Changes in the Demand for Skilled Labor within U.S. Manufacturing: Evidence from the Annual Survey of Manufacturers

Author(s): Eli Berman, John Bound and Zvi Griliches

Source: *The Quarterly Journal of Economics*, May, 1994, Vol. 109, No. 2 (May, 1994), pp. 367-397

Published by: Oxford University Press

Stable URL: https://www.jstor.org/stable/2118467

CHANGES IN THE DEMAND FOR SKILLED LABOR WITHIN U. S. MANUFACTURING: EVIDENCE FROM THE ANNUAL SURVEY OF MANUFACTURES*

ELI BERMAN
JOHN BOUND
ZVI GRILICHES

This paper investigates the shift in demand away from unskilled and toward skilled labor in U. S. manufacturing over the 1980s. Production labor-saving technological change is the chief explanation for this shift. That conclusion is based on three facts: (1) the shift is due mostly to increased use of skilled workers within the 450 industries in U. S. manufacturing rather than to a reallocation of employment between industries, as would be implied by a shift in product demand due to trade or to a defense buildup; (2) trade- and defense-demand are associated with only small employment reallocation effects; (3) increased use of nonproduction workers is strongly correlated with investment in computers and in R&D.

INTRODUCTION

As has been well documented, skill differentials rose sharply over the 1980s. Current Population Survey (CPS) data show that earnings differentials between high-school and college graduates rose by more than ten percentage points over the decade. Occupational differentials also rose. The Employment Cost index shows that between 1979 and 1989, the earnings differential between operatives on the one hand and managers and professionals on the other rose by ten percentage points, while the differential between laborers and operatives rose by four. While the increase in skill differentials has been well documented (e.g., Murphy and Welch [1989, 1992]; Bound and Johnson [1991]; Katz and Murphy [1992]), there is no consensus as to its explanation. Part of the widening educational differential can be attributed to a slowdown in the rate of growth of the college-educated population accompanied by continued growth in the demand for educated labor

*We have benefited from the comments of seminar participants at the University of Michigan, the University of Illinois, the University of Maryland, McMaster University, the Massachusetts Institute of Technology, and the NBER Labor Studies sessions and from comments on previous drafts by Jacob Mincer, Charles Brown, and an anonymous referee. We would like to thank Donald Siegel, Wayne Gray, Matthew Shapiro, and Frederic Scherer for providing data, John Horn and Shawn Chen for providing capable research assistance, and Cynthia Glovinsky and Carol Crawford for help in preparation of the manuscript. We would also like to acknowledge the financial support of the National Science Foundation and the Bradley Foundation.

The Quarterly Journal of Economics, May 1994

[Murphy and Welch 1989; Katz and Ravenga 1989; Katz and Murphy 1992; Katz, Loveman, and Blanchflower forthcoming], but the source of this growth in demand remains unexplained.

In the research reported here we rely on data drawn from the Annual Survey of Manufactures (ASM), the Census of Manufactures and the NBER trade data set to examine possible explanations for skill upgrading within U. S. manufacturing. To date, most work done on the widening of skill differentials has used CPS data. Unlike the CPS, the ASM contains information on outputs and nonlabor inputs. We use information on these inputs and the detailed classification of industries by output to evaluate alternative explanations for skill upgrading.

ASM data reveal a trend increase in the share of nonproduction labor in total employment consistent with the CPS evidence on skill upgrading. This increase accelerated during the 1980s. Between 1979 and 1989 the employment of production workers in U. S. manufacturing dropped by *15 percent* from 14.5 to 12.3 million, while nonproduction employment rose 3 percent from 6.5 to 6.7 million. Given the rise in the relative wages of nonproduction workers that occurred over this period, these dramatic shifts in utilization suggest shifts in labor demand within manufacturing away from production and toward nonproduction labor. Perhaps the most plausible explanations for such shifts are increased international competition and production-labor-saving technological change, both of which could be expected to decrease the (domestic) demand for production labor. Other possible explanations are the defense buildup and the severe recession of the early 1980s.

To preview our results, we find that less than one-third of the shift of employment from production to nonproduction workers can be accounted for by "between-industry" shifts, i.e., a reallocation of production away from those manufacturing industries with high shares of production workers in their workforce to those with low shares. We are able to attribute many of these between-industry shifts to increased defense procurements and some to increased trade during the 1980s. Most of the shift to nonproduction employment occurred within (as opposed to between) four-digit manufacturing industries. These within-industry shifts are largely unrelated to imports or to defense procurements. Within our accounting framework we attribute the residual to production-labor-saving technological change. We find skill upgrading to be positively correlated with investment in computers and to R&D

expenditures. These results are consistent with Bureau of Labor Statistics (BLS) case studies, which report that new technologies have generally displaced production workers. We infer a predominant role for production-labor-saving technological change in explaining the shift of demand toward skilled labor in the 1980s.

The remainder of the paper is organized as follows. Section I documents trends in the composition of manufacturing employment and discusses possible explanations. Section II presents variance decompositions that gauge the potential importance of trade and defense in explaining these trends. In Section III we present evidence from industry regressions on the effect of various technological factors on the demand for nonproduction workers. Section IV reviews other evidence consistent with the emphasis we have put on technological change. Section V concludes the paper.

I. Trends within Manufacturing

A. The Move Toward Nonproduction Labor

Much of the work in this paper is based on data drawn from the ASM, which is a survey of manufacturing establishments sampled from those responding to the comprehensive Census of Manufactures (COM). The ASM collects data on total employment, total payroll, production worker employment, production worker hours, the value of shipments, and expenditures on new capital investment, energy, and materials. The information is reported for four-digit SIC industries. Data from the ASM were combined with price deflators to construct measures of the capital stock.[1]

The ASM classifies employment in two broad occupational categories: production and nonproduction workers. Production workers are "workers (up through the working foreman level) engaged in fabricating, processing, assembling, inspecting and other manufacturing." Nonproduction workers are "personnel, including those engaged in supervision (above the working foreman level), installation and servicing of own product, sales, delivery, professional, technological, administrative, etc." [U. S. Bureau of the Census 1986, p. D-16]. These categories apply only to operating plants. Roughly 7 percent of manufacturing employment

1. The original version of these data, covering the 1958–1976 time period, was developed as a joint project by the University of Pennsylvania, the Bureau of the Census, and SRI, Inc. These data were then updated and classified consistently by Wayne B. Gray at the NBER. Gray [1989, 1992] includes a detailed description of the data.

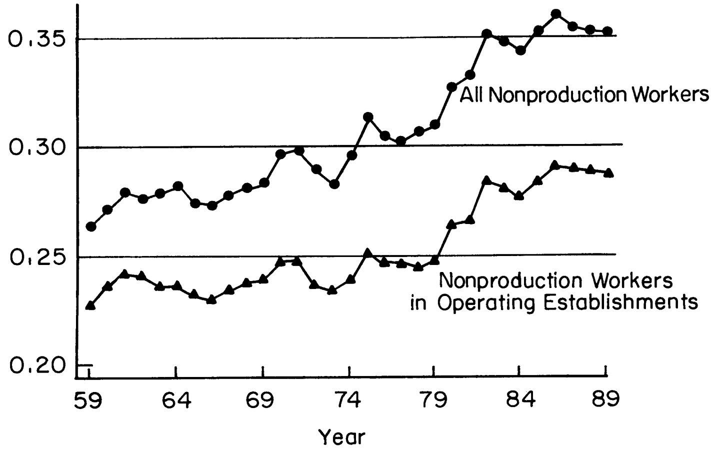

FIGURE I
Nonproduction Workers' Share in Total Employment

is in nonoperating plants (central offices and other auxiliary establishments) in which all employment is considered as nonproduction.[2]

Figure I plots nonproduction employment as a fraction of total employment in manufacturing. The top line represents the fraction of all nonproduction employment in employment, while the bottom line represents the fraction of nonproduction employment in operating establishments. This graph has three striking features. First, the fraction of employment that is nonproduction is countercyclical, since production employment is more cyclically sensitive than nonproduction employment. Second, abstracting from cycles, the fraction of nonproduction employment shows a clear upward

2. In recent years there has been an increase in the use of temporary employees provided by temporary service firms. Such workers are not included as part of the employment totals in the ASM. Thus, the apparent decrease in the employment of production workers in manufacturing might, to some extent, reflect the replacement of regular employees with temporary employees from temporary service firms [Uchitelle 1993]. A simple calculation based on information from the National Association of Temporary Services (NATS) reveals that increased use of temporary workers in manufacturing probably accounts for less than 5.2 percent of the increase in the share of nonproduction workers in total employment during the 1979–1987 period. Between 1979 and 1987 employment in the temporary help industry (SIC 7363) grew from 436.4 to 948.4 thousand [Steinberg 1993]. Data from NATS show that, as of 1992, roughly 22 percent of all temporary service workers were employed as production workers in manufacturing. These numbers imply that temporary workers as a share of production worker employment rose from about 0.66 percent in 1979 to 1.77 percent in 1987—a rise that was too small to account for more than a trivial fraction of the observed shift away from production labor.

