Employment shifts in high-technology industries, 1988–96

From 1988 to 1996, employment in high-technology industries shifted more toward services indeed, since 1988, growth in high-tech services accounted for all of the net increase in employment in the research-and-development-intensive sector

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High-technology industries are the most important source of strategically transformative products and processes in the U.S. economy. Changes in employment patterns in these industries thus command the interest of researchers, policymakers, and the general public. This article uses data from the BLS Current Employment Statistics (CES) program from January 1988 through January 1996 to survey the shifting levels and composition of employment in research-and-development (R&D)-intensive high-technology industries. The data reveal three noteworthy developments:

- Employment in R&D-intensive industries increased slowly over the period studied, contributing very little to the overall growth of total nonfarm employment. The result was that, at the beginning of 1996, employment in R&D-intensive high-technology industries was an appreciably smaller share of total nonfarm employment than at the beginning of 1988.

- The industrial composition of employment in R&D-intensive high-technology industries is shifting dramatically toward services industries, as employment in R&D-intensive, defense-dependent manufacturing industries declines, and employment in civilian high-tech manufacturing remains essentially static. In fact, R&D-intensive services accounted for all of the net increase in employment in the R&D-intensive sector since 1988 and grew more rapidly than did employment in the services division as a whole.

- There are reliable indications that the demand for high-tech R&D workers—that is, those actually engaged in R&D in any given high-technology industry—is also shifting toward occupations that are more involved with the production of services than the production of goods.

In what follows, we consider these shifts in more detail and interpret their causes and consequences in light of recent observations about the evolving character of manufacturing and service industries both inside and outside of the high-tech sector.

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Three questions about high tech

Why are high-tech industries so important? At least one source of the general public's interest has been a fascination with the explosion of new products and processes made in the United States and other advanced industrial countries since the end of World War II. But innovative technologies—from the railroad and the telegraph to the airplane—have almost always created a sensation. Instead, 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]

But what is often overlooked in studies of the high-technology sector is that the sector itself is not insulated from the transformative effects of the innovations it unleashes upon other industries. Because changing employment patterns often provide the best indicator of the character of transformations within any industry, we ask three questions about recent employment patterns inside U.S. high-tech industries: (l) How many new jobs has the high-technology sector produced in recent years? (2) What is the industrial composition of these new jobs? and (3) What is happening to the occupational mix of employment in high-tech industries, particularly the demand for employees whose R&D activities actually lend technological intensity to these industries?

Defining high-technology industries

Before we examine recent data on employment in high-tech industries, we must first define the term. As one analyst has said, "Everyone knows what [high tech] is, but no two lists are alike."[2] In the early 1980s, for example, BLS analysts identified 48 manufacturing and service industries in which the percentages of "technology-oriented workers" (engineers, life and physical scientists, mathematical specialists, engineering and science technicians, and computer specialists) were at least 1.5 times the average for all industries.[3] A more recent effort by BLS researchers refines that earlier work and that of others who used occupational criteria to define high-tech industries.[4] In this study, Paul Hadlock, Daniel Hecker, and Joseph Gannon used BLS Occupational Employment Statistics surveys from 1987 to 1989 in which employers were asked explicitly to designate workers who were actually engaged in R&D activity, together with their occupations. From these data, they identified 30 "R&D-intensive" industries, in which the number of R&D workers was "at least 50 percent higher than the average proportion for all industries surveyed."[5]

We begin our analysis with the industries on Hadlock, Hecker, and Gannon's R&D-intensive high-tech list. (See exhibit 1.) These industries had the highest percentages of employer-identified R&D workers in the 1987–89 Occupational Employment Statistics surveys and are some of the most likely sources of strategic technical innovation in the U.S. economy. Therefore, we refer to two distinct sets of employees in these industries. We use the term "employment in" a given high-tech industry to mean all employment, irrespective of occupational category, in that industry with a high proportion of R&D workers. By contrast, "high-tech employment" or "high-tech workers" refers to those actually engaged in R&D.

This distinction is important because a high-tech classification scheme like that of Hadlock, Hecker, and Gannon—that is, one that uses an aggregate indicator to identify three-digit industries—invariably generates identification problems. Empirical work based on microlevel employment data shows a tremendous heterogeneity in the performance of firms and of establishments within firms: many plants shut down even in expanding industries, while the reverse may be true in declining industries.[6] And the range of technical innovation embodied in plants is extremely wide in R&D-intensive industries. With regard to our question about the demand for high-tech workers, this heterogeneity occurs in awkward (and sometimes intractable) combinations. At one end of the spectrum, three-digit schemes tend to *exclude* the development of new products or processes by skilled workers at an individual establishment (for example, an experimental plant or a research laboratory) in an industry whose score on the aggregate indicator used does not qualify it for high-tech status.[7] Alternatively, such schemes may *include* industries in which most output is standardized and produced in large volume by relatively unskilled, low-wage workers.[8] These industries may have a proportion of scientific or engineering workers high enough to make them "R&D moderate" or even R&D intensive, but the bulk of this talent may be used to incrementally alter the characteristics of established products in slowly growing, advertising-intensive markets.

One or the other of these two problems occurs in a number of industries, including cigarettes (SIC 211),[9] soap, cleaners, and toilet goods (SIC 284), paints and allied products (SIC 285), and, arguably, many of the chemical industries on Hadlock, Hecker, and Gannon's R&D-intensive list. Such problems also are present even in the apparently uncontroversial classification of the computer and office equipment industry (SIC 357) as high tech: along with producers of office equipment, not elsewhere classified (SIC 3572)—who make, among other items, staple removers and paper punches—many low-cost manufacturers of electronic computers (SIC 3571) now use mass-produced components assembled in highly routine settings with minimal engineering and scientific input. Outside of semiconductors and related devices (SIC 3674), the same is true in several of the four-digit industries classified under electronic components and accessories (SIC 367). And even within the semiconductor industry, high-volume chip manufacturing can involve high capital-to-labor ratios and relatively low scientific labor requirements.

Nevertheless, because the effects of technological change can be seen in almost every industry, these uncertainties are inevitable in *any* high-tech study, no matter how precise the classifying metric. In our investigation of the demand for high-tech workers, we confront such uncertainties by examining changes in "production and nonsupervisory employment" at the four-digit level of the three-digit industries on Hadlock, Hecker, and Gannon's list. This broad occupational category consists of working supervisors and all nonsupervisory workers, including nonsupervisory professional specialists and workers engaged in "product development."[10] Granted that it is a blunt instrument for measuring high-tech occupational

Exhibit 1. Research and development (R&D)-intensive high-technology industries

SIC code	Industry
131	Crude petroleum and natural gas operations
211	Cigarettes
281	Industrial inorganic chemicals
282	Plastics materials and synthetics
283	Drugs
284	Soap, cleaners, and toilet goods
285	Paints and allied products
286	Industrial organic chemicals
287	Agricultural chemicals
289	Miscellaneous chemical products
291	Petroleum refining
335	Nonferrous rolling and drawing
355	Special-industry machinery
357	Computer and office equipment
362	Electrical industrial apparatus
366	Communications equipment
367	Electronic components and accessories
371	Motor vehicles and equipment
372	Aircraft and parts
376	Guided missiles and space vehicles and parts
381	Search and navigation equipment
382	Measuring and controlling devices
384	Medical instruments and supplies
386	Photographic equipment and supplies
737	Computer and data-processing services
871	Engineering and architectural services
873	Research and testing services
874	Management and public relations services

NOTE: SIC's 299 (miscellaneous petroleum and coal products) and 899 (services, not elsewhere classified) are omitted because publishable data are not available.

SOURCE: Paul Hadlock, Daniel Hecker, and Joseph Gannon, "High technology employment: another view," *Monthly Labor Review*, July 1991, pp. 26–30.

change, but clearly, the bulk of any given industry's R&D workers does exist in that occupational category. By examining such workers in the context of recent research on the effects of technology *within* high-tech industries, we can construct a plausible scenario about where the demand for high-tech workers may have been heading in recent years.

