such as technical innovation, economies of scale, labor composition changes (which are not accounted for in the measures analyzed here), organizational and institutional change, fluctuations in demand, omitted variables, and measurement errors.

[5] Executive Office of the President, Office of Management and Budget, *Standard Industrial Classification Manual 1987*. Data from the 1997 Economic Census of Manufactures were published primarily on the basis of the new North American Industry Classification System (NAICS); earlier censuses were published according to the Standard Industrial Classification (SIC) system. Implementation of NAICS by Federal agencies will be in phases. In order to update the three-digit industry productivity series used in this article, BLS converted the NAICS-based manufacturing data to an SIC basis. BLS will continue to publish the productivity series on an SIC basis until all the data underlying the productivity series have been converted to a NAICS basis.

[6] Multifactor productivity and related measures for the 108 industries for which the data meet BLS publication standards were published in *Multifactor Productivity Measures for Three-digit SIC Manufacturing Industries*, Report 956 (Bureau of Labor Statistics, January 2002). This article makes use of the data for all 140 three-digit manufacturing industries, including the 32 industries for which data have not been published.

[7] Data limitations prevented the development of productivity series for many industries prior to 1987. Data requirements for calculating multifactor productivity are even greater, further constraining the industrial detail for which these series are available.

[8] For a discussion of these issues, see, for example, Andrew W. Wyckoff, “The impact of computer prices on international comparisons of labour productivity,” *Economics of Innovation and New Technology*, Overseas Publishers Association, 1995, vol. 3, pp. 277–93; Jack Triplett, “High-tech industry productivity and hedonic price indices,” chapter 4 in *Industry Productivity: International Comparison and Measurement Issues* (Organization for Economic Co-operation and Development (OECD), Paris, October 1996), pp. 119–42. On the Internet at **http://www.oecd.org/dsti/sti/stat-ana/prod/**; Bruce T. Grimm, “Price Indexes for Selected Semiconductors, 1974–96," *Survey of Current Business* (Bureau of Economic Analysis, February 1998), pp. 8–24; Ernst R. Berndt, Zvi Griliches, and Joshua G. Rosett, "Auditing the Producer Price Index: Micro Evidence from Prescription Pharmaceutical Preparations," *Journal of Business and Economic Statistics*, July 1993; and William Gullickson and Michael J. Harper, "Possible measurement bias in aggregate productivity growth,” *Monthly Labor Review*, February 1999, pp. 47–67.

[9] Richard W. Riche, Daniel E. Hecker, and John U. Burgan, “High technology today and tomorrow: a small slice of the employment pie,” *Monthly Labor Review,* November 1983, pp. 50–58. (See page 51 and footnote 1.)

[10] *Technology, Innovation, and Regional Economic Development,* (United States Congress, Office of Technology Assessment), September 9, 1982.

[11] Thomas Hatzichronoglou, “Revision of the High-Technology Sector and Product Classification,” *STI Working Papers* (Organization for Economic Co-operation and Development, 1997, pp. 1–25).

[12] Daniel Hecker, “High-technology employment: a broader view,” *Monthly Labor Review,* June 1999, pp. 18–28; quote, p. 19.

[13] In 1999, employment in SIC 357, computer and office equipment, accounted for 14.2 percent of total employment in SIC 35, industrial and commercial machinery and equipment and computer equipment; SIC 366, communications equipment, and SIC 367, electronic components and accessories, accounted for 8.6 percent and 20.6 percent, respectively, of total employment in SIC 36, electronic and other electrical equipment and components.

[14] Calculations based on the data underlying *Productivity and Costs, Third Quarter 2001*, USDL 01–452 (U.S. Department of Labor), December 6, 2001.

[15] Riche, Hecker, and Burgan, “High technology today and tomorrow”; Paul Hadlock, Daniel Hecker, and Joseph Gannon, “High technology employment: another view,” *Monthly Labor Review*, July 1991, pp. 26–30; Luker and Lyons, ”Employment shifts in high-technology”; Hecker, ”High-technology employment.”

[16] National Science Board, *Science and Engineering Indicators–1998* (Arlington, VA, National Science Foundation, 1998).

[17] Hecker, “High-technology employment.”

[18] The earlier study listed only eight separate manufacturing industries because several three-digit manufacturing industries were grouped together: industrial inorganic chemicals and industrial organic chemicals (SICs 281 and 286) were combined to form industrial chemicals; and aircraft and parts and guided missiles, space vehicles, and parts (SICs 372 and 376) were combined to form aerospace. When considered on its own (that is, when not combined with industrial organic chemicals), industrial inorganic chemicals meets one but not both criteria for inclusion in the set of high-tech intensive industries – the proportion of technology-oriented workers falls slightly below the cut-off proportion. For purposes of consistency with the earlier study, however, this industry is nevertheless included in the high-tech manufacturing sector as defined in this article.

[19] See chapters 10 and 11 of Bureau of Labor Statistics, *BLS Handbook of Methods*, Bulletin 2490, April 1997 (on the Internet at: **http://stats.bls.gov/opub/hom/homhome.htm**). One significant difference between the two data sets that affects the comparisons of trends in capital services in high-tech manufacturing and total manufacturing is noted later in this article. (See footnote 29.)