trend. This trend occurs for both operating and auxiliary establishments. Third, the trend accelerates in the 1980s. Between business cycle peaks years 1959 and 1973, the ratio of nonproduction workers in operating establishments to total employment rose from 0.227 to 0.234 (0.05 percentage points per year); between 1973 and 1979 the ratio rose to 0.248 (0.23 percentage points per year); and from 1979 to 1989 it rose to 0.286 (0.38 percentage points per year).[3]

The increased fraction of nonproduction labor in employment will likely underrepresent the shift in demand toward skilled labor that occurred during the 1980s for two reasons. First, the increase in the relative wages of nonproduction workers that occurred during the 1980s would induce substitution away from nonproduction labor. Second, to the extent that skill upgrading occurs among either production or nonproduction workers, the increase in the nonproduction fraction will underestimate this shift toward more skilled labor. An alternative measure of the changes in the demand for skilled labor is the change in nonproduction labor's share in the wage bill. As long as the elasticity of substitution between production and nonproduction labor is above one, changes in the nonproduction share in the wage bill provide a better measure of the demand shift toward nonproduction labor during the 1980s, understating by less than changes in the employment share. Figure II replicates Figure I, using the fraction of the wage bill going to nonproduction labor rather than the fraction of employment. It shows the same pattern as that of Figure I which is a trend increase in the nonproduction share of wage bill with a sharp acceleration in the 1980s.

B. The Move Toward Nonproduction Labor as Skill Upgrading

Both conceptually and empirically, the production/nonproduction worker distinction closely mirrors the distinction between blue- and white-collar occupations. Table I compares CPS and ASM data for the years 1973, 1979, and 1987. Comparing the fraction nonproduction in the first line with the fraction white-collar in the second, we see that the two categories rise together from 1973 until 1987, with the discrepancy never more than two percentage points. The blue-collar/white-collar classification, in turn, closely reflects

3. Nonproduction employment in nonoperating establishments increased by 0.09, 0.20, and 0.04 percentage points per year, respectively. The move toward nonproduction labor slowed in the 1980s in nonoperating establishments, in contrast to the acceleration in operating establishments.

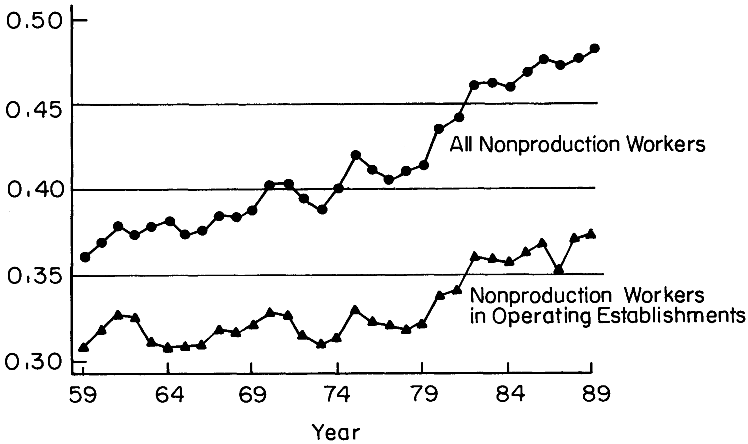

FIGURE II
Nonproduction Workers' Share in the Wage Bill

an educational classification of high school/college. Our tabulations based on CPS data show that, as of 1987 in manufacturing, only 17 percent of blue-collar workers had more than a high-school education, as opposed to 35 percent of clerical workers, 70 percent of sales workers, and 78 percent of managers and professionals.

The remaining lines of Table I show that occupational upgrading also occurred *within* both white- and blue-collar occupations. (Census classifications [U. S. Bureau of the Census 1989a] are used to construct consistent occupational groupings.) Between 1973 and 1987 the fraction of white-collar workers in clerical jobs dropped by 18 percent, while the fraction in managerial or professional jobs rose by 11 percent. Similarly, the fraction of blue-collar workers working as operatives dropped by over 5 percent, while the fraction working in the more skilled crafts jobs rose by over 20 percent.

In order to establish how much of skill upgrading is represented by the shift from blue- to white-collar occupations, we constructed skill indexes based on the occupational distribution of the workforce within manufacturing. To calculate these indexes, we regressed the log of hourly earnings on occupational category (as in Table I) indicators. Regressions were run separately for 1973, 1979, and 1987, and coefficients were then averaged. These regression coefficients were then applied to the 1973–1979 and 1979–1987 changes in the share of workers in each occupational group. The results are reported in the first two columns of Table II.

TABLE I
OCCUPATIONAL DISTRIBUTIONS WITHIN MANUFACTURING BY YEAR

	1973	1979	1987
Total nonproduction	28.3%	30.9%	35.4%
Percent in central offices	17.3%	19.7%	18.4%
White-collar	28.6%	31.9%	37.2%
Manager	27.0	27.0	29.4
Professional	18.8	19.9	21.5
Technician	8.7	9.0	9.0
Sales worker	7.3	7.5	8.8
Clerical worker	38.1	36.6	31.4
Subtotal	100.0	100.0	100.0
Blue-collar	71.4%	68.1%	62.8%
Craft	24.4	25.7	30.3
Operative	62.3	61.6	57.6
Laborer	9.8	9.5	9.0
Service worker	3.0	2.8	2.6
Agricultural labor	0.5	0.5	0.6
Subtotal	100.0	100.0	100.0

Source. Annual Survey of Manufacturing and CPS, May 1973, Outgoing Rotations, 1979 and 1987.

Fifty-three percent of the occupational upgrading that occurred between 1973 and 1987 is accounted for by shifts from blue- to white-collar occupations. The same calculation using single years of education rather than occupation groups as predictors yields a figure of 27 percent. We conclude that a large part, though not all,

TABLE II
SKILL UPGRADING WITHIN MANUFACTURING

	Occupation		Education	
	1973–1979	1973–1987	1973–1979	1973–1987
Total	2.50	6.33	4.34	9.31
White-collar	1.57	4.58	4.27	9.34
Blue-collar	0.77	2.19	2.83	5.58
Within	1.03	2.97	3.30	6.81
% Between	59%	53%	24%	27%

Source. CPS, May 1973, Outgoing Rotations, 1979 and 1987.
Note. Numbers represent 100 times the increase in predicted log hourly earnings with coefficients generated by a regression of log earnings on occupational category indicators (as in Table I) for columns 1 and 2 and single years of education for columns 3 and 4. Regressions are run separately in 1973, 1979, and 1987, and coefficients are averaged across years.

of the skill upgrading that occurred in manufacturing during the 1980s can be accounted for by the shift to white-collar or nonproduction labor. This wage metric also shows more skill upgrading among white-collar than among blue-collar workers. By examining the increase in the nonproduction proportion of the wage bill rather than its proportion of employment, we may capture part of the skill upgrading within the nonproduction category as well.

C. Possible Explanations for the Move Away from Production Labor

What can explain the shift away from production labor in the 1980s? Given the increased relative costs of skilled labor during the 1980s, substitution effects should have worked in the opposite direction. Figure III compares employment trends with trends in output, capital, and materials. The graph shows that capital, materials, and output grew at roughly similar rates; while employment, especially of production workers, grew much more slowly. Since, as Figure III shows, aggregate capital intensity as measured by the capital/output ratio did not rise appreciably during this period, it seems unlikely that capital skill complementarity [Griliches 1969, 1970] can explain the observed shifts in labor demand. On the other hand, the figure does show that inputs (primarily labor) grew less rapidly than output, suggesting labor-saving technological change.