These caveats aside, it is important to point out the distinct analytical advantages of Hadlock, Hecker, and Gannon's list of R&D-intensive industries with respect to our questions about the growth of high-tech employment and the industrial composition of that growth. First, the industries on the list are similar to sets of industries identified by other researchers.[11] At the same time, the innovative use of *employer-specified* R&D occupations as a classifying metric captures four service industries whose employment behavior has not previously been examined in a high-tech setting: computer and data-processing services (SIC 737), engineering and architectural services (SIC 871), research and testing services (SIC 873), and management and public relations services (SIC 874).[12]

Second, the list includes aircraft and parts (SIC 372), guided missiles and space vehicles (SIC 376), and search and navigation equipment (SIC 381), three industries that have been identified elsewhere by BLS researchers as "defense dependent"—that is, at least 50 percent of the output of these industries was for defense in 1987, the most recent peak year for defense expenditures.[13] (See exhibit 2.) We can therefore distinguish employment changes in defense-dependent R&D-intensive manufacturing from employment changes in primarily civilian R&D-intensive manufacturing .[14]

High-tech industry employment growth

Because employment in many high-tech industries grew faster than nonfarm employment as a whole during the 1970s and early 1980s,[15] observers hoped that these sectors would eventually make large contributions to total nonfarm employment, both nationally and regionally.[16] Coincident with this expectation was the realization that the secular decline in high-wage production jobs in heavily unionized sectors of U.S. manufacturing would be unlikely to reverse itself. At the confluence of revolutions in microelectronics, genetics, aeronautics, physics, and materials sciences, high technology was envisioned as a potential engine for creating employment on a scale that could more than make up for the permanent loss of high-wage production jobs.

It is no news to close observers that this scenario has not materialized. In tables 1 and 2, CES data (not seasonally adjusted) document the employment behavior of 28 R&D-intensive high-tech industries from January 1988 through January 1996.[17] Total employment in these industries increased by slightly more than 400,000, or about 5 percent. At the same time, total nonfarm employment grew more than twice as fast (13.7 percent), generating almost 14 million jobs. The contribution of employment growth in R&D-intensive high-tech industries to total nonfarm employment growth, then, was a relatively small 2.9 percent. The immediate cause of these industries' lagging performance as a job producer was obvious: R&D-intensive manufacturing, encompassing 23 of the 28 three-digit industries in our analysis, lost almost 600,000 jobs, more than 10 percent of the 5.8 million workers employed in the sector as of January 1988. Ninety-one percent of this job loss, amounting to 547,000 employees, occurred in durable goods manufacturing, in which the decline of 12 percent from January 1988 total employment was more than twice that of durable goods manufacturing as a whole (–5.3 percent). Employment in R&D-intensive nondurable goods manufacturing also fell, but at a rate (–4.4 percent) much closer to that of all nondurable goods industries (–3.5 percent).

However, R&D-intensive *services*—management and public relations, computer and data-processing, engineering and architectural, and research and testing services—outperformed employment growth both in the economy as a whole and in the services division. More than 1 million new jobs were added, a gain of almost 46 percent. Of these new positions, more than 80 percent were created by the management and public relations and computer and data-processing services industries, in which total employment came close to doubling over the 8-year period. Clearly, all of the net increase in employment in R&D-intensive high-tech industries was due to growth in high-tech services.

Table 2 shows the effect of slow aggregate employment growth in high-tech industries on these industries' overall share of U.S. nonfarm employment. Total employment in R&D-intensive industries fell from 8.1 percent of all nonfarm workers in 1988 to 7.5 percent in January 1996. Not surprisingly, employment in all R&D-intensive manufacturing, durable goods manufacturing, and mining also fell as percentage shares of their divisions. R&D-intensive nondurable manufacturing's share remained roughly constant. Employment in R&D-intensive services was the only high-tech division that increased its share, rising from 9.5 percent to 10.2 percent of all services division employment.

Structural change in high-tech industries

Industrial composition of employment growth. The figures in table 1 afford us a closer look at the industrial composition of employment growth in R&D-intensive industries. One feature of the precipitous fall in R&D-intensive durable goods manufacturing immediately emerges: 526,000 of the 547,000 jobs lost were in aircraft and parts (SIC 372), search and navigation equipment (SIC 381), and guided missiles and space vehicles and parts (SIC 376), the three defense-dependent R&D-intensive manufacturing industries in Hadlock, Hecker, and Gannon's three-digit high-tech list. The last two industries lost more than half of their total employment (–53.0 percent and –55.9 percent, respectively), and aircraft and parts fell by more than a third (–34.5 percent). Clearly, defense-dependent industries accounted for a much larger share of employment in the U.S. high-technology sector than some analysts may have previously recognized.[18]

In contrast, total employment in the 18 civilian R&D-intensive manufacturing industries listed in exhibit 2 was roughly stable, with a loss of 54,400 (–1.3 percent) out of a total of almost 4.2 million in January 1988. (See table 1.) This small decline

Exhibit 2 Research and development (R&D)-intensive high-technology manufacturing industries: defense dependent and civilian

SIC code	Industry
	Defense dependent:[1]
372	Aircraft and parts
376	Guided missiles and space vehicles and parts
381	Search and navigation equipment
	Civilian:
211	Cigarettes
281	Industrial inorganic chemicals
282	Plastics materials and synthetics
283	Drugs
284	Soap, cleaners, and toilet goods
285	Paints and allied products
286	Industrial organic chemicals
287	Agricultural chemicals
291	Petroleum refining
335	Nonferrous rolling and drawing
355	Special-industry machinery
357	Computer and office equipment
362	Electrical industrial apparatus
367	Electronic components and accessories
371	Motor vehicles and equipment
382	Measuring and controlling devices
384	Medical instruments and supplies
386	Photographic equipment and supplies

[1] SOURCE: Division of Monthly Industry Employment Statistics, Current Employment Statisticsprogram.

was less than one-quarter of the percentage loss recorded by all of U.S. manufacturing (–4.6 percent) during the same period. Four civilian R&D-intensive manufacturing industries gained employment [medical instruments and supplies (17.6 percent, 39,700); drugs (14.9 percent, 33,200); special industry machinery (14.6 percent, 22,600); and motor vehicles and equipment (13.7 percent, 114,200)], and four were unchanged, at plus or minus about 2 percent over the entire 96-month interval [industrial organic chemicals (2.3 percent, 3,300); agricultural chemicals (2.2 percent, 1,100); electronic components and accessories (0.0 percent, 300); and soap, cleaners, and toilet goods (–2.4 percent, –3,700)].

All told, the four civilian R&D-intensive manufacturing industries that increased their employment added almost 210,000 jobs, of which slightly more than half were in the automotive industry. About one-third of the 210,000 were created in medical instruments and drug manufacturing, the two health care-related industries on Hadlock, Hecker, and Gannon's R&D-intensive list.[19] By way of contrast, computer and office equipment (SIC 357), an industry that many regard as having *begun* the "high-tech revolution" of the 1970s and 1980s, experienced the largest net employment decline (–97,700) among the civilian R&D-intensive industries. The relative stability of employment levels in electronic components and accessories—which includes semiconductors and related devices, another "signature" high-tech industry that has seen rapidly growing demand for its products since the end of the 1990–91 recession—seems robust in comparison.

Burgeoning service industry employment and rapidly declining defense-dependent manufacturing employment, then, represent the two main shifts in the industrial composition of employment in the R&D-intensive high-tech sector. The effect of the shift from manufacturing to services is depicted in chart 1. The services share of all R&D-intensive high-technology employment rose by almost 11 percentage points, from 28.0 percent to 38.9 percent, between 1988 and 1996; manufacturing's share fell from about 70 percent to 60 percent. Moreover, the shift to services is not merely an artifact of declining employment in defense-related high-tech manufacturing: even if defense-related employment levels had remained unchanged, the stagnation of employment in civilian high-tech manufacturing would have meant that manufacturing's share of all employment in R&D-intensive industries would still have fallen, from 70 percent to 66 percent.[20] This is at least one indication that employment patterns in high-tech industries are repeating the decades-old shift to services in U.S. nonfarm employment at large. Later, we will examine some of the reasons that this is happening.

