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THE GROWTH OF INFORMATION WORKERS IN THE U.S. ECONOMY, 1950-1990: THE ROLE OF TECHNOLOGICAL CHANGE, COMPUTERIZATION, AND STRUCTURAL CHANGE

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The Growth of Information Workers in the U.S. Economy, 1950-1990: The Role of Technological Change, Computerization, and Structural Change

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Abstract. This paper uses data from the U.S. Decennial Censuses of 1950 through 1990 to measure the growth of information workers in the U.S. economy and analyze the sources of their growth. There are three major findings. First, information workers increased from 37 percent of the workforce in 1950 to 55 percent in 1990. Second, using a decomposition analysis, I find that the growth in information workers was driven not by a shift in tastes toward information-intensive goods and services (as measured by the composition of final demand) but rather by a combination of the substitution of information workers for goods and service workers within the structure of production of industries and by the unbalanced growth effect -- that is, the slower productivity growth of the more information-intensive industries. Third, on the basis of econometric analysis, it is found that while technological change, as measured by the growth in total factor productivity, has a negative effect on the employment of information workers, the pace of new investment as reflected in the growth in the capital-labor ratio, R&D intensity, and the rate of computerization has a positive relation to the change in information employment.

JEL Codes: J21, O30, O51.

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Fritz Machlup's classic 1962 book, The Production and Distribution of Knowledge in the United States, found that with the growth of clerical occupations at the turn of the century, "the ascendancy of knowledge-producing occupations has been an uninterrupted process... a movement from manual to mental, and from less to more highly trained labor" (p. 396-7). Baumol, Blackman, and Wolff (1989, Chapter 7) updated these results to 1980, finding that information workers increased from about 42 percent of the workforce in 1960 to 53 percent in 1980, and Howell and Wolff (1993) found a further gain between 1980 and 1985.[1]

The paper is divided into three parts. The first updates the statistics on the composition of the workforce between information and non-information jobs to 1990. Particular interest in focused on the post-1980 period, which has seen a tremendous growth in the use of computers in production and which Freeman (1987) and others have termed a new "techno-economic paradigm," based on computer-driven information technology. For this analysis, I rely on matrices of employment by occupation and industry derived from the decennial U.S. Censuses of 1950, 1960, 1970, 1980, and 1990. The occupations are aggregated into four categories: (i) knowledge producers; (ii) data processors; (iii) service workers; and (iv) goods-processing workers. I find that information workers (the sum of the first two categories) increased from 37 percent of the workforce in 1950 to 55 percent in 1990, with the rate of increase for knowledge-producing workers accelerating in the 1980s, while that of data workers markedly slowing down.

The second part uses a decomposition analysis to break down the changes in the information workers' share of the labor force into three parts: (i) the substitution of information labor for labor of other types within the production process -- that is, the change in the proportion of information workers in each industry's labor force; (ii) the change in each industry's share of the economy's total output; and (iii) the change associated with relative variations in labor productivity of the different industries.

The first of these three components can be interpreted to indicate the extent to which the composition of the labor force in a typical industry has become more information-intensive (assuming all other things remain the same). The second element in our breakdown, output composition, relates to different industries' shares of the economy's total output and is pertinent in determining the extent to which the expansion in information-related employment is attributable to an increase in the economy's demand for products with a high information content. Finally, the productivity-growth component in our breakdown plays the part in testing the role of unbalanced growth in the information explosion -- that is, the extent to which growth of information workers can be attributed to relatively lower productivity growth in industries using more information. I find that the growth in information workers was driven not by a shift in tastes toward information-intensive goods and services (as measured by the composition of final demand) but rather by a roughly equal combination of the substitution of information workers for goods and service workers within the structure of production of industries and the unbalanced growth effect.

The third part relies on econometric analysis to analyze the sources of growth of information workers on the industry level. The dependent variables are the changes in knowledge, data, service, and goods-processing workers as a percent of total employment in the industry over the period. I use five measures of technological activity as independent variables: (1) average annual rate of total factor productivity (TFP) growth, (2) investment in office, computer and accounting machinery (OCA) over the previous 7 years per full-time employee; (3) ratio of expenditures on research and development to industry GDP; (4) the ratio of computer specialists and engineers to full-time employees; and (5) new investment in equipment per full-time employee. The regressions also control for a number of structural and organizational dimensions of production, such as the unionization rate, as well as indices of international competitiveness.

The strongest result is that computerization, as reflected in investment in OCA, has a strong positive effect on the relative growth in knowledge workers but a strong negative effect on the employment share of data workers. TFP growth, on the other hand, has a negative effect on the growth of knowledge workers but no significant effect on the growth of data workers, suggesting that technological change by itself tends to simplify tasks and thus reduce reliance on knowledge producers.

1. **Growth of Information Employment**

The basic data are from the U.S. Decennial Censuses of 1950, 1960, 1970 1980, and 1990. In the calculations, the figures in the Census tables of employment by occupation and industry were first aggregated, in conformity with an internally consistent classification scheme, into 267 occupations and 64 industries (see Howell and Wolff, 1991, for details). The occupations were aggregated once more into six categories:

(i) knowledge production,

(ii) data processing,

(iii) supply of services,

(iv) goods production,

(v) a hybrid class including both knowledge and data activities, and

(vi) a second hybrid class including both data and service activities.

I then (somewhat arbitrarily) divided those that fell into the hybrid knowledge/data category, classing half of them as knowledge workers and half as data workers and, in similar fashion, I have split the hybrid data/service category half into data and half into service workers. The resulting groups are referred to as the "total knowledge", "total data", and "total service" categories. Information workers were then defined as the sum of (total) knowledge and (total) data workers. The non-information category is composed of the residual, including (total) service and goods-processing workers.[2]

In the classification schema, professional and technical workers have generally been classified as knowledge or data workers, depending on whether they are producers or users of knowledge. The line is somewhat arbitrary at points, and judgment calls have been made. Moreover, in some cases, professional workers have been classified as data-service workers. For example, doctors and nurses were treated in this way, since they use information and also perform a personal service. Management personnel have been taken to perform both data and knowledge tasks, since they produce new information for administrative decisions and also use and transmit this information. Clerical workers were classed as data workers for obvious reasons. We have classified as goods-processing workers all labor that transforms or operates on materials or physical objects. These include craft workers, operatives (including transportation workers who move physical goods), and unskilled labor. The remaining group is made up of the service workers, who, primarily, perform personal services.