Other technology indicators are also consistent with an accelerating pace of technological change during the 1980s. BLS data

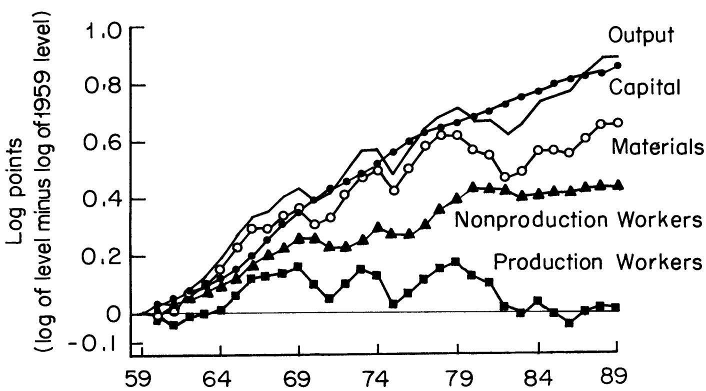

FIGURE III
Output and Inputs in Manufacturing

TABLE III
POSSIBLE CONTRIBUTORS TO THE INCREASED RELATIVE DEMAND FOR SKILLED LABOR

	1959	1973	1979	1987
R & D expenditures as a fraction of manufacturing shipments				
Total	2.6	2.4	2.2	3.9
Privately funded	1.6	0.9	0.7	1.3
Government funded	1.1	1.5	1.5	2.6
Share of high tech capital in total manufacturing capital stock				
Total	1.0	1.4	3.3	6.9
Computing eq.	0.3	0.2	0.5	2.3
Communications eq.	0.2	0.3	0.6	2.2
Scientific eq.	0.5	0.6	1.3	1.2
Photocopy eq.	0.0	0.3	1.0	1.2
Imports and exports as a fraction of manufacturing shipments				
Exports	4.5	8.4	10.6	10.7
Imports	4.2	8.2	12.3	17.3
Department of Defense purchases as a fraction of manufacturing shipments				
Purchases	5.9	2.1	2.0	4.2

Source. Rows 1–3, National Science Foundation [1991] and ASM; Rows 4–8, unpublished tabulations, Bureau of Economic Analysis; Rows 9–11 National Income and Products Accounts and ASM.

reveal that multifactor productivity [Gullickson and Harper 1987] in manufacturing rose by 1.6 percent per year between 1979 and 1988, 40 percent faster than in the previous twenty years. Table III shows that R&D expenditures rose, as did expenditures on "high tech" capital such as computers and communication equipment.[4] A 1988 Census Bureau survey shows a large fraction of manufacturing establishments using a variety of innovative computer-aided technologies. BLS industry case studies suggest that these new technologies have often involved the loss of semiskilled jobs [Mark 1987].

However, there were also other forces at work during the 1980s that could also have worked to shift the composition of the demand for labor within manufacturing. Table III shows the dramatic opening of the American economy over the last twenty years. The United States has typically imported goods that are

4. For a description of how these data were constructed, see Gorman et al. [1985] and Musgrave [1986].

intensive in less-skilled (production) labor (e.g., apparel) and exported goods that are intensive in skilled (nonproduction) labor (e.g., aircraft), so an increase in trade will tend to decrease the demand for production labor and increase the demand for nonproduction labor. Moreover, U. S. companies are carrying out an increasing amount of production abroad. Even within specific industries this "foreign outsourcing" is likely to have disproportionate effects on less skilled labor for two reasons. First, production but not development can be moved abroad. Second, we might expect the more production-labor-intensive operations to be moved abroad in order to take advantage of low foreign wages for less skilled workers.

Defense Department procurements also rose dramatically during the 1980s, from 2.0 percent of total shipments in manufacturing in 1979 to 4.2 percent in 1987 (Table III). Defense-related industries tend to employ a disproportionate share of nonproduction workers, particularly with the emphasis put on high tech weapons during the 1980s. Thus, increases in procurements may have shifted manufacturing employment from production to nonproduction workers.

Aggregate time series data will not allow us to evaluate the various possible explanations for the increased share of nonproduction employment in manufacturing. In what follows, we exploit disaggregated data at the four-digit industry level in two ways. In the following section we decompose shifts in the nonproduction share of employment and the wage bill into within- and between-industry shifts in order to examine the importance of demand shift explanations. Then, in Section III we examine the causes of changes in the nonproduction shares within four-digit industries by applying regression analysis to cross-sectional variation in the growth of these shares.

II. Industry-Sector Decomposition

A. Within/Between Decompositions

Among the explanations offered for the shift in employment toward nonproduction workers, the increase in international trade and the military buildup would work primarily by shifting the derived demand for labor between industries from those intensive in production workers to those intensive in nonproduction workers. On the other hand, biased technological change would shift the skill composition of labor demand within industries. For this reason, a decomposition of the increase in the nonproduction fraction of total employment (or the wage bill) into shifts that occur within and between industries is a useful indicator of the source of changes in labor demand.

A standard way of decomposing a change in an aggregate proportion into a term reflecting reallocation of employment between industries and another reflecting changes of proportions within industries is as follows:

$$\Delta P_n = \sum_i \Delta S_i \overline{P}_{n_i} + \sum_i \Delta P_{n_i} \overline{S}_i, \tag{1}$$

for $i = 1, \ldots, N$ industries. $P_{n_i} = E_{n_i}/E_i$, is the proportion of nonproduction labor in industry i, $S_i = E_i/E$, is the share of employment in industry i. The first term on the right reports the change in the aggregate proportion of nonproduction workers attributable to shifts in employment shares *between* industries with different proportions of nonproduction workers. The second term reports the change in the aggregate proportion attributable to changes in the proportion of nonproduction workers *within* each industry. A bar over a term denotes a mean over time.

Table IV reports between and within decompositions of both the proportion of nonproduction employment and of their share in the wage bill. Here and for the remainder of the paper we restrict our attention to labor employed in operating establishments.[5] We focus on changes between business cycle peak years, 1959–1973, 1973–1979, and 1979–1987. The line labeled total in each block contains the annual rate of increase in the share of nonproduction workers in both employment and in the wage bill for each period. A comparison of the rates in different periods shows that both in employment and in the wage bill, the move toward nonproduction labor *accelerated* over time, as we saw in Figures I and II. The shift toward nonproduction employment occurred at a rate of 0.069 percentage points per year in 1959–1973 and increased to 0.299 points per year in 1973–1979 and then to 0.552 points per year in 1979–1987. The line above the total change in share reports the between and within components. *Note that the within-industry component dominates the between in each period.* The within

5. The ASM does not classify the 7 percent of workers in nonoperating establishments into four-digit industries.

TABLE IV
INDUSTRY/SECTOR DECOMPOSITIONS OF THE RISE IN THE SHARE OF NONPRODUCTION WORKERS

	Employment		Wage bill	
	Between	Within	Between	Within
		1959–1973		
Imports	0.007	−0.001	0.005	−0.001
Exports	0.010	0.002	0.012	0.003
Domestic consumption	−0.026	0.076	−0.035	0.067
	−0.009	0.078	−0.018	0.069
Total		0.069		0.051
		1973–1979		
Imports	0.001	−0.006	−0.007	−0.002
Exports	0.021	0.007	0.028	0.004
Domestic consumption	0.089	0.186	0.064	0.206
	0.112	0.187	0.085	0.208
Total		0.299		0.293
		1979–1987		
Defense	0.072	0.014	0.101	0.004
Imports	0.029	−0.002	−0.024	−0.006
Exports	0.019	0.014	0.035	0.014
Domestic comsumption	0.044	0.361	0.193	0.456
	0.165	0.387	0.306	0.468
Total		0.552		0.774

Note. A calculation for the defense sector is possible only for the 1979–1987 period. Its contribution in earlier periods is included in domestic consumption. All calculations have been annualized.

component accounts for 0.387 of the 0.552 percentage point per annum increase in the nonproduction share of employment in the 1979–1987 period and for almost all of the acceleration between the 1970s and the 1980s. This finding is consistent with biased technological change playing a dominant role in explaining the increased share of nonproduction employment. It is not consistent with a dominant role for factors that shift product demand such as trade or the defense buildup.

The same patterns emerge for wage bill shares. Most of the increase in nonproduction labor's share occurs within rather than between four-digit industries, and this trend accelerates in the final period. One difference worth noting is that during the 1979–1987 period, between-industry shifts play a relatively larger role in the wage bill decomposition. This indicates that the between-industry reallocation that did occur was to nonproduction-intensive industries that use relatively highly paid and presumably highly skilled labor.[6]

In order to investigate the effect of trade and the defense buildup on the shift in demand for skills, we further decompose within- and between-industry terms into "sectors," where the sectors of interest are imports, exports, and defense procurements.

Conceptually, employment in each industry i can be allocated into four sectors: domestic consumption (C), exports (X), imports (M), and defense (D). As in the national accounts, imports replace employment in other sectors so

$$E_i = E_i^X - E_i^M + E_i^D + E_i^C. \tag{2}$$

In the calculation below, this allocation is performed by assuming that employment in each industry sector is proportional to its output, for which we have data. The standard within-between industry decomposition of equation (1) can now be developed into a sectoral within-between decomposition. (A detailed derivation is presented in the Appendix.) The between term can be decomposed to reflect the effect on the aggregate proportion of reallocation between industry sectors as follows:

$$\sum_i \Delta S_i \overline{P}_{n_i} = \sum_i \Delta S_i^X(\overline{P}_{n_i} - \overline{P}_n^C) + \sum_i \Delta S_i^M(\overline{P}_{n_i} - \overline{P}_n^C) + \sum_i \Delta S_i^D(\overline{P}_{n_i} - \overline{P}_n^C) + \sum_i \Delta S_i^C(\overline{P}_{n_i} - \overline{P}_n^C). \tag{3}$$

S_i^J are the shares of industry sector i-J in aggregate employment. In this accounting exercise the working assumption is that reallocations of employment are made to and from a residual pool of labor in the domestic consumption sector C with proportion of nonproduction workers $\overline{P}_n^C$ ($\overline{P}_n^C = \Sigma_i\, S_i^C \overline{P}_{n_i} / \Sigma_i\, S_i^C$). For example, an increase in the employment share of the defense aerospace industry will increase the aggregate proportion of nonproduction workers by the product of the change in the employment share ΔS_i^D and the degree

6. A decomposition based on a more aggregated three-digit classification yields similar results. Aggregating industries increases the relative importance of the within component of the decomposition, especially if there are large differences in labor utilization within three-digit industries. At the four-digit level the between component explains 39 percent (30 percent) of the shift in the wage bill (employment) share, while at the three-digit level of aggregation this drops only slightly to 37 percent (27 percent for employment). At the two-digit level there is a bigger shift to 15 percent (13 percent for employment). Thus, distinctions between three-digit industries within two-digit industries appear to be more important than those between four-digit industries within three-digit industries. Detailed results are available from the authors.

to which aerospace is more nonproduction-intensive than the general consumption sector $(\overline{P}_{n_i} - \overline{P}_n^C)$. Summing over all industries gives the contribution of defense-related reallocations to skill upgrading.