The demand for high-tech workers. Gauging the demand for high-tech workers—that is, those whose R&D activities gen-

Table 1. Levels and net and percent changes, research and development (R&D)-intensive high-technology employment, January 1988 and January 1996, not seasonally adjusted, ranked by percent change, January 1988–January 1996

[Numbers in thousands]

SIC code	Industry	January 1988	January 1996	Net change	Percent change
874	Management and public relations	482.3	859.0	376.7	78.1
737	Computer and data-processing services	656.7	1,139.1	482.4	73.5
873	Research and testing services	470.4	562.6	92.2	19.6
384	Medical instruments and supplies	225.2	264.9	39.7	17.6
283	Drugs	222.2	255.4	33.2	14.9
871	Engineering and architectural services	708.2	813.0	104.8	14.8
355	Special-industry machinery	154.4	177.0	22.6	14.6
371	Motor vehicles and equipment	835.0	949.2	114.2	13.7
286	Industrial organic chemicals	143.6	146.9	3.3	2.3
287	Agricultural chemicals	51.0	52.1	1.1	2.2
367	Electronic components and accessories	608.6	608.9	.3	.0
284	Soap, cleaners, and toilet goods	153.4	149.7	–3.7	–2.4
366	Communications equipment	272.9	263.0	–9.9	–3.6
335	Nonferrous rolling and drawing	179.0	167.3	–11.7	–6.5
289	Miscellaneous chemical products	99.5	90.6	–8.9	–8.9
282	Plastics materials and synthetics	173.4	155.5	–17.9	–10.3
382	Measuring and controlling devices	318.7	284.7	–34.0	–10.7
362	Electrical industrial apparatus	178.1	159.0	–19.1	–10.7
285	Paints and allied products	62.2	55.3	–6.9	–11.1
281	Industrial inorganic chemicals	133.0	116.4	–16.6	–12.5
291	Petroleum refining	123.4	99.7	–23.7	–19.2
357	Computer and office equipment	455.0	357.3	–97.7	–21.5
386	Photographic equipment and supplies	109.8	84.7	–25.1	–22.9
131	Crude petroleum and natural gas operations	198.1	143.2	–54.9	–27.7
211	Cigarettes	40.6	28.2	–12.4	–30.5
372	Aircraft and parts	682.2	446.9	–235.3	–34.5
381	Search and navigation equipment	325.4	153.0	–172.4	–53.0
376	Guided missiles, space vehicles, and parts	211.6	93.4	–118.2	–55.9
	All R&D-intensive employment	8,273.9	8,676.0	402.1	4.9
	R&D-intensive manufacturing	5,758.2	5,159.1	–599.1	–10.4
	R&D-intensive durables	4,555.9	4,009.3	–546.6	–12.0
	R&D-intensive nondurables	1,202.3	1,149.8	–52.5	–4.4
	Defense-related R&D-intensive manufacturing	1,219.2	693.3	–525.9	–43.1
	Civilian R&D-intensive manufacturing	4,166.6	4,112.2	–54.4	–1.3
	R&D-intensive services	2,317.6	3,373.7	1,056.1	45.6
	R&D-intensive mining	198.1	143.2	–54.9	–27.7

Table 2. **Employment in R&D-intensive high-technology industries as a percent of all nonfarm, all manufacturing, all services, and all mining employment, 1988–96**

Category	January 1988	January 1996
Employment in all R&D-intensive high-technology industries as a percent of all nonfarm employment	8.1	7.5
Employment in R&D-intensive manufacturing as a percent of:		
All manufacturing employment	30.2	28.4
All durable manufacturing employment	40.7	37.8
All nondurable manufacturing employment	15.3	15.1
Employment in R&D-intensive services as a percent of all services employment	9.5	10.2
Employment in R&D-intensive mining as a percent of all mining employment	27.7	25.7

erate the innovations for which these industries are known—is a more difficult matter. Ideally, we would have liked to examine changes in the percentages of workers *actually engaged in R&D* in these industries. Unfortunately, the occupation-by-industry employment data that Hadlock, Hecker, and Gannon used to identify their high-tech industries cannot be reliably tracked across time. But, as we noted earlier, by looking at four-digit industry shifts in levels of production and nonsupervisory employment—which includes "product development" workers and nonsupervisory professional specialists—we can try to construct a plausible scenario of where high-tech occupational demand may have headed in recent years.

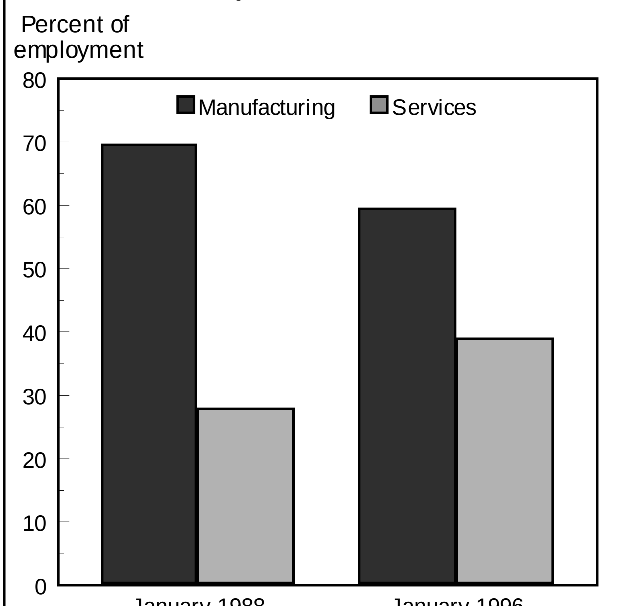
From the 12 three-digit industries that recorded growing or stable employment levels between 1988 and 1996, we selected 22 four-digit component industries, based on our judgment of their relative levels of R&D-intensity. Table 3 summarizes employment changes in the 15 of these 22 industries in which total employment also grew or was essentially unchanged and for which data on production workers were available.[21] Finally, to survey the employment behavior of these industries over the most recent business cycle, we broke the 96 months between January 1988 and January 1996 into three periods: January 1988 through July 1990 (period 1), the final months of the ascent to the peak of the economic expansion of the mid- and late 1980s; July 1990 to March 1991 (period 2), the decline in output and employment to the trough of the 1991 recession; and March 1991 to January 1996 (period 3), encompassing the recovery from the recession and the current expansion.[22]

Before we examine the data, what can we glean from recent research on the demand for high-tech workers? Several studies have shown that the higher levels of computerization and more rapid investment in newer technologies that characterize the operations of high-tech firms raise their demand for more educated workers and also can increase the overall share of these types of workers in a given company's work force.[23] In his summary of these and other studies, Daniel S. Hamermesh concludes that the demand for highly educated and skilled labor *complements* more rapid turnover in technology and higher levels of capital investment.[24] This suggests that the closer a firm is to the technological frontier, either in its use of advanced processes or in its efforts to design new products or processes, the stronger will be its demand for high-tech workers.

Clearly, these firms have a strong incentive to continually improve their core areas of technical capability. Whether they can do this, of course, is constrained by their success in attracting and retaining high-quality research, design, and engineering talent. And no matter how many scientists and engineers there are at any given time, the best and the brightest are always in short supply. Because research-grade scientists and engineers are in such great demand, they tend to change jobs more frequently. Analysts almost across the board have observed that the highest rates of job creation, job destruction, and—most vexing for personnel managers and corporate research planners—job switching (both from firm to firm and within firms) occur among the most technologically innovative firms in sectors in which overall employment is growing.[25]

Technological leaders thus face serious problems in finding workers with the right skills[26] and difficulty in maintain-

Chart 1. **Industrial composition of employment in R&D-intensive high-technology industries, January 1988 and January 1996**



ing stable R&D work forces, in terms of both numbers and productivity. Instability, of course, can result in dynamic losses of knowledge, the accumulation of which is central to the success of high-tech firms. Accumulating knowledge involves positive feedback in the form of increasing returns,[27] which enable high-tech firms not only to remain high tech, but also to maintain their presence in, or even persistently dominate, innovative markets.[28]

In order to attract and keep R&D talent, then, firms must cultivate well-articulated internal labor markets for scientists, engineers, and other classes of skilled employees, provide high wages and benefits, and emphasize participation in state-of-the-art projects.[29] As Lia Pacelli, Fabio Rapiti, and Ricardo Revelli note, “whenever the value of a job-worker match is high, firms will take actions to reduce the risks that the match breaks up.”[30] By helping retain workers whose skills are hard to come by, these measures keep training costs lower and allow internal investments in human capital to pay off.

The conflict between maintaining a technological edge and the intense competition between firms to attract scarce research-grade talent leads us to conclude that R&D-intensive firms face a continuous struggle to retain adequate levels of R&D workers. Plausibly, one of two scenarios occurs. In the first, firms will try to maintain relatively constant levels of R&D workers, increasing them slowly in response to product or price competition, growing demand, or both. In this “constant-levels” scenario, the number of R&D workers in a firm would tend to lag behind changes in production employment, causing the ratio of R&D workers to production workers to vary inversely with growing demand, measured in terms of revenue or output. We believe that this is likely to be the “minimum program” that many, if not most, R&D-intensive firms are realistically able to attain.