Table 1 gives a breakdown of total employment by type of worker from 1950 to 1990, the corresponding growth rates in each category, and the percentage composition.[3] Over the four decades, knowledge workers were the fastest growing of the group, increasing 3.1 percent per year. They were followed by data workers and service workers, each at 2.6 percent per year. In contrast, goods producers increased their number by only 0.3 percent per year. Altogether, employment of information workers grew 2.7 percent per year (one percentage point above average), while non-information workers increased 0.9 percent per year (about one point below average).

The developments differ by decade. Between 1950 and 1960, the fastest growing group was service workers, whose numbers grew by 3.2 percent per year, followed by data workers (2.6 percent per year) and knowledge workers (1.7 percent). Goods producers declined in absolute number. In the next decade, knowledge workers led the way, at 2.8 percent per year, followed by data workers (2.5 percent), and service workers (1.4 percent). The number of goods producers again fell in absolute terms.

The decade of the 1970s again saw knowledge workers with the highest growth rate, 4.5 percent per year, in this case followed by service workers (3.8 percent), data workers (3.6 percent), and goods-processing workers, whose employment increased in absolute terms, by 1.7 percent per year. During the decade of the 1980s knowledge workers again led all groups, at 3.3 percent per year, followed by data and service workers in a virtual tie, at 1.8 percent per year, and goods-processing workers, at 0.9 percent per year.

The last panel of Table 1 (as well as Figure 1) provides another way of viewing the growth of the information sector. In 1950, 8 percent of total employment consisted of knowledge workers and 29 percent of data workers. Altogether, 37 percent of the employed labor force was made up of information workers. Good workers formed a majority of total employment, at 52 percent, while service workers constituted only 12 percent of total employment. By 1990, the proportion of information workers in total employment had increased to 55 percent of the total. The number of knowledge workers had risen to 13 percent and that of data workers to 42 percent of total employment. Service workers were up to 16 percent and goods producers dramatically down to 29 percent.

In sum, knowledge workers grew as a share of total employment in each of the four decades and was the fastest growing group in all but the 1950s. However, its biggest increase in relative terms occurred during the 1980s, when its share of total employment increased by almost two percentage points. Data workers enjoyed their largest growth in relative terms during the 1950s and 1960s. There was a marked slowdown in the increase in their share of total employment in the 1970s, and during the 1980s there was virtually no change in their share. The share of service workers in total employment rose quite rapidly in the 1950s and 1970s while during the 1980s it experienced almost no change. The share of goods producers in total employment fell in every decade, and in the 1950s and 1960s its number declined in absolute terms as well.

2. **Industry Changes in Information Employment**

Since our subsequent analysis depends substantially on comparative shifts in the share of information workers among industries, we first examine the relative information-intensity of the various sectors of the major industrial groups of the economy. As shown in Table 2 and Figure 2, in 1990 the finance, insurance, and real estate sector; business and other services; and the government sector were in a virtual tie in having the highest percentage of knowledge workers in their employment, about 16 percent. The mining sector was next, at almost 15 percent, followed by manufacturing, construction, transportation, communications, and utilities, and trade, at 10 to 12 percent. Agriculture had the smallest percentage of knowledge workers -- only 4 percent. All told, service industries had a higher share of knowledge workers than goods-producing sectors -- 14 versus 11 percent.

There is more variation in the share of data workers among sectors. In 1990, the finance, insurance, and real estate sector led the way at 76 percent, and it was also the most information-intensive: about 90 percent of its employees were knowledge or data workers. The trade, business and other services, and government sectors were next in line, with between 45 and 53 percent of their employees in data-related occupations. In mining, construction, manufacturing, and transportation, communications, and utilities, data workers comprised between 19 and 36 percent of total employment. Agriculture is the least information-intensive, with only 6 percent of its employees in data jobs and 11 percent in information jobs. The share of data workers in total employment was twice as high in services as in goods industries.

There are also marked differences in time trends between goods-producing sectors and services. In the former, there was a steady rise in both knowledge workers and data workers as a share of total industry employment between 1950 and 1990. In manufacturing, in particular, information workers constituted 39 percent of total employment by 1990, up from 28 percent in 1950, and blue-collar production workers made up 59 percent, down from 70 percent in 1950 (service workers constituting the remainder). This result confirms the growing "white-collarization" of manufacturing in the U.S., often alluded to in the press.

Among service industries, there was generally a fall-off in the percentage of knowledge workers in employment between 1950 and 1960 (1970 in one case), followed by a steady rise through 1990. In contrast, data workers increased relative to total employment in all four service sectors between 1950 and 1960. In both trade and the government, there was a gradual decline in the share of data workers in total employment from 1960 to 1990; in finance, insurance, and real estate, the share remained relatively constant between 1960 and 1980 and then declined in 1990; and in business and other services, the share increased from 1960 to 1980 and then remained constant from 1980 to 1990. All told, between 1950 and 1990, information workers increased in number relative to non-information workers in all sectors except the government.

The growth in the overall share of information workers in total employment is due to two proximate causes. The first is technological change on the industry level which may favor information workers relative to non-information workers. This may be attributable to the increasing sophistication and complexity of productive techniques, which requires more producers, manipulators, and transmitters of knowledge. The second is shifts in the industrial composition of employment. In particular, industries more intensive in their use of information workers may have grown in terms of employment relative to industries which rely more heavily on service and goods-processing workers.