The within-industry change term in (1) can also be decomposed into sectors:

$$(4)\quad \sum_i \Delta P_{n_i}\overline{S}_i = \sum_i (\Delta P_{n_i} - \Delta P_n^C)\overline{S}_i^X + \sum_i (\Delta P_{n_i} - \Delta P_n^C)\overline{S}_i^M + \sum_i (\Delta P_{n_i} - \Delta P_n^C)\overline{S}_i^D + \sum_i (\Delta P_{n_i} - \Delta P_n^C)\overline{S}_i^C + \Delta P_n^C.$$

Each industry-sector term $(\Delta P_{n_i} - \Delta P_n^C)\overline{S}_i^J$ in this decomposition expresses the contribution of ΔP_n in sector J of industry i to the general increase in the aggregate P_n. Industry sectors with skill upgrading faster than that of the C sector have positive contributions; the others have negative contributions. The assumption inherent in this form is that if $\overline{S}_i^J$ had been different, employment would have been allocated to (or from) a use with $\Delta P_n^C \times [\Delta P_n^C = (\Sigma_i\, \overline{S}_i^C \Delta P_{n_i} / \Sigma_i)\, \overline{S}_i^C]$, the average for the domestic consumption sector. We sum these terms over all industries for each sector to measure the contribution of a sector to the within-industry variation. The fourth summation in equation (4), $\Sigma_i\, (\Delta P_{n_i} - \Delta P_n^C)\overline{S}_i^C$, is equal to zero.

We decompose changes in nonproduction workers' share in the total wage bill analogously. We sum 450 industries in each of the four sectors to obtain the four between terms of equation (3) and the four (nonzero) within terms of equation (4). They are reported in Table IV.

The source of import and export data is the NBER Trade-Immigration-Labor Market data set [Abowd 1991].[7] Shipments to the Department of Defense are from the Survey of Manufacturers'

7. It extends the Bureau of Labor Statistics Trade Monitoring System data set for 1972–1981, based on official trade statistics export and import data are available for 432 of 450 industries representing 98 percent of output. We imputed 0's for the other 18. The last year for which the NBER trade data exist is 1984. Changes in the classification of imports after this date have made it hard to update these data any further. In our tabulations we extrapolated the data linearly through 1987, estimating 1987 imports as a fraction of shipments in an industry as $8/5 \times (i/y_{1984} - i/y_{1979}) + i/y_{1979}$. A similar extrapolation was done for exports. To check that our results for the decompositions were not unduly influenced by these imputations, we redid the calculations for the 1979–1984 period and obtained results very similar to those reported in Table IV.

Shipments to the Federal Government, a sample of manufacturing plants conducted occasionally in the ASM framework.[8]

Breaking the between-industry component down by sectors in the 1979–1987 period, we see that for employment (column 1) the largest sectoral increase is in defense, which accounts for 0.072 percentage points. Imports and exports together account for 0.048 points, and the domestic consumption sector (the residual) accounts for 0.044 points. Surprisingly, the role of trade in shifting employment away from production-labor-intensive industries is quite small. The wage bill decompositions show similar patterns, though here the tabulations show imports actually lowering the nonproduction workers' share during the 1979–1987 period.[9]

Turning to the within-industry component of ΔP_n in the 1979–1987 period, the second column reports the contributions of each sector to within-industry skill upgrading. The domestic consumption term accounts for 93 percent (0.361 of the 0.387 points) of skill upgrading, reflecting its weight in aggregate demand for manufactures. The small positive term for defense indicates that skill upgrading occurred slightly faster in industries with large defense sectors than in the domestic consumption sector. But this upgrading matters little for the aggregate since the defense sector itself is small. The same is true for export and import sectors. The main conclusion from this sectoral analysis is that the domestic consumption sector accounts for almost all of within-industry skill upgrading and indeed for most of the skill upgrading overall. This conclusion holds for the earlier periods as well. *Most of the change and most of the acceleration in both P_n and S_n is due to within-industry skill upgrading unrelated to either trade or defense sectors.*

Since the move away from production workers occurred no

8. Sampling is conducted in approximately 70 four-digit industries engaged heavily in contracting for the Federal Government [U. S. Bureau of the Census 1981, 1991]. They account for the vast bulk of procurement. One problem with these data is that subcontracts to the Department of Defense, representing roughly one-third of all procurements, are not separately identified. Such subcontracts are double counted, resulting in an overestimate of total defense procurements of about 30 percent.

9. The switch in signs on the import term may seem odd. During the 1980s imports were displacing workers in both production-worker-intensive industries (e.g., apparel) and nonproduction-worker-intensive industries (e.g., electronics). The displacement of workers in the production-worker-intensive industries serves to raise the nonproduction worker share in total employment, while the displacement of workers in the nonproduction-worker-intensive industries works in the opposite direction. The wage bill decompositions put relatively more weight on the more highly paid, nonproduction-worker-intensive industries.

more rapidly in defense or trade sectors than in the rest of manufacturing, it is hard to believe that either the defense buildup or the increase in imports that occurred during the 1980s can explain the dramatic shift away from production workers. We are not arguing that the defense buildup and the increase in imports played no role in explaining observed shifts in labor utilization in manufacturing. For example, there is evidence that the overseas production of electronic components decreased domestic demand for production workers in some sectors of the electronic industry [Alic and Harris 1986; U. S. International Trade Commission 1982, 1988]. However, the decompositions imply that the bulk of the skill upgrading that occurred within manufacturing industries during the 1980s cannot be accounted for by overseas production of labor-intensive goods. Detailed calculations using information on the use of intermediate goods produced overseas support this view [Berman, Bound, and Griliches 1993].

III. Cross-Sectional Comparisons

A. Estimates of the Nonproduction Share Equation

We found in the previous section that skill upgrading *within* industries accounted for most of the increase in the share of nonproduction labor in employment and wages. To further explore factors that might explain these within-industry changes in the nonproduction labor's share in the wage bill, it is natural to turn to a regression format. It is possible to put much of what we do into a cost function framework. This is a natural approach as it puts the within-industry variation in shares on the left-hand side of a regression which estimates the parameters of a cost function.

We follow Brown and Christensen [1981] in deriving the share equation of a quasi-fixed cost function. Assume that the cost function has a translog form, firms minimize costs in choosing inputs, and returns to scale are constant. We choose to estimate the share equation in the quasi-fixed form, as it allows capital to be treated as a fixed factor and because we have no reliable price deflator for the capital stock. The additional assumption necessary is that the variation in the quantities of the variable labor inputs comes from firms constrained in the short term in their choice of capital levels. We can then derive the following "share" equation [Berman, Bound, and Griliches 1993] in first differences for the change in the share of nonproduction wages in total wages (variable costs):

$$(5) \qquad dS_{n_j} = \beta_0 + \beta_1 d \ln (W_{n_j}/W_{p_j}) + \beta_2 d \ln (K_j/Y_j) + \epsilon_j,$$

where n and p indicate nonproduction and production labor, respectively; j indexes industry; W_n and W_p represent the wages of nonproduction and production workers, respectively; K represents capital; and Y represents value added. β_1 will be positive or negative according to whether the elasticity of substitution between production and nonproduction labor is below or above one. Capital-skill complimentarily implies that $\beta_2 > 0$. β_0 is a measure of the cross-industry average bias in technological change while $\beta_0 + \epsilon_j$ represents the industry-specific bias. The equation for dS_{p_j} is redundant.