In the second scenario, which we might call the “constant-

Table 3. Changes in total employment and in production employment, selected four-digit R&D–intensive industries, not seasonally adjusted, ranked by percent change in total employment, January 1988–January 1996

[Numbers in thousands]

SIC code	Industry	January 1988–January 1996		January 1988–July 1990		July 1990–March 1991		March 1991–January 1996	
		Net	Percent	Net	Percent	Net	Percent	Net	Percent
7371	Computer programming services	140.9	120.3	33.8	28.9	1.7	1.1	105.4	69.1
	Production workers	124.2	133.1	26.0	27.9	2.7	2.3	95.5	78.3
8742	Management consulting services	158.7	112.9	48.9	34.8	7.0	3.7	102.8	52.3
	Production workers	122.5	120.7	34.4	33.9	6.2	4.6	81.9	57.6
8732	Commercial nonphysical research	38.4	47.8	17.1	21.3	–1.5	–1.5	22.8	23.8
	Production workers	36.4	60.2	14.1	23.3	.4	.5	21.9	29.2
7373	Computer integrated system design	40.7	44.1	5.1	5.5	1.1	1.1	34.5	35.0
	Production workers	28.6	41.2	10.0	14.4	.2	.3	18.4	23.1
3714	Motor vehicles parts and accessories	108.9	27.2	2.5	.6	–25.5	–6.3	131.9	35.0
	Production workers	87.7	27.3	–5.2	–1.6	–23.7	–7.5	116.6	39.9
8711	Engineering services	93.6	17.4	83.1	15.4	–38.0	–6.1	48.5	8.3
	Production workers	73.5	16.3	63.8	14.1	–32.9	–6.4	42.6	8.8
2834	Pharmaceutical preparations	23.3	12.8	16.1	8.8	2.9	1.5	4.3	2.1
	Production workers	25.1	30.8	8.3	10.2	2.4	2.7	14.4	15.6
3556	Food products machinery	2.9	12.8	1.3	5.8	–1.0	–4.2	2.6	11.4
	Production workers	2.2	16.5	1.0	7.5	–.9	–6.3	2.1	15.7
2869	Industrial organic chemicals, n.e.c.[1]	8.8	8.0	14.9	13.6	–1.9	–1.5	–4.2	–3.4
	Production workers	2.3	3.6	2.7	4.2	–4.2	–6.2	3.8	6.0
8712	Architectural services	8.4	7.0	9.6	8.0	–8.2	–6.3	7.0	5.8
	Production workers	6.0	6.4	8.4	8.9	–7.1	–6.9	4.7	4.9
8731	Commercial physical research	13.5	6.5	33.0	16.0	3.1	1.3	–22.6	–9.3
	Production workers	11.2	7.6	10.5	7.1	.0	.0	.7	.4
3841	Surgical and medical instruments	5.3	5.5	5.6	5.8	5.9	5.8	–6.2	–5.8
	Production workers	8.2	14.8	3.6	6.5	4.7	8.0	–.1	–.2
8733	Noncommercial research organizations	2.9	2.3	19.0	15.0	–7.7	–5.3	–8.4	–6.1
	Production workers	–.4	–.4	6.5	6.5	–4.6	–4.3	–2.3	–2.3
3711	Motor vehicles and car bodies	.7	.2	–19.6	–5.7	–31.3	–9.6	51.6	17.4
	Production workers	9.1	3.5	–22.0	–8.5	–25.0	–10.6	56.1	26.6
3674	Semiconductors and related devices–	–3.0	–1.2	–13.4	–5.3	–6.2	–2.6	16.6	7.1
	Production workers	13.0	13.1	–5.5	–5.5	.6	.6	17.9	19.0
	All R&D–intensive employment	644.0	22.7	257.0	9.1	–99.6	–3.2	486.6	16.3
	Manufacturing	146.9	10.4	7.4	.5	–57.1	–4.0	196.6	14.4
	Services	497.1	35.0	249.6	17.6	–42.5	–2.5	290.0	17.8
	Production employment	549.6	27.3	156.6	7.8	–81.2	–3.7	474.2	22.7
	Manufacturing	147.6	16.5	–17.1	–1.9	–46.1	–5.3	210.8	25.4
	Services	402.0	35.9	173.7	15.5	–35.1	–2.7	263.4	21.0

[1] n.e.c. = not elsewhere classified.

proportions" model, levels of R&D employment might increase in rough consonance with production employment levels, thereby maintaining a constant proportion of R&D workers in the production worker mix. In either model, other things remaining equal, the demand for R&D workers increases in growing industries, but more slowly in the "constant-levels" model than in the "constant-proportions" model.

Does the welter of "up-and-down" detail in table 3 give us significant clues about which model is operating in the real world? First, total employment grew by 644,000 across the 15 industries. Of the 644,000 new jobs, roughly 85 percent (550,000) were in production and nonsupervisory occupations. Consistent with the overall shift toward services and away from manufacturing in the R&D-intensive sector, almost three-quarters of the new production and nonsupervisory occupations (402,000) were created by R&D-intensive service industries. Given our understanding of the constraints on R&D-intensive firms as they recruit and retain high-tech workers, these aggregate figures alone tell us that, even if the "constant-levels" model is operating across all the firms and industries listed in table 3, demand has been relatively strong in this cross section of industries for high-tech product developers and the professional specialists from which R&D (and D&E—design and engineering) employees emerge.

But both models may be operating. Production employment—and, within that, R&D employment—varies across establishments of different sizes and ages. For example, we know that both kinds of employment rise in high-tech firms that focus on new products and fall where the focus is on adopting new processes.[31] But firms in a high-tech industry may do both, or change emphasis from one to the other, in relatively quick succession. In automobiles, a sector that usually appears to concentrate on supplying new products, restructuring throughout most of the 1980s resulted in the loss of hundreds of thousands of production jobs—the last vestige of which may be visible in period 1. But there was relatively strong production employment growth after the recession and well into the mature phase of the recovery (period 3), as new products (car models with new features and accessories) intensified competition in the North American-based auto industry. Table 3 shows that the lion's share of growth in period 3 was for production employment in motor vehicle parts and accessories (SIC 3714), where competition in developing new products (and, to some degree, new processes) is especially keen. It is likely that engineers working on D&E for new products were in great demand among the firms in this industry. In that case, the faster growth, "constant-proportions" scenario may have been in force as firms scrambled to rapidly increase their product development capabilities.

The same sequence of restructuring appears to have occurred in semiconductor manufacturing (SIC 3674) over roughly the same period, when markets, technologies, and scientific talent shifted from mainframes to PC's. But it may have had a different outcome in terms of the demand for high-tech workers. Production employment continued to fall in period l, but stabilized and reversed course after the recession, as new generations of chips followed each other in quick succession. However, microprocessors are both a product and a process, with end uses (in a home or business computer) and intermediate uses as elements *in their own*, as well as in other, industries' production systems. Production employment in semiconductor manufacturing, then, is bracketed simultaneously by process innovations that *reduce* it and product innovations that *increase* it. Semiconductor firms maintained their production work forces at essentially constant levels during the recession and, in response to vastly increased demand for chips after the recession, slowly added production workers between l991 and 1996. In this instance, the "constant-levels" scenario of high-tech worker demand may be more plausible.

The data in table 3 also reveal that, since the end of the recession, many high-tech firms maintained or increased their production work-force levels while reducing supervisory employment. Production employment constituted about 60 percent of total employment growth during period l, compared with *98 percent* during period 3. In manufacturing, 5 of the 7 industries (pharmaceutical preparations, industrial organic chemicals, surgical and medical instruments, motor vehicles and car bodies, and semiconductors and related devices) maintained or increased their production work-force levels while displacing supervisors. In services, the proportion of production jobs created moved from about 70 percent in period l to 91 percent of the total change in employment during period 3. Only in noncommercial research organizations (SIC 8733) were production worker positions eliminated along with those of supervisory workers.

A large amount of the supervisory loss would appear to be almost certainly the result of the recent corporate emphasis on "flattened" organizational structures that has led to layoffs among middle managers.[32] Further, in commercial physical research (SIC 8731) and noncommercial research services (SIC 8733), it is probable that supervisory employment shrank along with production employment during period 3 as a result of cuts in the growth of the national defense budget.[33] But the husbanding of production workers in strategically important four-digit R&D-intensive industries during the recession and afterward is consistent with the need to conserve high-tech know-how upon which technically sensitive production systems ultimately depend. In general, it indicates that the overall demand for high-tech workers is, at the very least, *stable*, no matter which demand scenario is operating in a particular industry.