The second, in turn, can be further decomposed into two additional effects. The first of these is from changes in the composition of final output. In particular, an increasingly educated population may be demanding products with an ever increasing information content over time. The second of these may arise from differential movements in industry labor productivity.

In particular, from the unbalanced growth hypothesis, employment in activities with relatively slower rates of productivity growth must increase relative to employment in high productivity growth activities, even with constant output proportions (see, for example, Baumol, 1967, or Baumol, Blackman, and Wolff, 1989, Chapter 6). There may be some presumption that information-intensive industries, such as business services and the government, may suffer form relatively stagnant productivity growth.

We can address this issue formally through the use of an input-output model. First, define the following matrix and vector components:

X = column vector showing the total output (gross domestic output or GDO) by sector;

Y = column vector showing the final output by sector;

M = the employment matrix, where M_{ij} shows the total employment of occupation i in industry j;

L = a row vector showing total employment in industry j, where $L_j = \Sigma_i M_{ij}$;

B = a column vector of total employment by occupation, where $B_i = \Sigma_i M_{ij}$.

Let us now define the following coefficients:

a = the square matrix of interindustry input-output coefficients, where a_{ij} indicates the amount of input i required per unit of output j.

y = a column vector showing the percentage distribution of total fianl output by sector, where $y_i = Y_i/\Sigma Y_i$;

n = an employment distribution matrix, showing the percentage distribution of employment by occupation within each sector, where $n_{ij} = M_{ij}/L_j$;

m = the employment coefficient matrix, showing employment by occupation per unit of output, where $m_{ij} = M_{ij}/X_j$;

p = a row vector showing the percentage distribution of employment by sector, where $p_j = L_j/\Sigma L_j$;

ℓ = a row vector of labor coefficients showing total employment per unit of output, where $\ell_j = L_j/X_j$;

b = a column vector showing the percentage distribution of employment by occupation, where $b_i = B_i/\Sigma B_i$.

To derive the basic relationship, we can first express the matrix of occupational output-employment coefficients, m, in terms of the vector of industry labor coefficients, ℓ, obtaining

$$(1) \qquad m = n\hat{\ell},$$

where a hat (^) connotes a diagonal matrix whose elements are those of the associated vector (ℓ). It follows from the basic Leontief identity $X = (I - a)^{-1}$ and (1) that

$$(2) \qquad b* = m(I - a)^{-1}y,$$

where b* is the distribution of employment by occupation generated by the percentage output vector y. Then by (1) and (2)

$$b* = n\hat{\lambda}x,$$

where $\lambda = \ell(I - a)^{-1}$ and λ_i shows the direct and indirect labor requirements per unit of output i. We have, directly,

$$(3) \qquad \Delta b(y) = \Delta n\hat{\lambda}y/\Sigma b* + n(\Delta\hat{\lambda})y/\Sigma b* + n\hat{\lambda}\Delta y/\Sigma b*,$$

where b(y) is the percentage distribution of employment generated by the output vector y. This equation, then, decomposes a change in occupational composition of employment $\Delta b(y)$, into three parts:

(i) The first term corresponds to the change in the n_{ij}, the shares of the different occupations, by industry. In other words, this term reflects the extent to which production processes within industries have changed their techniques so as to substitute information labor for labor of other types. This term is referred to as the substitution effect.

(ii) The second term in (3) involves $\Delta\hat{\lambda}$, the change in the vector of quantities of direct plus indirect labor per unit of output, by industry -- that is, the change in the reciprocal of each industry's "total" labor productivity. I call this the productivity effect.

(iii) The final term involves the incremental change, Δy, in the shares of the total outputs of the different industries, which I call the (final) output effect.

If the last term turns out to be significant and substantial in an empirical calculation, this will imply that the growth in information employment is indeed attributable to an information revolution. For a large third term indicates that buyers are typically turning increasingly to outputs whose production has a large information content. The same may also be true, in part, of a large first term, which may indicate that a typical production process has increased in reliance on information labor. However, if the second term turns out to be substantial and significant it will suggest that a corresponding portion of the increase in share of information labor is attributable not to an upsurge in information use, but rather to unbalanced growth -- the shift of labor out of activities whose productivity growth is atypically large.

My primary data source consists of U.S. standard 87-order Bureau of Economic analysis input-output tables for years 1947, 1958, 1963, 1967, 1972, 1977, 1982, and 1987, which are used to compute the vector of final demand, Y, and the vector λ, which shows the direct and indirect labor requirements.[4] These data are aggregated to 47 sector to align with the occupation by industry matrices already described above.[5] Results of the decomposition are shown in Table 3.[6]

The substitution effect gained continuing strength over time as a source of growth of employment for knowledge workers (Panel 1). During the 1950s, in fact, the effect was negative, indicating that industries substituted other types of workers for knowledge workers in their industry employment. During the 1960s, this effect contributed 0.8 percentage points to the increase in the share of knowledge workers in total employment; in the 1970s, 1.1 percentage points;, and in the 1980s, 1.5 percentage points.

In contrast, the (differential) productivity effect is a diminishing source of growth for knowledge workers, accounting for 0.9 percentage points in the period 1950-60, 0.7 percentage points in 1960-70, 0.2 percentage points in 1970-80, and 0.4 percentage points in 1980-90. Differences in productivity growth between information-intensive industries and other industries fell considerably between the first two decades of the period and the last two, a reflection mainly of the sharp drop in overall productivity growth between the 1960s and 1970s. Changes in (final) output composition played virtually no role at all in the growth of the share of knowledge workers in the labor force. All told, about half the growth in this share over the four decades, 1950-90, was attributable to the substitution of knowledge workers for other types of workers within industry and the other half to the unbalanced growth effect.