Three remarks are worth making about the specification before turning to the results. First, while Y represents value added, in the empirical work we use shipments instead. Our reason for doing so is entirely pragmatic. Good price deflators for materials do not exist at the four-digit level. This makes it impossible to construct reliable real value added measures.[10]

Second, it is not plausible to treat relative wages as exogenous. In fact, there may be no useful exogenous cross-sectional variation in changes over time in relative wages. While some of the variation may be due to different skill mixes of labor in different industries, some of it probably involves within-industry skill upgrading. In other words, price changes are confounded with quality changes. Furthermore, given the definitional relationship between our dependent variable (changes in the nonproduction workers' share in the wage bill) and the wage measures, estimates will suffer from a version of division bias. However, on the assumption that the price of quality-adjusted production and nonproduction labor does not vary across industries $d \ln (W_{n_j}/W_{p_j})$ will be a constant. Thus, ignoring relative wages, as we do, will affect the constant term in our equations but nothing else.

Third, there is a possible endogeneity bias in the estimation of (5) due to correlation between factors that affect both investment in plant or equipment and unexplained changes in the nonproduc-

10. As an alternative, we tried explicitly including materials as a third-variable factor. The estimate of the elasticity of substitution between materials and nonproduction labor was almost exactly the same as that of the elasticity between materials and production labor. The implication of these estimates is that while changes in the price of materials might cause substitution toward or away from labor, such changes will not affect the relative utilization of production and nonproduction labor.

tion share ϵ_j. Since planning horizons for new investments are presumably a couple of years in length, this endogeneity bias would not be too severe if we were using annual data. While we focus on changes that occur over six to fourteen years, results based on annual data are not qualitatively different from the ones we report.

We weight these regressions by the industry's average share in the total manufacturing payroll over each period.[11] Doing so implies that our dependent variable aggregates to the within-industry changes in the decompositions reported in Table IV. Weighting also serves to reduce noise in the data due to the periodic redrawing of the sample and the migration of firms between industries (see Siegel and Griliches [1992]). This noise is particularly evident in small industries.[12]

Table V reports summary statistics for (logarithmic) rates of change in the three subperiods. The means reproduce what we have seen already: annual growth in the share of wages paid to nonproduction labor accelerated over time, rising from 0.07 percentage points per year during the 1960s to 0.21 points per year during the 1970s and to 0.47 points per year during the 1980s. The growth rate of output dropped over time, from 3.9 percent per year during the 1960s to 1.7 percent per year in the 1980s, while capital accumulation dropped from 4.2 percent per year in the 1960s to 2.8 percent per year in the 1980s. Capital intensity increased at about the same rate in the 1980s as it did in the 1970s, an increase due to the high growth rate of equipment.

In Table VI we combine the three periods, including dummy variables for the second and third time period. Thus, we estimate coefficients using the cross-sectional variation (of growth rates) in the data. The first of the five specifications includes only the two time period dummies; the second includes $d \ln (K/Y)$ as well; the third separates $d \ln (P/Y)$ and $d \ln (E/Y)$ entered separately; while

11. Averaged over 1959 and 1973 for the 1959–1973 change, 1973 and 1979 for the 1973–1979 change, and over 1979 and 1987 for the 1979–1987 change.

12. We have experimented with alternative dependent variables—the change in nonproduction workers' share in total employment and the change in the log of the ratio of nonproduction to production worker employment. Results using these alternative dependent variables are very similar to those reported here. We also experimented with two alternative samples. We tried eliminating the 57 "nec" industries whose fourth digit was a nine. These industries are the ones most likely to have firms migrate into and out of them. Also, to the extent that we match data from other sources with this ASM data set, these matches are often not possible for four-digit nec industries. We also tried eliminating the four-digit computer industry (SIC 3573). The computer industry shows growth in output unmatched by any growth in inputs. One plausible explanation for this phenomenon is that input and output deflators have not been correctly matched. In both cases, results for the smaller samples were very similar to the results we report.

TABLE V
MEAN RATES OF CHANGE OF INPUTS

	1959–1973	1973–1979	1979–1987
$d\,S_N$	0.069	0.208	0.468
$d \ln (K)$	4.201	3.127	2.807
$d \ln (P)$	3.662	1.916	1.361
$d \ln (E)$	4.670	3.868	3.493
$d \ln (Y)$	3.892	2.115	1.694
$d \ln (K/Y)$	0.309	1.012	1.113
$d \ln (P/Y)$	−0.230	−0.200	−0.333
$d \ln (E/Y)$	0.778	1.753	1.800

Source. Authors' tabulations based on the Annual Survey of Manufacturing.
Sample. 450 four-digit manufacturing industries.
Notes. Data weighted by average share of industry wage bill in manufacturing.

Variable	Description
$d\,S_N$ = 100 × annual change in nonproduction workers' share of wage bill.	
$d \ln (K)$ = 100 × the annual change in the log of the capital stock.	
$d \ln (P)$ = 100 × annual change in the log of plant.	
$d \ln (E)$ = 100 × annual change in the log of equipment.	
$d \ln (Y)$ = 100 × annual change in the log of real output.	
$d \ln (K/Y) = d \ln (K) - d \ln (Y)$.	
$d \ln (P/Y) = d \ln (P) - d \ln (Y)$.	
$d \ln (E/Y) = d \ln (E) - d \ln (Y)$.	

the fourth and fifth repeat the third and fourth but include output separately. The first column reproduces the familiar result that the change in wage bill share of nonproduction labor is higher in the second than in the first period, and even higher in the third (the acceleration). When the plant and equipment intensity variables are included, they explain about 10 percent of the accelerated move away from nonproduction labor, but when $d \ln (Y)$ is added, the capital and output variables together explain none of the acceleration. The estimated coefficients suggest capital-skill complimentarity in general and equipment skill complimentarity in particular, but capital accumulation is capable of explaining little of observed skill upgrading.[13]

Within industries, shifts away from production and toward nonproduction labor not explained by measured factors can be

13. For example, using the coefficients from column (3) in Table VI and the means from Table V, we calculate that changes in plant and equipment intensity account for 15 percent of the shift in the wage bill share that occurred during the 1979–1987 period.

TABLE VI
CHANGES IN THE NONPRODUCTION WORKERS' SHARE IN THE WAGE BILL, 1959–1973, 1973–1979, AND 1979–1987, COMBINED
(DEPENDENT VARIABLE: ANNUAL CHANGE IN NONPRODUCTION WORKERS' SHARE IN THE TOTAL WAGE BILL)

Equation	(1)	(2)	(3)	(4)	(5)
$d \ln (K/Y)$		0.014		0.038	
		(0.003)		(0.005)	
$d \ln (P/Y)$			−0.022		0.003
			(0.006)		(0.008)
$d \ln (E/Y)$			0.035		0.033
			(0.006)		(0.006)
$d \ln (Y)$				0.027	0.025
				(0.004)	(0.005)
1973–1979	0.139	0.129	0.105	0.160	0.150
	(0.035)	(0.035)	(0.035)	(0.035)	(0.036)
1979–1986	0.399	0.389	0.361	0.427	0.420
	(0.035)	(0.035)	(0.036)	(0.035)	(0.037)
Constant	0.069	0.065	0.037	−0.047	−0.052
	(0.025)	(0.025)	(0.025)	(0.030)	(0.031)
R^2	0.029	0.099	0.113	0.125	0.129
$\hat{\sigma}$	0.531	0.528	0.524	0.521	0.520

Source. Authors' tabulations based on the Annual Survey of Manufacturing.
Sample. 450 four-digit manufacturing industries.
Note. Equations weighted by average share of industry wage bill in manufacturing.

interpreted as representing biased technological change. (While this is not the only possible explanation for these results, we have seen that the most plausible alternative—foreign outsourcing—cannot explain the bulk of the observed change.) In the next section we present some direct evidence implicating technological change.

B. Indicators of Technological Change

Direct evidence of the impact of technological change on demand for skills in manufacturing is available at the industry level from two indicators: investment in computers and expenditures on research and development. The impact of computers on the workplace in the 1980s has been dramatic. BLS case studies reveal that computerization has played a part in most major innovations in the 1980s [Mark 1987]. Census of Manufactures

TABLE VII
THE IMPACT OF R&D INVESTMENTS AND COMPUTERS (DEPENDENT VARIABLE: ANNUAL CHANGE IN NONPRODUCTION WORKERS' SHARE IN THE WAGE BILL: 1979–1987)

	Mean	(1)	(2)	(3)	(4)
Computer/total investments					
1987	7.36%	0.028	0.032		0.025
		(0.006)	(0.007)		(0.006)
1977	2.69%		−0.013		
			(0.011)		
R&D/sales					
1974	1.82%			0.097	0.087
				(0.021)	(0.019)
R^2		0.420	0.425	0.420	0.496
$\hat{\sigma}$		0.496	0.496	0.496	0.496

Source. Authors' tabulations based on the Annual Survey of Manufacturing supplemented with information on computer investments drawn from the Census of Manufacturing and data on R&D expenditures kindly provided by Frederic Scherer.
Sample. 143 three-digit manufacturing industries.
Notes. Regressions weighted by average share of industry wage bill in manufacturing. All regressions include $d \ln (P/Y)$, $d \ln (E/Y)$ and $d \ln (Y)$. Mean of dependent variable is 0.00423.

figures reveal that the fraction of investment devoted to computers *tripled* between 1977 and 1987, from 2.8 percent to 7.5 percent. Berndt and Griliches [1993] find that the real price of microcomputers dropped by 28 percent *annually* between 1982 and 1988. The impact of computerization on the demand for skills depends on whether this form of capital complements or substitutes for skills. It is easy to think of examples either way: computerized sorting and handling replaces low skilled production workers in the newspaper industry, while computerized design replaces drafting personnel in the automobile industry.