Given that we analyzed only the performance of the components of three-digit R&D-intensive industries in which total employment was at least stable over the period in question, this conclusion is true, but trivial. So we ask a more poignant question: what kind of R&D workers have been demanded? Neal H. Rosenthal reports that three of the fastest growing occupations in the United States between 1983 and 1993 (an interval that partially overlaps our study period) have been computer systems analysts, engineers, and scientists.[34] The industrial composition of changes in production employment in table 3 is consistent with this finding. Two of the components of computer and data-processing services—computer programming services (SIC 7371) and computer integrated systems design (SIC 7373), the latter a more specialized and, arguably, a more R&D-intensive industry—had the first- and fourth-highest percentage increases in production employment, 133 percent and 41 percent, respectively. Together, these industries produced 3 times more production positions in period 3 than in period 1 (114,000, compared with 36,000) and more than one-quarter of all the production jobs created between 1988 and 1996. It is not mere speculation to assert that in these two industries, computer systems analysts, engineers, and scientists are the occupational groups from which cadres of nonsupervisory R&D workers emerge.

Another industry in which production employment more than doubled over the last 8 years was management consulting services (sic 8742). The approximately 123,000 new positions, two-thirds of which were added after the recession, almost certainly included R&D workers in professional specialty occupations such as management analysis, operations research, industrial engineering, psychology, economics, and other social, behavioral, and management sciences. These occupations were also likely to be in great demand in the commercial nonphysical research industry (SIC 8732), in which production employment increased by 60 percent.

The preceding four computer, management consulting, and commercial research services industries generated 312,000 of the 550,000 new production jobs in the R&D-intensive industries in table 3. Elsewhere, the biggest increases in production worker employment were in motor vehicle parts and accessories (87,700), engineering services (73,500), pharmaceuticals (25,100), semiconductors (13,000), commercial physical research (11,200), and motor vehicles (9,100). As mentioned earlier, firms in the automotive sector and in engineering services appear to have added relatively large numbers of nonsupervisory engineers, as cyclical forces and technological mandates for cleaner and safer vehicles compelled them to enlarge their pools of research talent. However, production worker employment levels in commercial physical research have been flat throughout the recession and the current expansion. And demand for the life and physical scientists, computer scientists, mathematicians, and statisticians that fill the R&D positions in pharmaceuticals and semiconductors has probably not been as strong as that for the professional specialists most likely to fill R&D positions in the four service industries discussed previously.

We can further examine these qualitative inferences about *which* high-tech occupations have been in demand by looking at the number of new openings that the Bureau of Labor Statistics expects to be created in the next decade for occupations we have deemed most likely to engage in R&D.[35] The following tabulation shows total projected job openings and percent changes in employment between 1994 and 2005 for likely R&D occupations in the four services industries at the top of table 3.[36]

	Job openings (thousands)	*Percent change*
Total	1,100	—
Computer systems analysts, scientists, and engineers	819	91
Management analysts	109	35
Industrial engineers	47	13
Psychologists	45	23
Operations researchers	35	50
Economists	30	25
Other social scientists	15	19

NOTE: Dash indicates no figure calculated.

The next tabulation shows projections for likely R&D occupations in the seven four-digit R&D-intensive manufacturing industries and for architectural services, noncommercial research, commercial physical research, and engineering services.[37] Significantly, the last two are recognizable as "producer services" that typically carry out specialized tasks for manufacturers, construction firms, and mining concerns.

	Job openings (thousands)	*Percent change*
Total	518	—
Electrical engineers	157	20
Physical scientists	104	19
Mechanical engineers	98	19
Life scientists	94	24
Architects	35	17
Chemical engineers	21	13
Metallurgical, ceramic, and materials engineers	6	5
Mathematicians	3	5

NOTE: Dash indicates no figure calculated.

In the first tabulation, total job openings are projected to outnumber those in producer services and manufacturing by roughly 2 to 1. The total is, of course, heavily weighted by the large number of computer-related professional specialty openings. Clearly, not all computer professionals will be hired by computer and data-processing firms. Many—along with some social scientists and management specialists—will be hired by service providers and manufacturers, so the total in the second tabulation is biased downward. But the disparity between what we can infer about recent and projected demand for occupations in industries that principally provide R&D-intensive computer, management, and nonphysical research services, compared with those historically associated with the production of goods, does not seem merely coincidental: it is consistent with the shift toward services in the industrial composition of employment that is occurring in the R&D-intensive sector of the entire U.S. economy.

Causes of high-tech change

So far, we have uncovered hard evidence for two significant employment shifts in U.S. high-tech industries: (1) very slow growth in overall employment, held down by huge losses in R&D-intensive defense-dependent manufacturing and the virtual stagnation of employment in civilian R&D-intensive manufacturing; and (2) a shift in the industrial composition of high-tech industries toward services and away from manufacturing, driven by large employment gains in computer and data processing and in management and public relations. With these numbers as a backdrop, we have also seen evidence suggesting that the demand for high-tech workers is shifting toward occupations that have more to do with the production of services than the production of goods.

Outside of the events occurring within the defense industry, which operates according to the logic of what might be called the "geopolitical business cycle," what is causing these trends? Technological change is certainly the most important determinant.[38] The critical point here is that labor-saving processes developed by R&D-intensive industries not only are adopted in other sectors, *but cause changes in their industry of origin as well.* This is nowhere more vividly seen than in the computer and office equipment industry. Today, approximately 15 years after PC's were first widely marketed, there is an installed base of tens of millions of these devices. In accordance with the empirical regularity in computing technology known as "Moore's law,"[39] the computing power embedded in these machines has continually *increased* over the last two decades, while the price of that power has *decreased*. This phenomenon has lowered the cost of automating ("computerizing") design and manufacturing processes in computers and other civilian high-tech manufacturing industries. In turn, automation has reduced the number of workers required at any output level, while both production capacity and demand for computers have continued to grow.[40] The result has been not only rising output and falling employment in computer manufacturing, but the likelihood of a relentless continuation of these trends: the Bureau of Labor Statistics projects that, between 1994 and 2005, annual output in the computer industry will rise by 7.3 percent. This is the fastest rate of output growth of the detailed industries for which the Bureau prepares projections. Employment levels, on the other hand, will fall by an annual rate of 2.6 percent.[41]

In addition, the perverse economic logic of Moore's law holds for other types of consumer electronics manufacturing (for example, cellular phones and pagers).[42] In some cases, it forces producers to sell these products at or below cost in order to boost sales of complementary goods with higher profit margins, such as software or technical services. This tendency not only gives impetus to the shift to services in the industrial composition of employment in high-tech industries, but may even help accelerate the observed increase in the proportion of nonproduction occupations—for example, in sales and marketing—*within* manufacturing as a whole.[43]

The Bureau of Labor Statistics has noted that for electronics and computer manufacturers who are less willing to invest in automation, another strategy that reduces labor requirements is to shift "subassembly or component production functions to countries where labor is cheaper."[44] This, too, is facilitated by vastly improved communications technologies, which are themselves the products of the microelectronics revolution that began in the mid- and late 1950s. These technologies allow R&D-intensive firms to disperse their production facilities internationally, yet control them effectively on a day-to-day basis. Further, "if this trend continues, assembly work sent abroad may well cost more jobs than [do] robots or other automated manufacturing systems."[45]

Finally, across a broader spectrum of industries, including the automotive and special-industry machinery industries (for example, machine tools), the linkage of ever more powerful and cheaper computing technology with manufacturing processes has made possible the vertical *dis*integration of both the design and manufacture of components previously made in-house. A leading trade publication recently reported that two of the world's biggest automobile manufacturers now "outsource" as much as 70 percent of their production of components to smaller companies.[46] Typically, competition among these suppliers for contracts from larger firms is intense. This generates additional motivation to cut labor requirements by introducing computer technology that lowers the number of relatively high-waged employees necessary to produce a given component or subassembly.

Consequences of high-tech change

While technological change is eliminating jobs in civilian R&D-intensive manufacturing, it is simultaneously creating a very large pool of new employment in R&D-intensive services. More importantly, we have seen evidence that it may be changing the composition of demand for high-tech workers, as well as the character of the work they perform.[47] The R&D of professional specialists in management consulting, for example, is quite different from what we usually picture when we think of high technology. These workers do not wear lab coats, nor do they do applied physical research for manufacturing firms.