Results for data workers differ with those for knowledge workers. The substitution effect was much stronger in the decades of the 1950s and 1960s than the last two decades. In fact, the substitution effect fell from 1.6 percentage point in the 1950s to virtually zero in the 1980s. However, as with knowledge workers, the productivity effect shows a diminishing influence over time, falling from 3.3 percentage points in the period 1950-60 to 0.3 percentage points in 1980-90. Changes in the composition of final output did play a modest role on changes in the share of data workers in total employment in the 1960s, though the effect was negative (-0.6 percentage points). Over the entire 1950-90 period, output changes had only a very minor bearing on the growth of data workers in total employment. The dominant effect was uneven productivity growth, which accounted for two-thirds of the increase in its share of total employment, while the substitution effect contributed one third.

For service worker employment, the substitution effect was positive and relatively strong in the 1950s, contributing 1.1 percentage points to the growth in their share of total employment. However, the effect was very weak in the 1970s, and during the 1960s and 1980s, the effect was actually negative, indicating that information workers were substituted for service employees. The unbalanced growth effect was also strong in the 1950s, 1.3 percentage points, but gradually lessened over time, reaching 0.1 percentage points in the 1980s. Changes in output composition had a positive effect on the employment of service workers. It generally increased over time, from 0.3 percentage points in the 1950s to 0.7 percentage points in the 1980s, reflecting primarily the increased demand for medical, educational, social, and personal services. Over the entire 1950-90 period, the principal source of growth in the share of service employment in total employment was the productivity effect, which accounted for almost 60 percent of its growth, followed by changes in output composition, which accounted for 30 percent, and, lastly, the substitution effect, which accounted for only about 10 percent.

The story for goods-processing workers is very different than that for the other types of workers. All three effects were strongly negative, and each played a role in the decline in the share of goods-processing workers in total employment. The strongest influence was the differential productivity effect, which accounted for about half its total decrease between 1950 and 1990. The effect was extremely strong in the 1950s and 1960s -- -5.3 and -4.7 percentage points, respectively -- and accounted for over 60 percent of the relative decline of good workers. In the 1970s and 1980s, the effect had fallen to -1.3 percentage points. The substitution effect explained another third of the decrease in the share of goods-processing workers in total employment over the entire 1950-90 period. The effect gradually diminished over time, from -2.3 percentage points in the 1950s to -0.8 percentage points in the 1980s. Changes in output composition also played a role, accounting for 14 percent of its overall decline as a share of total employment. The effect was particularly strong in the 1970s, when it contributed -1.4 percentage points or 30 percent of the drop in its share.

In sum, on the production side of the economy, a large contribution was made by technological change within each industry which substituted information labor for other types of labor. The substitution component explained over half the growth in the share of knowledge workers and over a third of the growth in the share of data workers. It also accounted for 12 percent of the growth in the percentage of service workers in total employment and over a third of the decline in the share of goods-processing workers.

The unbalanced productivity component was the strongest of the three effects. The absorption of workers from industries whose productivity grew relatively slowly explained almost half the increase in the share of knowledge workers in total employment, two thirds of the increase in the share of data workers, almost 60 percent in the share of service workers, and half the decline in the share of goods-processing workers. The output composition effect contributed almost nothing to the growth of information employment but accounted for a third of the growth in the share of service workers in total employment and 14 percent of the decline in the share of goods-processing workers.

These results also imply that the so-called "information explosion" is almost entirely a consequence of unbalanced growth and the substitution of information labor within production. Demand shifts towards heavily information-using products did not play a role in the relative growth of information workers.

3. Technology and the Growth in Information Employment

Though most of the growth in information employment has resulted from the less rapid productivity growth of the more information-intensive industries in the economy, a large portion has also arisen from changes in employment patterns within industry. This section uses econometric analysis to analyze the sources of growth of information workers on the industry level. I use three sets of independent variables: (i) measures of technological activity, including computerization; (ii) structural and organizational dimensions of production; and (iii) indices of international competitiveness.

There is some suggestions from the case study literature that with the introduction of new information technologies there is a growing demand for various professional, technical and skilled production occupations, while the shares of lower and middle level managers and supervisors, inspectors, semi-skilled operatives and many clerical occupations decline. Strong support for this pattern of effects was found by Milkman and Pullman in their 1991 study on employment restructuring at a GM auto assembly plant. Freeman (1987) reported that extensive research conducted by the Science Policy Research Unit at the University of Sussex showed that information technology tended to reduce the requirements for lower management and clerical employees but increased the need for skilled systems designers and engineers. Osterman (1987) found that a ten percent increase in company computing power led to a 1 percent reduction in managerial employment. Zuboff (1988) in a study of several manufacturing plants concluded that lower and middle managers were particularly "vulnerable" to deskilling and displacement by the introduction of information technologies.

Some descriptive statistics, shown in Figure 3, do suggest a relation between some indices of technological activity and the rate of change in the share of both knowledge and data workers in total employment. The accelerating growth in the share of knowledge workers seems to correlate well with both investment in office, computer and accounting machinery (OCA) per full-time equivalent employee (FTEE) and with total equipment investment per FTEE.[7] The change in the share of knowledge workers increased from 0.5 percentage points during the decade of the 1950s to 1.9 percentage points in the 1980s. The average period investment in OCA per FTEE rose from 6 thousand dollars (in 1987 dollars) in the 1950s to 211 thousand dollars during the 1980s, and total equipment investment per FTEE expanded from 2.0 million dollars (in 1987 dollars) to 3.8 million dollars. The number of full-time equivalent scientists and engineers engaged in R&D per 1,000 FTEE also increased, from 40.1 in the 1950s to 57.3 in the 1980s.[8] In contrast, the ratio of R&D expenditures to GDP remained virtually flat over the four decades, about 2 percent. Moreover, the annual rate of total factor productivity growth, measured using GDP for output and FTEE and gross capital stock for inputs, fell rather sharply from 1.6 percent in the 1950s and 1.8 percent in the 1960s to 0.5 percent in the 1980s.

The change in the share of data workers in total employment was quite strong in the 1950s and 1960s, increases of 4.9 and 5.4 percentage points, respectively, and then fell off to 2.0 percentage points in the 1970s and only 0.4 percentage points in the 1980s. This pattern is very similar to the time path of TFP growth but almost the exact opposite of that evidenced by OCA investment per FTEE and total equipment investment per FTEE.