In Table VII we report the result of adding computers as a share of total investments in 1987 to the share equation estimates of Table VI.[14] Since the data on R&D are available only at the three-digit SIC level, we have aggregated the wage bill share, capital stock, and computer investment numbers up to the three-

14. The data on investment in computers come from the Census of Manufactures, which asked questions about such investments in 1977, 1982, and 1987. Not all industries reported computer investments. Of our 450 industries, 169 failed to report any computer investments in 1977, as did 45 in 1982 and 35 in 1987. In the results reported we have treated these missing values as 0's. Correlations based on pairwise complete observations are very similar.

digit level.[15] While, ideally, we would like to have a measure of the change in the total stock of computer capital, such a measure cannot readily be derived from the available data. However, under the assumption that what varies across industries is the adaptability of different technologies to computerization, the cross-sectional variation in computers as a share of total investments should proxy for the variation in computers as a share of the total capital stock.[16]

The fraction of investment devoted to computers as of 1987 has a highly statistically significant positive coefficient. The estimated coefficient of 0.028 is also quantitatively large. In 1987 the average share of computers in total investments was 7.36 percent. Multiplying 7.36 by 0.028 gives 0.21, or over 40 percent of the shift that occurred in the wage bill share over this period. In the second column of Table VII, we include computer investments in 1977 as an additional variable to control for both initial levels of computerization and other preexisting differences across industries. Once the 1977 variable is included in the equations, the coefficient on the 1987 variable should be interpreted as the effect of increases in the share of computers in total investments over the 1977–1987 period. We see that the inclusion of the earlier variable has little effect on the coefficient on the 1987 variable.[17]

Another technological change indicator, R&D expenditures by three-digit SIC, is available for 1974. Scherer [1984] used data from the Federal Trade Commission's Line of Business Survey to calculate R&D expenditures by industry. We included in our regressions the estimated R&D expenditures as a fraction of 1974 shipments in that industry. Results from including the R&D measures in the share equations are reported in column (3) of Table VII. The variable picks up a both statistically and quantitatively significant effect. The coefficient of 0.097 suggests that a one-percentage-point increase in R&D expenditures increases the

15. Results using the computer investment variable at the four-digit level are quite similar to those we report [Berman, Bound, and Griliches 1993].

16. Since investment in computers grew rapidly over the 1980s, the share of computers in the capital stock in 1987 will also closely approximate the change in the share over the 1980s.

17. Note that computer investments are associated with declines in production labor employment, rather than increases in nonproduction employment. Using four-digit industries, we regressed the log of production and nonproduction employment on the log of capital intensity, the log of output, and the share of computers in total investments as of 1987. The coefficient on the computer variable was −0.20 (0.18) in the nonproduction worker equation and −0.45 (0.17) in the production worker equation. Thus, computers seem to be substitutes (not complements) for both production and nonproduction labor, but with the larger effect on production labor.

annual rate of change in S_n by roughly 0.10 percentage points. Using the average R&D intensity reported in the first column of Table VII, we calculate that R&D expenditures accelerated the shift away from production labor by about 0.18 percentage points per year, or just less than 40 percent of the total.[18] In column (4) we report the result of including both the computer and R&D measures in the same equation. Both variables pick up significant coefficients, and together they account for 70 percent of the move away from production labor.

These results support the notion that biased technological change has been an important contributor to within-industry skill upgrading. Regardless of the causal interpretation of coefficients in Table VII, it is clear that within-industry skill upgrading has occurred both in those manufacturing industries that invested heavily in computers during the 1980s and in those that are R&D intensive.

IV. Other Evidence

Other researchers have found evidence in favor of complementarity between educated or skilled labor and technological change [Welch 1970; Bartel and Lichtenberg 1987; Mincer 1989; Lillard and Tan 1986; Gill 1990]. However, on the whole, these authors have not tried to use cross-sectional relationships to explain the growth of skill differentials over the 1980s. Some recent work does explicitly examine the extent to which technological change might explain increases in the demand for skilled labor. Mincer [1991] reports on time series regressions in which he included both supply and demand measures. Mincer's estimates imply an important role for technology in explaining recent increases in the returns to education. At the same time, as Mincer acknowledges, the limited information available in time series raises questions about the robustness of the inferences drawn. In other work, Berndt, Morrison, and Rosenblum [1992] use the Bureau of Economic Analysis

18. The variable used is referred to by Scherer [1984] as R&D by *industry of origin*. Since most innovations are product rather than process innovations, productivity increases may accrue primarily to the industries in which the product is actually used. Scherer used patent data to map the R&D expenditures by *industry of origin* into R&D expenditures by *industry of use* to capture this effect. This *industry of use* measure did not perform as well. The estimated coefficient was smaller (0.021 versus 0.097) and standard error larger (0.044 versus 0.021). While the argument above suggests that R&D by *industry of use* is the appropriate variable, given the nature of the way this variable was constructed it may suffer from substantial measurement error, which would explain these results.

(BEA) data available by two-digit industries to examine the impact of investments in high tech capital on the demand for skilled labor. They regress the nonproduction share in total employment on a capital-intensity measure and a measure of the share of high tech capital in total capital. Their estimates imply both capital-skill complementarity and complementarity of high tech capital and skills.

More qualitative information supports the notion that production-labor-saving technological change has played an important role in explaining the decline in production workers' share in wages. Case studies conducted by the Bureau of Labor Statistics [Mark 1987; U. S. Department of Labor 1986, 1982a, 1982b; Alic and Harris 1986] on industries reporting large within-industry skill upgrading, such as aerospace, printing and publishing, electronic and micro-electronics almost uniformly implicate innovations that are production labor saving.[19] For example, in printing and publishing "electronic composition (is responsible for) shifting almost all composition and keyboarding to professional and clerical employees, bypassing typesetting employees altogether," and "bundling and handling machines drastically reduce labor requirements. . . ." In aerospace numerically controlled and computer numerically controlled machines, industrial robots, and flexible manufacturing systems are mentioned as "New production methods (which) are reducing requirements for a wide range of production workers while increasing the demand for highly educated and skilled professional and technological workers."

It is striking how often the BLS case studies written over the past decade mention the introduction of technologies that reduce unit labor requirements for production jobs. What is also striking is that the industries in which BLS finds little evidence of the introduction of such technologies (meat packing, tires and inner tubes, hosiery and bakery products) are industries that show little or no movement away from production workers [U. S. Department of Labor 1979, 1982a, 1984, 1986]. In meat packing, for example, an industry in which the fraction of the workforce in production jobs actually increased over the last three decades, the BLS report mentions the "difficulty in developing automated techniques that will accommodate the physical differences in carcasses being processed."

A 1988 survey of metals, machinery, electronics, transporta-

19. A summary of these studies is available from the authors on request.

tion, and instruments branches [U. S. Bureau of the Census 1989b] shows just how widespread is the use of computer-aided technologies. In establishments of 500 or more employees, 83 percent used computer-aided design (CAD) or computer-aided engineering (CAE), 70 percent used numerically controlled or computer numerically controlled machines, 36 percent used flexible manufacturing cells or systems, and 43 percent used robots. Dunne and Schmitz [1992] found that nonproduction worker's share in total employment was 2.5 percentage points higher in plants using three or more of these advanced technologies than in plants using none.[20]

If increases in the (relative) demand for skilled or educated labor are linked to technological change, we would expect this to occur not just in the United States, but also in other developed countries. Work by Machin [forthcoming] using British data finds results very similar to those we report. Machin finds that a significant shift away from manual toward nonmanual employment occurred in Britain during the 1980s. Most of this shift represented changes that occurred within (rather than between) industries and even within establishments. Machin found within-industry and within-establishment changes to be associated with various measures of innovative activity. Furthermore, he finds that, within nonmanual workers, innovations tend to shift employment away from clerical and toward managerial and professional workers. Similarly, within manual workers, innovations are associated with a move away from the unskilled toward the skilled and semiskilled.

V. Discussion

We have argued that biased technological change has been the major cause of skill upgrading in American manufacturing. While both the defense buildup and increased international trade no doubt caused some increase in the share of nonproduction employment, the magnitudes of these effects are not large enough to explain the bulk of observed skill upgrading. That argument implicates technological change by default. Furthermore, the strong correlations that within-industry upgrading has with both

20. Applying Dunne and Schmitz's [1992] reported coefficients on the technology variables (column 1, Table 6) to the means they report in Table 3 suggest that advanced technologies can explain at least 38 percent of the increase in nonproduction workers' share in employment in the 1979–1987 period.