[20] More precisely, logarithmic growth rates are additive. The average annual compound growth rates used in this analysis are approximately equal to the logarithmic growth rates, thus conceptually additive, when the growth rates are “small.”

[21] For a discussion of this issue, see William Gullickson, “Measurement of productivity growth in U.S. manufacturing,” *Monthly Labor Review*, July 1995, pp. 13–28.

[22] The issue of the potential effect of not removing intrasectoral transactions from the high-tech aggregate estimates is discussed briefly in the section on multifactor productivity.

[23] Although the composition of labor input may be influenced by changes in factors such as training, experience, and education, the data used in this article treat labor input as a homogeneous factor. Thus, employee hours are weighted equally; no distinction is made between workers in different industries or with different skill levels or wages. The effects of changes in labor composition are included in the productivity residual.

[24] In “High-technology employment,” Hecker reported an increase of 3 percent in employment in high-tech intensive industries between 1986 and 1996. However, Hecker’s high-tech intensive subset includes two service-producing industries, computer and data processing services (SIC 737) and research, development, and testing services (SIC 873). If these two industries, which recorded employment gains over the period, are excluded, the earlier BLS study’s data also show employment in high-tech intensive manufacturing industries to be falling.

[25] The small incompatibilities in the two data sets used make direct comparisons of levels of high-tech and total manufacturing hours problematic. Hours series for the industry data used to develop the high-tech sector measures are on an hours-paid basis and

cover only employees, or wage and salary workers. Hours for the manufacturing sector as a whole are adjusted to an hours-worked basis and include hours worked by proprietors and unpaid family workers in addition to those worked by wage and salary workers. See *BLS Handbook of Methods*, chapters 10 and 11, for an overall description of the measures. While these differences may affect comparisons of the levels of hours worked, they are not likely to significantly affect comparisons of trends or growth rates over the period studied given that proprietors' and unpaid family workers' share of employment is small in manufacturing and there was little trend in the ratio of hours worked to hours paid for this period.

[26] See Evsey D. Domar, "On the measurement of technological change," *Economic Journal*, 1961, pp. 709–29. Using this method, sector multifactor productivity growth is the weighted sum of the component industry multifactor productivity growth rates, where the weights are the ratios of each industry's value of production to the sector's value of production (the sum of the industries' value of production is greater than the sector net value of production, thus the industry weights sum to more than 1).

[27] A Domar aggregation of component industry growth rates yielded a high-tech multifactor productivity growth rate of 5.8 percent per year over the period 1987 to 1998. Over the same period, multifactor productivity growth in the high-tech aggregate constructed for this article (unadjusted for intrasectoral transactions) averaged 5.1 percent per year. The difference between the adjusted (Domar-weighted) and unadjusted multifactor growth rates, or 0.7 percent per year, represents an estimate of the bias arising from failing to adjust the high-tech manufacturing aggregate for intrasectoral transactions.

[28] The multifactor productivity growth rate for the "non-high-tech sector" is a Domar-weighted aggregate of the multifactor productivity growth rates of the 130 non-high-tech manufacturing industries. The multifactor productivity growth rates of the high-tech and non-high-tech sectors are not additive.

[29] In addition to equipment, structures, inventories, and land, the BLS capital measures for the aggregate manufacturing sector treat computer software as a capital asset and thus include capital services from software. Data limitations prevent the inclusion of software in capital services for the three-digit industry capital measures used for the high-tech manufacturing industries. This difference could significantly affect the comparison of trends in high-tech manufacturing and aggregate manufacturing capital input in this article. Since software has been growing more rapidly than most other asset types over the period studied, the likely effect of omitting software from the industry capital measures would be to bias the high-tech capital measures downward relative to overall manufacturing.

[30] See footnote 20.

[31] See, for example, Berndt, Griliches, Rosett, "Auditing the Producer Price Index." The pharmaceutical industry discussed in that article is characterized by rapid innovation and an institutional environment in which prices of newly introduced products tend to increase more slowly than prices of established products, or even to decline. The authors found that the BLS producer price index (PPI) for prescription pharmaceutical preparations was growing much more rapidly than several indexes of pharmaceutical prices they had constructed. This occurred, in part, because of an underrepresentation of new products in the PPI sample.

[32] Beginning in January 1996, the PPI program began using supplemental samples in order to improve the representation of new products in the pharmaceutical industry.

[33] If price increases over the period studied are overstated (or price declines understated), real output and productivity growth will be understated.

[34] For a discussion, see Allison Thomson, "Defense-related employment and spending, 1996–2006," *Monthly Labor Review*, July 1998, pp. 14–33. In 1987, with defense spending at a post-Vietnam War high, over half of employment in the search and navigation equipment and aerospace industries—aircraft and parts and guided missiles, space vehicles, and parts—was defense-related. By 1996, the proportion of defense-related employment in each of these industries had fallen sharply but remained substantial. (See tables 3 and 4.)