As organizational theorists have noted repeatedly in recent years,[48] the new type of development of products and processes of management consulting specialists—a development that nevertheless has a feature instantly recognizable as common to all R&D activity—is to *take existing knowledge* about how organizations carry out their missions *and fashion it into more efficient organizational structures* for doing so. Fundamentally, whether the firm is a for-profit, nonprofit, or government entity, management consultants and researchers attempt to manage knowledge *about* knowledge, to improve their clients' organizational capabilities. And at least one set of researchers has argued forcefully that in high-tech goods production, organizational structure, more so than the technical breakthroughs that R&D workers produce, provides the salient difference in the competitiveness of firms, both domestically and internationally.[49]

However, our discussion of occupational employment trends was an imprecise way of analyzing recent and future demand for high-tech workers. Because we chose only the four-digit components of three-digit industries in which total employment either grew or remained static over the January 1988–January 1996 interval, we omitted trends in the three-digit R&D-intensive manufacturing industries identified by Hadlock, Hecker, and Gannon that *lost* employment over that time. It is important to note that the Bureau of Labor Statistics expects all of these industries to continue to increase output and shed jobs over the next decade.[50] In light of their increasing use of automation and transfer of relatively labor-intensive production work to subsidiaries offshore and subcontractors at home, will their demand for high-tech workers fall along with production employment? If so, what will be the effect on the capacity of these industries to generate innovations? These questions bear directly on the global demand for U.S.-made high-tech goods and on the developmental trajectory of the U.S. economy in the long term.

No direct evidence exists about R&D workers as such, but, as we stated earlier,[51] there is empirical support for the belief that in manufacturing at large, the introduction of new technologies is associated with *increased* demand for skilled workers.[52] These findings support the hypothesis that a process of "skill-biased technical change" is occurring in American manufacturing and, by extension, in high-tech manufacturing. Ernst Berndt, Catherine Morrison, and Larry Rosenblum, for example, found positive correlations at the industry level between expenditures on high-technology capital goods (for example, computers) and the educational attainment of workers.[53] Eli Berman, John Bound, and Zvi Griliches obtained similar results.[54] But the most recent and direct evidence pertaining to skill-biased changes in the occupational structure of high-tech manufacturing gives a conflicting picture. In cross-sectional analyses of 358 plants, researchers from the Census Bureau's Center for Economic Studies found that the more technologically advanced establishments relied more heavily on educated workers, employed a higher fraction of workers in skilled occupations, and had higher proportions of college-educated workers in their employee mix.[55] In a separate time-series analysis of plants that survived across the 1977-to-1992 interval, however, these same researchers indicate that the direction of causality may be the other way—that is, that "the adoption of new technologies is more likely to occur in plants with skilled workforces."[56]

Some of the lack of clarity about the effects of technology on the R&D intensity of occupational employment in manufacturing may have to do with technologically driven changes in our definition of the term "skill." For example, U.S. firms in the R&D-intensive automotive, electronics, industrial equipment, and instruments sectors have recently adopted an organizational regime called "lean manufacturing."[57] Pioneered originally by the Japanese, this process has a dimension that is crucial to the aforementioned debate: firms require production workers to be "flexible," rather than intensively specialized in a narrow function or set of skills. A report by the McKinsey Global Institute notes that the latter characteristic is often disparaged by managers in a lean manufacturing environment, because they believe that it fosters rigidity and "compartmentalization" on the assembly line, thereby undermining productivity.[58]

One recent firsthand account describes the effect of lean production on the skill mix of workers in U.S.-based (but Japanese-owned) automobile manufacturing plants.[59] Productivity increased in these plants after the replacement of more traditionally "skilled" production workers with "integrated workers" who have few recognizable skills other than the general physical and mental dexterity that allows them to fit easily into different "teams" with rapidly changing tasks. Managers were reported to have little regard for the educational or vocational qualifications of prospective workers, outside of their aptitude and enthusiasm for the work team concept and practices.

It seems clear that the movement of "flexible" production employees into jobs once occupied by traditionally skilled workers—those who were adept at performing one task or operating one machine in the manner of Adam Smith's pin factory or Henry Ford's early assembly lines—is a manifestation of skill-biased technical change, albeit of a different character than that envisioned by those who have researched the issue so far. Although it may be several steps removed from the final product, Moore's law is present even in autos and highly specialized fields like special-industry machinery, in which retail prices (and, presumably, unit production costs) still tend to rise as the quality of final outputs increases. Not only can the design and production of *final goods* in these industries be simplified through computerization, but so can the design and production of *the machines that make the final goods*, and so on. Technological advance thus makes available to managers increasingly powerful and more inexpensive computing technology, enabling an array of "lean" strategies for cutting production costs, which further spurs competition. As we have said, these strategies include automation, exporting jobs, and outsourcing, all of which reduce employment and redefine the skilled production worker as a worker whose social skills and natural dexterity matter more than specialized training.

Because much of the specialized work of translating product design into more easily assembled commodities is, and will continue to be, assisted by computers, some analysts believe that the near-term result of this progression will be the so-called soft factory. This locus links computer and data-processing service providers with high-tech manufacturers who have adopted PC's as both labor-saving and "labor-enhancing" technologies. For many of these firms, software—and, by implication, *the high-tech workers in R&D-intensive industries who design and integrate the software into production systems*—is now more important in manufacturing than is hardware.[60] Today, human workers utilize custom software in PC networks to do an increasing share of simple "mass-customized" assembly of components using data on consumer preferences relayed directly from customers, through sales offices, to factory-floor PC's. One prominent electronics manufacturer uses an assembly line staffed by 40 workers to turn out custom orders for 27 different products simultaneously, specifications for which are entered into the computer network by telephone sales operators hundreds or thousands of miles away.[61] Although this stage in the evolving relationship between robots and human workers may translate into greater demand for computer- and statistically literate production workers,[62] those workers may not be required to possess specialized technical skills. Instead, if lean manufacturing takes hold throughout the high-tech sector, they will be required to have the more general capacity of being able to move, think, and—most important—*learn quickly,* as their companies respond to rapidly changing market conditions.

Other things equal, then, the progression of these forces undergirds our earlier assertion that demand will continue to increase for R&D workers in computer and data-processing services, management consulting, and nonphysical research. As the scope of these workers' activities widens, and their linkages with high-tech manufacturing firms become more numerous, the learning-by-doing inherent in any specialized activity will tend to enhance the innovative capacity of the providers of these R&D-intensive services. In high-tech manufacturing industries in which employment is falling, however, job loss among production workers will at best tend to hold down the growth of workers engaged in R&D. But because R&D workers will continue to have more powerful research technologies at their disposal, if the absolute number of such workers in these industries decreases over time, it is not a foregone conclusion that their innovative capacity will decline as well. In short, R&D-intensive firms will tend to remain that way.[63] But the "creative destruction"[64] of technological change occurring within R&D-intensive industries will undoubtedly constrain our predictions about other developments. □

Footnotes

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[1] This argument is most often attributed to Joseph Schumpeter; see his *Theory of Economic Development* (Cambridge, MA, Harvard University Press, 1934). But it is strongly implied, if not explicitly stated, in the works of Adam Smith, Karl Marx, and Alfred Marshall, among others.

[2] See E. J. Malecki, *Technology and Economic Development: The Dynamics of Local, Regional, and National Change* (Essex, England, Longman Scientific and Technical, 1991). The Massachusetts Division of Employment Security employed a definition that identified 20 industry groups as high-technology industries based on the perceived degree of technical sophistication of their products. (See R. Vinson and P. Harrington, *Defining high technology industries* (Boston, Massachusetts Department of Manpower Development, 1979.) Also, R. McArthur, "Replacing the concept of high technology: towards a diffusion-based approach," *Environment and Planning A*, vol. 22, no. 6, 1990, pp. 811–28; *Technology, innovation, and regional economic development* (Congressional Office of Technology Assessment, United States Congress, 1984); and W. B. Stohr, "Regional innovation complexes," *Papers of the Regional Science Association*, vol. 59, 1986, pp. 29–44, all proposed broad and intuitively appealing conceptual definitions, but the authors acknowledged that the definitions were difficult to measure.

[3] 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.