The descriptive statistics do suggest that the growth of knowledge workers is positively related to computerization and new equipment investment in general and negatively related to TFP growth, while the growth of data workers is negatively related to new investment and positively associated with productivity growth. I next turn to regression analysis to analyze formally the relation between changes in information employment and technological advance.

Because of differences in industry classification schemes in the underlying data sources, 43 industries are used in the regression analysis. Moreover, because of data limitations, the period of analysis is limited to 1970-1990. The primary sample consists of pooled cross-section time-series data, with observations on each of the 43 industries in 1970-80 and 1980-90, for a total of 86 observations.[9] The error terms are assumed to be independently distributed but may not be identically distributed and I use the White procedure for a heteroschedasticity-consistent covariance matrix in the estimation (see White, 1980).

The dependent variable in the regressions is the change in the share of employment by type of worker in total industry employment over the ten-year period. I use five measures of technological activity: (1) average annual rate of total factor productivity growth (TFP growth), (2) investment in office, computer and accounting machinery over the previous 7 years per FTEE (OCA/FTEE); (3) ratio of expenditures on research and development to industry GDP (R&D/GDP); (4) the ratio of computer programmers, computer systems analysts, computer specialists, n.e.c., and engineers to FTEE (CSE/FTEE); and (5) the sum of constant dollar purchases of equipment over the previous ten years as a ratio to FTEE (NEWKFTEE), which may be interpreted as an indicator of the rate at which new vintages of capital are introduced into the industry.

A number of structural and organizational dimensions of production may have independent effects on the demand for skills. These include: (i) the share of employees in an industry covered by union contracts (%UNION); (ii) the share of employees working in large establishments (defined here as those with 500 or more employees); (iii) industry employment growth; and (iv) a dummy variable distinguishing goods from service industries (DUMSERV).

International competitiveness, as measured by the ratio of imports to industry gross output (IMP/GDO) and the ratio of exports to industry gross output (EXP/GDO), may also affect the rate of change in information employment. Industries competing against imports and those competing in international product markets may be forced to recruit relatively more information workers (particularly, knowledge workers) in order to remain competitive.

Other control variables are introduced as well. Capital intensity, measured as the ratio of capital to output, is used. High capital intensity may reflect the continued use of old technologies and methods of production that rely upon large scale operations and high shares of semi-skilled workers with specialized mechanical skills. A dummy variable distinguishing the 1970-80 from the 1980-90 period (DUM8090) is also introduced.

Results are shown in Table 4 for the change in the shares of four employment groups -- knowledge workers, data workers, service workers, and goods-processing workers. I have selected the regression form with the highest adjusted R^2-statistic (or, correspondingly, the lowest standard error of the regression). Of the five technology variables, the strongest effects come from the rate of computerization (OCA/FTEE). The variable has a positive and statistically significant effect, at the one percent level, on the growth in the share of knowledge workers in industry employment, a negative and significant effect, also at the one percent level, on the growth in the share of data workers, and a negative and significant effect, at the five percent level, on the change in the share of service workers. The variable is not statistically significant in the case of goods-processing workers.

TFP growth is negatively related to the growth in the share of knowledge workers in total employment, though the variable is significant at only the 10 percent level, but is positively related to the change in the share of goods workers, where it is significant at the one percent level. It is not significant in the other two cases. R&D intensity (R&D/GDP) is not significant in any case (its strongest effect is for knowledge workers). Computer scientists and engineers employed per FTEE (CSE/FTEE) is significant in only one case, for data workers at the five percent level, where it has a negative effect. On the other hand, the growth in data workers is positively linked to new equipment investment (NEWKFTEE), where the coefficient is significant at the five percent level.

Unions have the expected positive effect on the share of goods workers and the expected negative effect on the employment of service workers, though in both case the coefficient is significant at only the 10 percent level. Presumably, this is due to the fact that unions help support craft workers and operative jobs at the expense of non-unionized service jobs, like restaurant workers.

Industries which export a high percentage of their output have a higher than average growth in data workers but a lower growth in goods workers (the variable is significant at the five percent level in both cases). The former result may reflect the need for additional administrative layers to compete successfully in international markets, whereas the latter may reflect the need to "downsize" production jobs in order to reduce costs to be competitive in the international market place.

The dummy variable for service industries comes up positive and significant for the employment of goods-processing workers. This seems to reflect the fact that the decline in the relative employment of goods workers has been much faster in goods-producing industries, where they began as a large share of total employment, than in service industries, where their share has always been relatively small. The other variables fail to appear as statistically significant in any case. These include capital intensity, import intensity, the share of employees working in large establishments, and industry employment growth.

The results generally confirm the case study literature. Computerization, as reflected in investment in OCA, has a strong positive effect on the growth in knowledge workers but a strong negative effect on the employment of data processors and transmitters of information. The latter effect also shows up in the number of computer specialists and engineers employed per FTEE.

Interestingly, TFP growth has a negative effect on the growth of knowledge workers but a positive effect on the growth of goods-processing workers. These results suggest that technological change by itself tends to simplify tasks and thus reduce reliance on skilled workers in all dimensions. This result is consistent with product life cycle models. As originally argued by Vernon (1966, 1979), the creation of a new industry or product line usually entails high startup costs, the development of specialized processes, the training of labor for new skills, and so on. However, once this technology is in place, there is constant pressure to routinize the technology so that it becomes cheaper to use and less reliant on expensive, highly trained labor. This would presumably show up by a substitution of relatively less skilled production workers for the more expensive knowledge workers.

4. **Conclusion**

This paper documents once again the rapid growth of information workers in the U.S. economy. Information workers as a group grew from 37 percent of total employment in 1950 to 55 percent in 1990. However, the time patterns are quite different for knowledge-producing workers and data workers, with the increase in the share of the former accelerating from 0.5 percentage points during the 1950s to 1.9 percentage points in the 1980s and that of the latter slowing down from around 5 percentage points in the 1950s and 1960s to only 0.4 percentage points in the 1980s.