R&D investment and the increase in computer investments provide direct evidence for the importance of biased technological change.

The results we have reported in this paper are restricted to the manufacturing sector. Blue-collar and less educated workers are overrepresented in manufacturing—as of 1987, 23 percent of those with not more than a high-school education, but only 14 percent of those with a college education were employed in manufacturing. Thus, the overall decrease in manufacturing's share in total employment would have decreased demand for less skilled (less educated) labor disproportionately in the economy as a whole even if the proportion of production workers in manufacturing had remained the same. Trade may have played a greater role in this overall decrease in the size of manufacturing than it did in the reallocation of employment within manufacturing.

What our results *do* imply is that the bulk of skill upgrading that occurred within manufacturing cannot be attributed to trade. This is striking for two reasons. First, as Murphy and Welch [1993] have argued, over 20 percent of the total skill upgrading that occurred over the 1980s occurred in manufacturing. Second, manufacturing is the branch of the economy for which trade and foreign outsourcing are most important. If trade and foreign outsourcing explain little of the skill upgrading that we observe here, it seems implausible that they can explain much skill upgrading in other branches.

We have not attempted to sort out whether the incentives to adopt new technologies changed in the 1980s. Increased foreign competition or a change in the regulatory environment may have played a role. Nor have we speculated on what effects computerization may have had on the demand for skills in the rest of the economy. The extent of computerization has actually been greater in services than it has in manufacturing.

It is interesting to put skill upgrading in the 1980s in a larger historical context. The Census of Manufactures shows a dramatic shift toward nonproduction employment during the 1950s as well, when their share in total employment rose by 10.5 percentage points (from 16.6 percent to 27.1 percent between 1947 and 1958). In that decade imports represented a small and stable fraction of manufacturing shipments, Defense Department procurements as a fraction of total shipments actually fell; capital intensity within manufacturing remained constant; and skill premiums rose in the face of rising supplies of college graduates [Becker 1975; Coleman

1993; Goldin and Margo 1992]. These trends support the notion that, historically, biased technological change has been an important source of increased demand for skilled labor. They also suggest that we avoid exaggerating the uniqueness of the computer revolution.

Appendix: Derivation of Industry-Sector Decompositions

Employment in industry i can be allocated into three final use components: exports, defense, and domestic civilian production:

$$E_i = E_i^X + E_i^D + E_i^{DC}. \tag{A1}$$

The employment attributable to domestic civilian consumption (as opposed to production) in the home economy can be written as the sum of domestic civilian production and import components:

$$E_i^C = E_i^{DC} + E_i^M, \tag{A2}$$

where the final term represents the employment that would be required to produce imported goods domestically. (The term, E_i^C, is analogous to C in the national accounts. It includes employment displaced by imports consumed domestically.) Substitution yields

$$E_i = E_i^X - E_i^M + E_i^D + E_i^C. \tag{2}$$

That is, employment is attributed to exports, defense, and domestic civilian consumption, less that portion of employment due to domestic civilian consumption which is employed abroad producing imports.

Assuming that employment and nonproduction employment in each sector of an industry are allocated in the same proportions as output in the sector, we use industry-specific data on shipments of import, export, and defense goods to estimate each of the components of equation (2). Specifically, we estimate E_i^X as $E_i \times$ (exports$_i$/output$_i$), E_i^M as $E_i \times$ (imports$_i$/output$_i$) and E_i^D as $E_i \times$ (defense output$_i$/output$_i$).[21] E_i^C is defined as the residual.

Employment shares for each industry in total employment can be expressed as

$$S_i = S_i^X + S_i^M + S_i^D + S_i^C, \tag{A3}$$

21. Data on employment in defense production is actually available in slightly more detail. It allows $E_i^D = \Sigma_k E_{i_k}$ (defense shipments$_{i_k}$/output$_{i_k}$), where k indexes plants in industry i.

where $S_i^J = E_i^J/E$ for $J = (X,D,C)$, $S_i^M = -E_i^M/E$ is defined as negative, and E represents total employment in manufacturing (i.e., $E = \Sigma_i E_i$).

The standard within-between industry decomposition of equation (1) can now be developed into a sectoral within-between decomposition. We can decompose the between term into sectors by differencing (A3) and substituting into (1):

(3)

$$\sum_i \Delta S_i \overline{P}_{n_i} = \sum_i \Delta S_i^X \overline{P}_{n_i} + \sum_i \Delta S_i^M \overline{P}_{n_i} + \sum_i \Delta S_i^D \overline{P}_{n_i} + \sum_i \Delta S_i^C \overline{P}_{n_i}$$
$$= \sum_i \Delta S_i^X (\overline{P}_{n_i} - \overline{P}_n^C) + \sum_i \Delta S_i^M (\overline{P}_{n_i} - \overline{P}_n^C)$$
$$+ \sum_i \Delta S_i^D (\overline{P}_{n_i} - \overline{P}_n^C) + \sum_i \Delta S_i^C (\overline{P}_{n_i} - \overline{P}_n^C).$$

The within-industry change term in (1) can be decomposed into sectors by averaging (A3) and substituting into (1):

$$(4) \quad \sum_i \Delta P_{n_i} \overline{S}_i = \sum_i \Delta P_{n_i} \overline{S}_i^X + \sum_i \Delta P_{n_i} \overline{S}_i^M + \sum_i \Delta P_{n_i} \overline{S}_i^D + \sum_i \Delta P_{n_i} \overline{S}_i^C$$
$$= \sum_i (\Delta P_{n_i} - \Delta P_n^C) \overline{S}_i^X + \sum_i (\Delta P_{n_i} - \Delta P_n^C) \overline{S}_i^M$$
$$+ \sum_i (\Delta P_{n_i} - \Delta P_n^C) \overline{S}_i^D + \sum_i (\Delta P_{n_i} - \Delta P_n^C) \overline{S}_i^C + \Delta P_n^C.$$

Both (3) and (4) approximate a more accurate decomposition that would be possible if $\Delta P_{n_i}^J$ rather than ΔP_{n_i} were available for each industry-sector term.

BOSTON UNIVERSITY AND THE NATIONAL BUREAU OF ECONOMIC RESEARCH
UNIVERSITY OF MICHIGAN AND THE NATIONAL BUREAU OF ECONOMIC RESEARCH
HARVARD UNIVERSITY AND THE NATIONAL BUREAU OF ECONOMIC RESEARCH

REFERENCES

Abowd, John, "Appendix: The NBER Trade and Labor Markets File," *Immigration, Trade and the Labor Market,* J. Abowd and R. Freeman, eds. (Chicago, IL: University of Chicago Press, 1991), pp. 407–21.

Alic, John A., and Martha Caldwell Harris, "Employment Lessons from the Electronics Industry," *Monthly Labor Review,* CIX (February 1986), 27–36.

Bartel, Ann P., and Frank R. Lichtenberg, "The Comparative Advantage of Educated Workers in Implementing New Technology," *Review of Economics and Statistics,* LXIX (February 1987), 1–11.

Becker, G. S., *Human Capital,* 2nd ed. (Chicago, IL: University of Chicago Press, 1975).

Berman, Eli, John Bound, and Zvi Griliches, "Changes in the Demand for Skilled Labor Within U. S. Manufacturing Industries: Evidence from the Annual Survey of Manufacturing," NBER Working Paper No. 4255, 1993.