[4] Paul Hadlock, Daniel Hecker, and Joseph Gannon, "High technology employment: another view," *Monthly Labor Review*, July 1991, pp. 26–30. An early study by the U.S. International Trade Administration identified high-technology sectors as those in which at least 10 percent of the work force was composed of scientists, engineers, or technicians and at least 10 percent of sales was spent on research and development of new products or processes (*An assessment of U.S. competitiveness in high technology industry* (U.S. Department of Commerce, U.S. International Trade Administration, 1983)). In a later variant of Riche, Hecker, and Burgan's analytical strategy, Ann Markusen, Peter Hall, and Amy Glasmeier produced a widely cited classification of high-technology industries using 1984–85 data from the BLS Occupational Employment Statistics program to calculate the percentage of R&D employment across all three-digit manufacturing industries (Ann Markusen, Peter Hall, and Amy Glasmeier, *High-Tech America: The What, How, Where, and Why of the Sunrise Industries* (Boston, Allen and Unwin, 1986)). In their study, engineers, technicians, computer scientists, life and physical scientists, and mathematicians made up all R&D employment. These researchers identified 29 three-digit industries in which R&D employment exceeded the 1980 national average of 5.8 percent for all manufacturing.

[5] Hadlock, Hecker, and Gannon, "High technology employment," p. 26. Ten industries—namely, those in which the number of R&D employees was at least equal to the average for all industries surveyed—were termed "R&D moderate."

[6] Steve J. Davis and John Haltiwanger, "Wage Dispersion Between and Within U.S. Manufacturing Plants, 1963–1986," in *Brookings Papers on Economic Activity, Microeconomics* (Washingtons, Brookings Institute, 1991), pp. 115–20.

[7] For instance, in one R&D center funded by the textile industry, engineers and computer scientists are currently at work on a project aimed at automating the design, cutting, and fitting of garments for retail customers.

This project uses the latest in laser and computer technology. (See Richard Lipkin, "Fit for a King," *Science News*, May 18, 1996, pp. 316–17.)

[8] See Malecki, *Technology and Economic Development*; and Markusen, Hall, and Glasmeier, *High-Tech America*.

[9] "SIC" abbreviates "Standard Industrial Classification"; see *Standard Industrial Classification Manual* (Executive Office of the President, Office of Management and Budget, 1987).

[10] *Employment and Earnings*, May 1996, p. 192.

[11] See, for example, E. Appelbaum, "High tech and the structural employment problems of the 1980s," in E. L. Collins and L. D. Tanner, eds., *American Jobs and the Changing Industrial Base* (Cambridge, MA: Ballinger Publishing Co., 1984), pp. 23–48; *Technology, innovation, and regional economic development*; P. Haug's two articles, "U.S. high technology multinationals and silicon glen," *Regional Studies*, vol. 20, 1986, pp. 103–16, and "The location decisions and operations of high technology organizations in Washington State," *Regional Studies*, vol. 25, pp. 525–41; An assessment of U.S. competitiveness, D. Lyons, "Agglomeration Economies Among High-Technology Firms in Advanced Production Areas: The Case of Denver/Boulder," *Regional Studies*, vol. 29, in press; and Markusen, Hall, and Glasmeier, *High-Tech America*.

[12] L. E. Browne, "High technology and business services," *New England Economic Review*, July/August, 1983, pp. 5–17; John U. Burgan, "Cyclical behavior of high-tech industries," *Monthly Labor Review*, May 1985, pp. 9–15; E. J. Malecki, "High technology and local economic development," *Journal of the American Planning Association*, vol. 50, 1984, pp. 260–69; and Riche, Hecker, and Burgan, "High technology today and tomorrow" all examined employment in computer and data-processing services, along with the predecessors of engineering and architectural services and research and testing services in the 1972 SIC scheme, namely, research laboratories, SIC 7391; engineering, architectural, and surveying services, SIC 891; and noncommercial educational, scientific, and research organizations, SIC 892.

[13] See Norman Saunders, "Defense spending in the 1990's—the effect of deeper cuts," *Monthly Labor Review*, October 1990, pp. 3–15; and "Employment effects of the rise and fall in defense spending," *Monthly Labor Review*, April 1993, pp. 3–8. The Division of Monthly Industry Employment Statistics of the Current Employment Statistics program currently aggregates employment in the three industries mentioned, plus five others–explosives (SIC 2892), ordnance and accessories, n.e.c. (SIC 348), shipbuilding and repairing (SIC 3731), radio and TV communications equipment (SIC 3663), and tanks and tank components (SIC 3795). The Division then adjusts the aggregated result for seasonal variation on a monthly basis, as a longitudinal record of defense-dependent employment in the United States. Ordnance and accessories, and tanks and tank components (the latter as part of SIC 379, miscellaneous transportation equipment) appeared on Hadlock, Hecker, and Gannon's list of "R&D moderate" high-tech industries. Analysts from the Division of Monthly Industry Employment Statistics stress that, because not all employment in these industries is defense related, and because defense-related output shares have fallen along with defense expenditures since 1987, this data series (and its individual components) represent *overall* employment trends in industries whose main customers have historically been related to the Department of Defense.

[14] Exhibit 2 presents this decomposition. On the civilian side, we excluded miscellaneous chemical products (SIC 289) and communications equipment (SIC 366) because they contained two four-digit defense-dependent components with a 40-percent defense output share in 1987: explosives (SIC 2892) and radio and TV communications equipment (SIC 3663). Despite these exclusions, our distinction between defense-dependent and civilian R&D-intensive high-tech manufacturing industries captures all but a relatively small percentage of the employment shifts in R&D-intensive high-tech manufacturing industries attributable to recent changes in the Nation's defense priorities.

[15] Burgan, "Cyclical behavior."

[16] Dale Whittington, *High Hopes for High-Tech* (Chapel Hill, NC, University of North Carolina Press, 1985).

[17] These are the 30 industries identified by Hadlock, Hecker, and Gannon, minus miscellaneous petroleum and coal products (SIC 299) and services, n.e.c. (SIC 899), for which there were no publishable data. We chose January 1988 as the starting point for our analysis because 1987 revisions to the SIC system took effect at that point. These revisions created several new industrial classifications, notably in services (for example, research and testing services, SIC 873), that Hadlock, Hecker, and Gannon identified as R&D-intensive industries.

[18] With regard to its importance as a source of technical innovation in the U.S. economy over the last half century, the influence of defense expenditures on employment in high-tech industries has not been thoroughly documented. (See Malecki, *Technology and Economic Development*.) Saunders ("Defense spending in the 1990s" and "The rise and fall in defense spending") researched the national employment effects of reductions in defense expenditures, irrespective of the technological intensity of the industries in which the reductions occurred. Other studies of defense-dependent industries have been carried out primarily in the fields of economic geography and regional development. For example, both Annalee Saxenian ("The genesis of Silicon Valley," *Built Environment*, vol. 9, no. 1, 1983, pp. 7–17) and R. W. Wilson, P. K. Ashton, and T. P. Egan (*Innovation, Competition, and Government Policy in the Semiconductor Industry* (Lexington, MA, Lexington Books, 1980)) documented a rise in Federal research and procurement spending for experimental electronic devices during the Cold War that was concomitant with the development of the microelectronics industry in Silicon Valley. In a similar vein, R. A. Barff and P. L. Knight ("The role of Federal military spending in the timing of the New England employment turnaround," *Papers of the Regional Science Association*, vol. 65, 1988, pp. 151–66) and R. F. Ferguson and H. F. Ladd ("Massachusetts," in R. S. Foster, ed., *The New Economic Role of American States* (New York and Oxford, Oxford University Press, 1988) explored the relationship between the economic "rebirth" of New England during the 1980s, centered around Boston, and the growth of firms that produced missiles, computers, and communications equipment for the military. Markusen, Hall, and Glasmeier (*High-Tech America*) researched the post-World War II effects of defense expenditures on the geography of U.S. manufacturing, and post-Cold War changes in the regional distribution of defense employment have been examined by, for example, Yolanda Kodryzcki ("The Costs of Defense-related Layoffs in New England," *New England Economic Review* (March/April 1995) and B. Warf and A. K. Glasmeier ("Military Spending, the American Economy, and the End of the Cold War," *Economic Geography*, 1992, pp. 103–223).

[19] This is consistent with our knowledge that the Nation's health care sector—in both its high-tech and "low-tech" (for instance, home health care) manifestations—has continually created more new jobs than high-tech industry in general has ever been able to do. For example, with one exception (during the recession of 1974–75), employment growth in drugs manufacturing has been virtually uninterrupted since 1964. (See Stephen Heffler, "Drugs manufacturing: a prescription for jobs," *Monthly Labor Review*, March 1995, pp. 12–22.) Additionally, medical instruments and supplies was the only manufacturing industry within instruments and related products (SIC 38) that had employment gains between 1983 and 1988. (See James C. Franklin, "Industry output and employment projections to 2005," *Monthly Labor Review*, November 1995, pp. 45–59.)