About half the growth in the share of knowledge workers in total employment and two thirds of the increase in the share of data workers over the period 1950-90 was attributable to differential rates of productivity movements among the industries of the economy. However, the unbalanced growth effect diminished over time, a reflection of the general overall slowdown in productivity growth between the 1950s and 1960s and the ensuing two decades. On the production side of the economy, half the growth in the share of knowledge workers and over a third of the growth in the share of data workers was accounted for by the substitution of these workers for other types of workers. The substitution effect increased in importance over time in the case of knowledge workers (from -0.4 percentage points in the 1950s to 1.5 percentage points in the 1980s) but diminished over time for data workers (from 3.3 to 0.3 percentage points). In contrast, demand shifts towards heavily information-using products contributed virtually nothing to the growth of information employment.

The introduction of information technology (IT) in the 1970s and 1980s, as reflected primarily in the rate of computerization, was by far the strongest influence in explaining the growth of knowledge workers on the industry level. In fact, investment in OCA by itself explains 46 percent (2.72 x 0.0024/0.0142) of the average growth in the share of knowledge workers in industry employment during the 1980s. On the other hand, investment in OCA, along with increases in the number of computer specialists and engineers employed per FTEE, exerted a strong depressing effect on the growth in data workers. They were the two major factors accounting for the slowdown in the growth of the share of data workers in total employment in the 1980s.

IT has thus exerted a powerful positive effect on the growth in knowledge-producing workers and a strong negative effect on the growth in data processors and manipulators. The influence, however, has come through changes in production technology, not through the substitution of information-intensive products for others among final consumers.

Footnotes

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[1] A number of other studies have documented the explosive growth in the share of the labor force engaged in information-related activities. See, for example, Porat (1977), Beniger (1986), Rubin and Huber (1986), and Reich (1991).

[2] I also split these groups using other ratios. However, the major results concerning the growth of employment of knowledge and data workers and of the information sector are quite insensitive to the proportions into which the two hybrid groups are split.

[3] I have made some minor changes in the classification scheme used in earlier work so that the results reported here differ slightly from those reported in Baumol, Blackman, and Wolff (1989, Chapter 7).

[4] See Wolff, 1995, for details on sources and methods for the input-output data.

[5] Since the occupation-by-industry matrices were for different years than the input-output data, geometric interpolation of industry employment for the input-output data was used to align industry employment in the input-output data with the Census years.

[6] Estimates of the decomposition shown in equation 3 were based on three sets of weights: beginning of the period, end of the period, and average period shares. The results were quite insensitive to the choice of weights, and only results based on average period weights are shown.

[7] With the exception of the share of information workers in total employment, the variables shown in Figure 3 are period averages. See footnotes to Table 4 for sources and methods for these variables.

[8] The positive correlation between this variable and the share of knowledge workers in total employment is not too surprising since scientists and engineers engaged in R&D constitute a large proportion of knowledge workers.

[9] A second sample, limited to the 31 goods-producing industries for a sample size of 62, was also used. The results are not materially different than those reported in Table 4 and are not shown.

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Table 1
Employment Growth and Percentage Composition of Employment
By Type of Worker, 1950-1990[a]

Type of Worker	Total Employment (in millions) 1950	1960	1970	1980	1990
1. Knowledge	2.2	2.7	4.4	6.7	9.1
2. Data	13.9	18.6	24.5	34.0	40.0
3. Knowledge/Data	4.4	4.9	4.9	8.0	11.6
4. Data/Services	1.6	2.0	2.7	4.8	5.3
5. Services	5.9	8.3	9.3	13.3	16.0
6. Goods	30.0	28.1	25.8	30.6	33.5
7. Total Knowledge	4.4	5.2	6.8	10.7	14.9
8. Total Data	17.0	22.0	28.3	40.4	48.4
9. Total Information	21.4	27.2	35.1	51.1	63.4
10. Total Non-Information	36.7	37.3	36.4	46.2	52.2
11. Total Employment	58.1	64.5	71.6	97.3	115.5

Type of Worker	Annual Rate of Growth of Employment [percent] 1950-60	1960-70	1970-80	1980-90	1950-90
Total Knowledge	1.7	2.8	4.5	3.3	3.1
Total Data	2.6	2.5	3.6	1.8	2.6
Total Services	3.2	1.4	3.8	1.8	2.6
Goods	-0.7	-0.9	1.7	0.9	0.3
Total Information	2.4	2.6	3.7	2.2	2.7
Total Non-Information	0.2	-0.2	2.4	1.2	0.9
Total	1.1	1.0	3.1	1.7	1.7

Type of Worker	Percent Distribution of Employment 1950	1960	1970	1980	1990
Total Knowledge	7.5	8.0	9.6	11.0	12.9
Total Data	29.2	34.2	39.6	41.5	41.9
Total Services	11.6	14.3	14.9	16.1	16.2
Goods	51.7	43.5	36.0	31.4	29.0
Total Information	36.8	42.2	49.1	52.5	54.8
Total Non-Information	63.2	57.8	50.9	47.5	45.2
Total	100.0	100.0	100.0	100.0	100.0

a. The total for knowledge workers (line 7) is defined as the sum of line 1 and half of line 3. The total for data workers (line 8) is defined as the sum of line 2, half of line 3, and half of line 4. The total for information workers (line 9) is defined as the sum of line 7 and line 8. The total for non-information workers (line 10) is the residual.