Berndt, Ernst R., and Zvi Griliches, "Price Indexes for Microcomputers: An Exploratory Study," *Price Measurements and Their Uses: Studies in Income and Wealth,* Volume 57, Murray F. Foss, Marilyn E. Manser, and Allan H. Young, eds. (Chicago, IL: University of Chicago Press, 1993), pp. 63–93.
Berndt, Ernst R., Catherine J. Morrison, and Larry S. Rosenblum, "High-Tech Capital Formation and Labor Composition in U. S. Manufacturing Industries: An Exploratory Analysis," Paper presented in honor of Zvi Griliches' sixtieth birthday, Jerusalem, May 1991, NBER Working Paper No. 4010, 1992.
Bound, John, and George Johnson, "Changes in the Structure of Wages During the 1980s: An Evaluation of Alternative Explanations," *American Economic Review,* LXXXII (June 1992), 371–92.
Brown, Randall S., and Laurits R. Christensen, "Estimating Elasticities of Substitution in a Model of Partial Static Equilibrium: An Application to U. S. Agriculture, 1947 to 1974," *Modeling and Measuring Natural Resource Substitution,* Ernst R. Berndt and Barry C. Field, eds. (Cambridge, MA: MIT Press, 1981), pp. 209–29.
Coleman, Mary T., "Movement in the Earnings-Schooling Relationships," *Journal of Human Resources,* XXVIII (1993), 660–80.
Dunne, Timothy, and James A. Schmitz, Jr., "Wages, Employer Size-Wage Premia and Employment Structure: Their Relationship to Advanced-Technology Usage in U. S. Manufacturing Establishments," manuscript, Federal Reserve Bank of Minneapolis, 1992. *Econometrica,* forthcoming.
Gill, Indermit S., "Technological Change, Education, and Obsolescence of Human Capital: Some Evidence for the U. S.," mimeograph, State University of New York at Buffalo, 1990.
Goldin, Claudia, and Robert A. Margo, "The Great Compression: The Wage Structure in the United States at Midcentury," *Quarterly Journal of Economics,* CVII (February 1992), 1–34.
Gray, Wayne, "Productivity Database," NBER mimeo, 1989.
——, 'Upgrading Productivity Data Through 1989," NBER mimeo, 1992.
Gorman, John A., John C. Musgrave, Gerald Silverstein, and Kathy Comins, "Fixed Private Capital in the United States," *Survey of Current Business,* LXV (July 1985), 36–55.
Griliches, Zvi, "Capital-Skill Complementarity," *Review of Economics and Statistics,* LI (November 1969), 465–68.
——, "Notes on the Role of Education in Production Functions and Growth Accounting," *Education, Income and Human Capital: Studies in Income and Wealth,* 35, W. Lee Hansen, ed. (New York, NY: Columbia University Press for the National Bureau of Economic Research, 1970), pp. 71–114.
Gullickson, William, and Michael J. Harper, "Multifactor Productivity in U. S. Manufacturing, 1949–1983," *Monthly Labor Review,* CX (October 1987), 18–28.
Katz, Lawrence F., and Kevin M. Murphy, "Changes in Relative Wages, 1963–1987: Supply and Demand Factors," *Quarterly Journal of Economics,* CVII (February 1992), 35–78.
Katz, Lawrence F., and Ana Ravenga, "Changes in the Structure of Wages: The U. S. vs. Japan," *Journal of Japanese and International Economics,* III (1989), 522–53.
Katz, Lawrence F., Gary W. Loveman, and David G. Blanchflower, "A Comparison of Changes in the Structure of Wages in Four OECD Countries," *Differences and Changes in Wage Structures,* Richard B. Freeman and Lawrence F. Katz, eds. (Chicago, IL: University of Chicago Press, forthcoming).
Lillard, Lee A., and Hong W. Tan, *Private Sector Training: Who Gets It and What Are Its Effects* (Santa Monica, CA: The Rand Corporation, March 1986).
Machin, Stephen, "Changes in the Relative Demand for Skills in the UK Labor Market," *The Skills Gap and Economic Activity,* A. Booth and D. Snower, eds., forthcoming.
Mark, Jerome S., "Technological Change and Employment: Some Results from BLS Research," *Monthly Labor Review,* CX (April 1987), 26–29.
Mincer, Jacob, "Human Capital Responses to Technological Change in the Labor Market," NBER Working Paper No. 3207, 1989.
——, "Human Capital, Technology, and the Wage Structure: What Do Time Series Show?" NBER Working Paper No. 3581, 1991.

Murphy, Kevin M., and Finis Welch, "Wage Premiums for College Graduates: Recent Growth and Possible Explanations," *Educational Researcher,* XVIII (May 1989), 17–26.
Murphy, Kevin M., and Finis Welch, "The Structure of Wages," *Quarterly Journal of Economics,* CVII (February 1992), 285–326.
Murphy, Kevin M., and Finis Welch, "Industrial Wages and the Rising Importance of Skill," *Uneven Tides: Rising Inequality in America,* Sheldon H. Danziger and Peter Gottschalk, eds. (New York, NY: Russell Sage Foundation, 1993), pp. 101–32.
Musgrave, John C., "Fixed Reproducible Tangible Wealth in the United States: Revised Estimates," *Survey of Current Business,* LXVI (January 1986), 51–75.
National Science Foundation, *Selected Data on Research and Development in Industry: 1989,* principal author: John R. Gawalt (Washington, DC: National Science Foundation, 1991), mimeo, unpaged.
Scherer, Frederic M., "Using Linked Patent and R&D Data to Measure Interindustry Technology Flows," *R&D, Patents and Productivity,* Zvi Griliches, ed. (Chicago, IL: University of Chicago Press, 1984), Chapter 20, pp. 417–61.
Siegel, Donald, and Zvi Griliches, "Purchased Services, Outsourcing, Computers and Productivity in Manufacturing," *Output Measurement in the Service Sector: Studies in Income and Wealth,* Vol. 56, Zvi Griliches, ed. (Chicago, IL: University of Chicago Press, 1992), pp. 429–60.
Steinberg, Bruce, "The Temporary Help Industry, An Annual Update for 1992" (Alexandria, VA: National Association of Temporary Services, 1993); reprinted from *Contemporary Times* (Summer 1993).
Uchitelle, Louis, "Temporary Workers Are on the Increase in Nation's Factories," *New York Times,* July 6, 1993, Section A, p. 1.
U. S. Bureau of the Census, *Current Industrial Reports,* Shipments to Federal Government Agencies, 1980 (Washington, DC: U. S. Government Printing Office, 1981).
——, *1982 Census of Manufactures* (Washington, DC: U. S. Government Printing Office, 1986).
——, *The Relationship Between the 1970 and 1980 Industry and Occupation Classification Systems,* prepared by Paula L. Vines and John A. Priebe (Washington, DC: U. S. Government Printing Office, 1989a).
——, *Current Industrial Reports,* Manufacturing Technology 1988, prepared under the direction of Gaylord Worden (Washington, DC: U. S. Government Printing Office, 1989b).
——, *Census of Manufactures 1987, MC87-S-7, Subject Series,* Manufacturers Shipments to the Federal Government (Washington, DC: U. S. Government Printing Office, 1991).
U. S. Department of Labor, BLS. Bulletin 2033, "Technology and Labor in Five Industries: Bakery Products/Concrete/Air Transportation/Telephone Communication/Insurance," written under the supervision of Rose N. Zeisel and Richard W. Riche, by Gary E. Falwell (bakery), William C. Perkins (concrete), Gustav A. Sallas (air transportation), Michael D. Dymmel (telephone), and Gustav A. Sallas (insurance) (Washington, DC: U. S. Government Printing Office, 1979).
——, BLS. Bulletin 2104, "The Impact of Technology on Labor in Four Industries: Meat Packing/Foundries/Metalworking Machinery/Electrical and Electronic Equipment," written under the supervision of John J. Macut, Chief, Division of Technological Studies; Industry reports were written under the supervision of Richard W. Riche, and Rose N. Zeisel; Authors: Robert V. Critchlow (electrical and electronic equipment), Gary E. Falwell (meat products), Richard W. Lyon (foundries), and A. Harvey Belitsky (metal working machinery) (Washington, DC: U. S. Government Printing Office, 1982a).
——, BLS Bulletin 2137, "The Impact of Technology on Labor in Five Industries: Printing and Publishing/Water Transportation/Copper Ore Mining/Fabricated Structural Metal/Intercity Trucking." Written under the supervision of John J. Macut, Chief, Division of Technological Studies; Richard W. Riche; and Rose N. Zeisel. Final stages of preparation took place in Division of Industry Productivity Studies, Charles W. Ardolini, Chief. Authors: Robert V. Critchlow (printing/publishing, water transportation), Richard W. Lyon (copper), Charles

L. Bell (fabricated structural metal), and A. Harvey Belitsky (trucking) (Washington, DC: U. S. Government Printing Office, 1982b).

——, BLS Bulletin 2182, "The Impact of Technology on Labor in Four Industries: Hosiery/Folding Paperboard Boxes/Metal Cans/Laundry and Cleaning." Written under the supervision of Rose N. Zeisel and Richard W. Riche, by A. Harvey Belitsky (hosiery), Richard W. Lyon (folding paperboard boxes), Charles L. Bell (metal cans), and Robert V. Critchlow (laundry and cleaning). (Washington, DC: U. S. Government Printing Office, 1984).

——, BLS Bulletin 2242, "Technology and Its Impact on Labor in Four Industries: Tires/Aluminum/Aerospace/Banking." Written under the supervision of Rose N. Zeisel and Richard W. Riche, by A. Harvey Belitsky (tires), Richard W. Lyon (aluminum), Charles L. Bell (aerospace), and Robert V. Critchlow (banking) (Washington, DC: U. S. Government Printing Office, 1986).

U. S. International Trade Commission, *Summary of Trade and Tariff Information: Semiconductors,* Publication No. 841 (Washington, DC: U. S. Government Printing Office, 1982).

——, *Imports under Items 806.30 and 807.00 of the Tariff Schedules of the United States, 1984–1987,* Publication No. 2144 (Washington, DC: U. S. Government Printing Office, 1988).

Welch, Finis R., "Education in Production," *Journal of Political Economy,* LXXVIII (January/February, 1970), 35–59.