[20] And the share of total nonfarm employment held by R&D-intensive industries would have remained roughly constant, dipping from 8.1 percent to 7.9 percent.

[21] Agricultural chemicals (SIC 287) grew by 1,200 employees, or 2.4 percent, but we excluded it from the four-digit analysis because there were no published four-digit components within the three-digit industry. Also, production worker data were unavailable for SIC 7372.

[22] *Survey of Current Business* (U.S. Department of Commerce, Bureau of Economic Analysis, various years).

[23] Ann Bartel and Frank Lichtenberg, "The Comparative Advantage of Educated Workers in Implementing New Technology," *Review of Economics and Statistics*, vol. 69, 1987, pp. l–11; and "Technical Change, Learning, and Wages," *Economics of Innovation and New Technology*, vol. 1, 1991, pp. 215–31.

[24] Daniel S. Hamermesh, *Labor Demand* (Princeton, NJ, Princeton University Press, 1993).

[25] See three papers presented at a conference titled "The Effects of Technology and Innovation on Firm Performance and Employment," Washington, May 1–2, 1995: Lutz Bellman and Tito Boeri, "Internal and External Creative Destruction: Determinants of Changes of Employment and Productivity"; Tor Jacob Klette and Svein Erik Forre, "Innovation and Job Creation in a Small Open Economy"; and Lia Pacelli, Fabio Rapiti, and Riccardo Revelli, "Employment and Mobility of Workers in Industries with Different Intensity of Innovation: Evidence on Italy from a Panel of Work-

ers and Firms."

[26] Bellman and Boeri, "Internal and External Creative Destruction."

[27] Brian Arthur, "Positive Feedbacks in the Economy," *Scientific American*, February 1989, pp. 92–99.

[28] Tor Jacob Klette, *R&D, Scope Economies, and Company Structure: A "Not-so-Fixed Effect" Model of Plant Performance*, Discussion Paper 120 (Oslo, Statistics Norway, 1994).

[29] See John R. Baldwin, Brent Diverty, and Joanne Johnson, "Success, Innovation, Technology, and Human Resource Strategies—an Interactive System." Paper presented at conference on "The Effects of Technology and Innovation," Washington, May 1–2, 1995; Klette and Forre, "Innovation and Job Creation"; and Bellman and Boeri, "Internal and External Creative Destruction."

[30] Pacelli, Rapiti, and Revelli, "Employment and Mobility of Workers," p. 19.

[31] See Mark Doms, Timothy Dunne, and Ken Troske, *Workers, Wages, and Technology* (U.S. Bureau of the Census, Center for Economic Studies, December 1995); C. Freeman, J. Clark, and L. Soete, *Unemployment and Technical Innovation* (London, Pinter, 1982); C. Freeman and L. Soete, *Technical Change and Full Employment* (Oxford, Basil Blackwell, 1987); and Marco Vivarelli, Rinaldo Evangelista, and Mario Pianta, "Innovation and Employment: Evidence from Italian Manufacturing." Paper presented at conference on "The Effects of Technology and Innovation."

[32] See *Displacement Spreads to Higher-Paid Managers and Professionals*, Summary 95–10 (Bureau of Labor Statistics, August 1995).

[33] As of 1990, 45 percent of employment in research and testing services (SIC 873) was defense dependent. (See Saunders, "The rise and fall in defense spending.")

[34] Neal H. Rosenthal, "The nature of occupational employment growth: 1983–93, *Monthly Labor Review*, June 1995, pp. 45–54.

[35] All figures quoted are from the "moderate" case of the Bureau's occupational employment projections for 1994–2005.

[36] See George T. Silvestri, "Occupational employment to 2005," *Monthly Labor Review*, November 1995, pp. 60–84.

[37] *Ibid.*

[38] Because the period we studied covered an entire business cycle, nontechnological factors (for example, cyclical fluctuations in market demand) also played a significant role. However, some of these—like the emphasis on "flattened" management structures that has led to higher levels of job loss among managers and professionals than in the past—are arguably just as much the result of technological change as is job loss on the factory floor. For example, Baldwin, Diverty, and Johnson, "Success, Innovation, Technology, and Human Resource Strategies," note that layers of middle managers in Canadian high-tech firms who at one time collected and analyzed information about production and sales have been replaced by computer networks that link front-line supervisors with higher level decisionmakers.

[39] Three decades ago, Gordon Moore, one of the cofounders of the Intel Corporation, estimated that as the microelectronics revolution continued to advance, the amount of computing power available at a given price would double at a regular interval. One noted industry analyst and entrepreneur recently observed not only that this has occurred, but that the interval itself continues to shrink. It now stands at approximately 18 months (See Bill Gates, *The Road Ahead* (New York: Viking Press, 1995).)

[40] Don Clark, "All the chips: a big bet made Intel what it is today," *The Wall Street Journal*, June 7, 1995.

[41] See Franklin, "Output and projections."

[42] *Business Week*, Mar. 5, 1995.

[43] See Eli Berman, John Bound, and Zvi Griliches, "Changes in the Demand for Skilled Labor within U.S. Manufacturing Industries: Evidence from the Annual Survey of Manufacturing," *Quarterly Journal of Economics*, May 1994, pp. 367–98; and Rosenthal, "Occupational employment growth."

[44] *Occupational Outlook Handbook* (Bureau of Labor Statistics, 1994), p. 394.

[45] *Ibid.*

[46] *Fortune*, Oct. 3, 1994.

[47] See Schumpeter, *Theory of Economic Development*. Schumpeter called these related phenomena the process of "creative destruction" in capitalist economic development.

[48] See, for example, Peter Drucker, *Post-Capitalist Society* (New York: Harper Collins, 1995).

[49] Richard Florida and Martin Kenney, *The Breakthrough Illusion (New* York: Basic Books, Inc., 1990).

[50] Franklin, "Output and projections."

[51] Compare Hamermesh, *Labor Demand.*

[52] See John Bound and George Johnson, "Changes in the Structure of Wages in the 1980s: An Evaluation of an Alternative Explanation," *American Economic Review*, June 1992, pp. 371–92; Davis and Haltiwanger, "Wage Dispersion"; and Lawrence F. Katz and Kevin Murphy, "Changes in Relative Wages, 1963–1987: Supply and Demand Factors," *Quarterly Journal of Economics*, February 1992, pp. 1–34.

[53] Ernst Berndt, Catherine Morrison, and Larry Rosenblum, *High-Tech Capital Formation and Labor Composition in U.S. Manufacturing Industries: An Exploratory Analysis*, Working Paper 4010 (National Bureau of Economic Research, 1992).

[54] Berman, Bound, and Griliches, "Changes in the Demand for Skilled Labor."

[55] Doms, Dunne, and Troske, *Workers, Wages, and Technology.*

[56] *Ibid.*, p. 16.

[57] See Martin Kenney and Richard Florida, *Beyond Mass Production: The Japanese System and its Transfer to the U.S.* (Oxford, Oxford University Press, 1993); and James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World: The Story of Lean Production* (New York, Harper Collins, 1990).

[58] McKinsey Global Institute, *Manufacturing Productivity* (Washington, McKinsey and Co., 1993), especially chapter 2A, p. 8.

[59] Simon Head, "The New, Ruthless Economy," *New York Review of Books*, Feb. 29, 1996, pp. 47–52.

[60] Computer-aided design software, once relegated to relatively mundane drafting tasks, now allows manufacturing engineers to rapidly design, test, and make models and, in some cases, even "ride" in virtual simulations of prototype vehicles prior to their manufacture.

[61] See Baldwin, Diverty, and Johnson, "Success, Innovation, Technology, and Human Resource Strategies"; *Fortune*, Nov. 14, 1994; and *Business Week*, Mar. 6, 1995.

[62] *The Wall Street Journal*, Sept. 8, 1995.

[63] Cited on page 18 in the form "accumulating knowledge involves positive feedback," this observation is reminiscent of Brian Arthur's insight about "path dependence" among large firms with increasing returns: "the bigger you are, the bigger you get." (See Arthur, "Positive Feedbacks in the Economy.") More to the point in this instance, "the more innovative you are, the more innovative you become."

[64] Schumpeter, *Theory of Economic Development.*