Table 2

Knowledge and Data Workers as a Percent of Total Employment
By Major Industry, 1950-1990[a]

	1950	1960	1970	1980	1990
A. Knowledge Workers					
Agriculture	0.5	0.9	2.3	3.4	3.6
Mining	4.5	7.6	10.5	12.6	14.8
Manufacturing	5.9	7.0	9.3	9.8	11.9
Construction	4.9	7.2	7.7	7.6	10.1
Transportation, Communications and Utilities	5.8	6.7	7.8	9.5	11.3
Trade	10.6	7.9	7.0	9.3	10.7
Finance, Insurance, and Real Estate	9.2	10.6	10.6	12.1	15.4
Business and Other Services	12.0	11.1	12.5	13.7	15.6
Government	12.4	11.8	13.9	15.5	16.1
Total Goods[b]	4.4	6.1	8.3	9.0	10.9
Total Services[b]	11.2	9.9	10.5	12.2	14.0
Total	7.5	8.0	9.6	11.0	12.9
B. Data Workers					
Agriculture	0.7	1.4	3.9	6.2	7.2
Mining	11.2	17.3	23.4	26.3	28.5
Manufacturing	21.8	22.9	25.9	27.3	27.1
Construction	7.8	12.2	17.5	19.8	19.2
Transportation, Communications and Utilities	32.4	31.9	35.7	37.1	36.1
Trade	51.9	54.5	52.9	51.6	53.0
Finance, Insurance, and Real Estate	69.2	79.1	80.3	79.3	75.8
Business and Other Services	31.1	35.1	43.5	45.1	45.0
Government	53.7	54.2	52.9	51.1	48.2
Total Goods[b]	16.0	19.7	24.4	26.1	25.8
Total Services[b]	45.0	48.2	51.0	51.2	50.9
Total	29.2	34.2	39.6	41.5	41.9

a. Calculations are shown for total knowledge workers and total data workers.

b. The goods sector consists of agriculture, mining, manufacturing, construction, and transportation, communications, and utilities. The service sector includes trade; finance, insurance, and real estate; business and other services; and government.

Table 3

Decomposition of the Change in Employment Composition by Type of Worker Into a Substitution, Productivity, and Output Effect, 1950-1990[a]

Type of Worker	Decomposition of Change in in Employment Composition [in percentage points]				Percentage Decomposition of Change in Employment Composition			
	Subst. Effect	Prod. Effect	Output Effect	Total Change	Subst. Effect	Prod. Effect	Output Effect	Total Change
1. Knowledge Workers								
1950-60	-0.40	0.91	-0.03	0.49	-81.6	187.3	-5.7	100.0
1960-70	0.79	0.71	0.02	1.53	51.8	46.6	1.6	100.0
1970-80	1.11	0.24	0.08	1.42	77.8	16.6	5.5	100.0
1980-90	1.49	0.39	0.06	1.94	76.8	19.9	3.3	100.0
1950-90	2.86	2.55	-0.03	5.37	53.2	47.4	-0.6	100.0
2. Data Workers								
1950-60	1.57	3.31	0.03	4.91	32.0	67.4	0.6	100.0
1960-70	1.89	4.07	-0.57	5.40	35.1	75.5	-10.6	100.0
1970-80	0.63	1.32	0.02	1.97	32.0	67.0	1.0	100.0
1980-90	-0.02	0.34	0.09	0.40	-5.6	84.5	21.1	100.0
1950-90	4.38	8.44	-0.13	12.68	34.5	66.5	-1.1	100.0
3. Service Workers								
1950-60	1.14	1.29	0.33	2.76	41.4	46.6	12.1	100.0
1960-70	-0.54	0.91	0.20	0.57	-94.0	159.1	35.0	100.0
1970-80	0.13	0.61	0.45	1.18	10.7	51.5	37.8	100.0
1980-90	-0.69	0.08	0.69	0.08	--	--	--	--
1950-90	0.57	2.67	1.36	4.60	12.3	58.0	29.6	100.0
4. Goods-processing workers								
1950-60	-2.32	-5.31	-0.54	-8.16	28.4	65.0	6.6	100.0
1960-70	-2.14	-4.68	-0.67	-7.50	28.6	62.5	8.9	100.0
1970-80	-1.86	-1.33	-1.38	-4.57	40.7	29.2	30.1	100.0
1980-90	-0.77	-1.34	-0.31	-2.42	31.9	55.5	12.6	100.0
1950-90	-7.81	-11.64	-3.21	-22.65	34.5	51.4	14.2	100.0

a. Calculations are shown for total knowledge workers, total data workers, total service workers, and goods producers. Average period weights are used in all cases. The substitution, productivity, and output effects refer, respectively, to the three terms of equation (3):

$$\Delta b(y) = \Delta n\hat{\lambda}y/\Sigma b^* + n(\Delta\hat{\lambda})y/\Sigma b^* + n\hat{\lambda}\Delta y/\Sigma b^*. \quad (3)$$

Table 4

Regressions of Change in the Share of Workers in Total Employment By type of Worker on Technology and Other Variables[a]

Independent Variables	Dependent Variable: Change in the Share of Industry Employment of Knowledge Workers	Data Workers	Service Workers	Goods Workers
Constant	0.004 (0.45)	0.031*** (3.39)	0.011 (0.89)	-0.029*** (3.72)
TFP Growth	-0.133* (1.96)	-0.066 (1.17)	0.014 (0.36)	0.190*** (3.02)
Ln(OCA/FTEE)	0.0024*** (5.32)	-0.0018*** (3.47)	-0.0047** (2.07)	0.0022 (1.44)
R&D/GDP	0.0014 (1.27)			
Ln(CSE/FTEE)		-0.0060** (2.54)	0.0054 (1.62)	0.0027 (1.15)
Ln(NEWKFTEE)	-0.0045 (1.12)	0.0045** (2.14)	-0.0006 (0.36)	0.0016 (0.60)
%UNION			-0.021* (1.67)	0.021* (1.68)
EXP/GDO	-0.080 (1.20)	0.159** (2.52)		-0.157** (2.28)
DUMSERV	-0.016 (1.50)		-0.0092 (1.43)	0.031*** (3.54)
R^2	0.19	0.27	0.17	0.39
Adjusted R^2	0.13	0.23	0.11	0.34
Std. error	0.020	0.020	0.022	0.018
Sample Size	86	86	86	86

a. The sample consists of pooled cross-section time-series data, with observations on each of the 43 industries in 1970-80 and 1980-90, for a total of 86 observations. The coefficients are estimated using use the White procedure for a heteroschedasticity-consistent covariance matrix. The absolute value of the t-statistic is shown in parentheses below the coefficient estimate. Key:

1) TFP Growth: average annual rate of total factor productivity growth, using full-time equivalent employees (FTEE) and gross capital stock (source: NIPA on diskette).

2) Ln(OCA/FTEE): natural logarithm of the sum of constant dollar purchases of office, computer and accounting machinery over previous 7 years per FTEE (source for OCA: BIE computer tape; source for FTEE: NIPA on diskette)

3) R&D/GDP: ratio of expenditures on research and development to industry GDP (source: National Science Foundation, Research and Development in Industry, various years)

4) Ln(CSE/FTEE): natural logarithm of the ratio of computer programmers, computer systems analysts, computer specialists, n.e.c., and engineers to FTEE (source for computer specialists and engineers: decennial Census data).

5) LN(NEWKFTEE): natural logarithm of the sum of constant dollar purchases of equipment over the previous ten years as a ratio to FTEE (source for new equipment investment: BIE computer tape; source for FTEE: NIPA on diskette)

6) %UNION: share of employees covered by union contracts (Kokkelenberg and Sokell, 1985; and worksheets supplied by the U.S. Bureau of Labor Statistics).

7) EXP/GDO: ratio of industry exports to industry gross output (source: U.S. input-output tables).

8) DUMSERV: dummy variable which equals one for the 12 service industries and zero otherwise.

* Significant at the 10% level (two-tailed test)
** Significant at the 5% level (two-tailed test)
*** Significant at the 1% level (two-tailed test)

Fig 1 Percent Composition of Employment

by Type of Workers, 1950–90

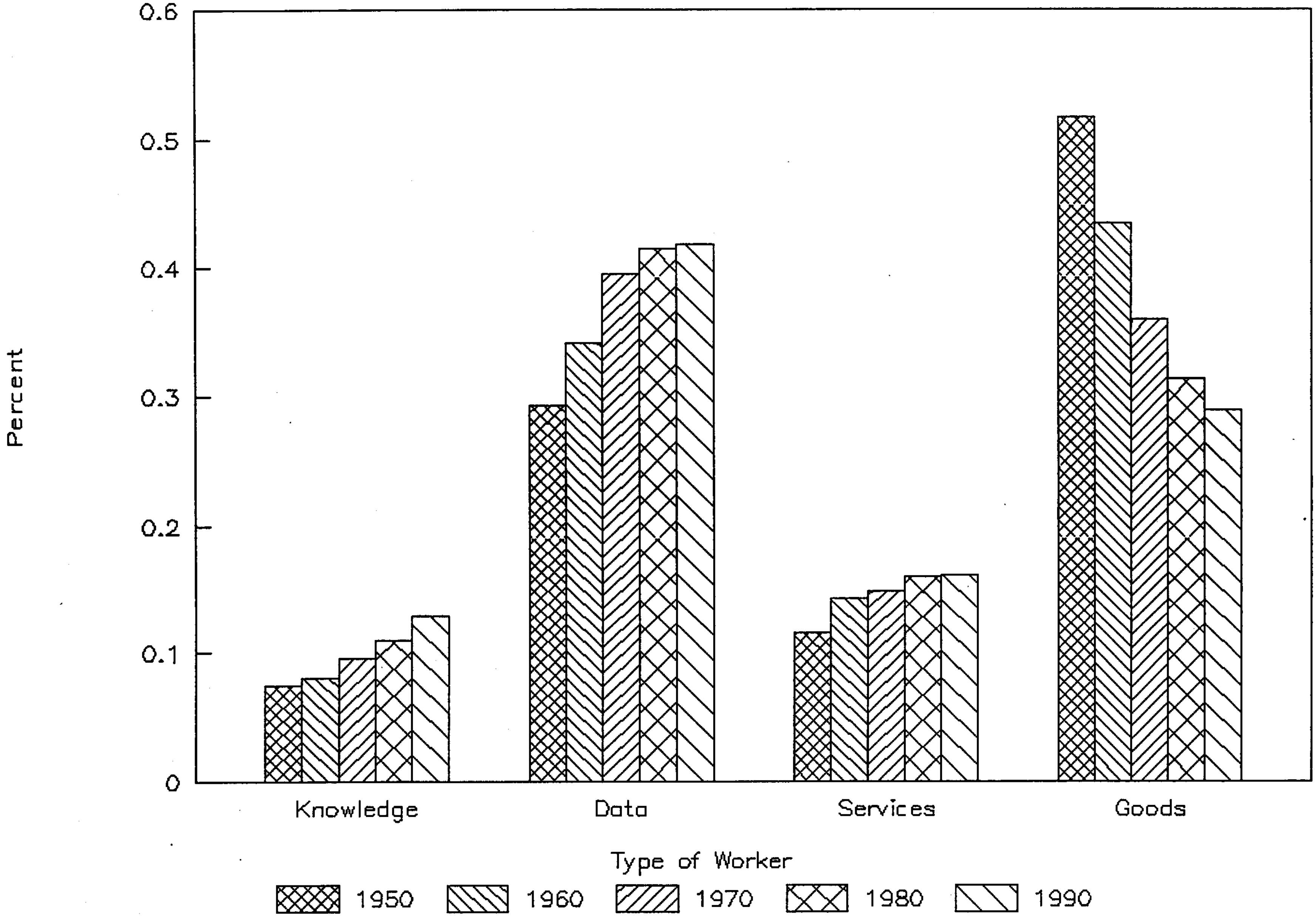

Fig 2 Knowledge and Data Workers as a

Share of Employment by Industry, 1990

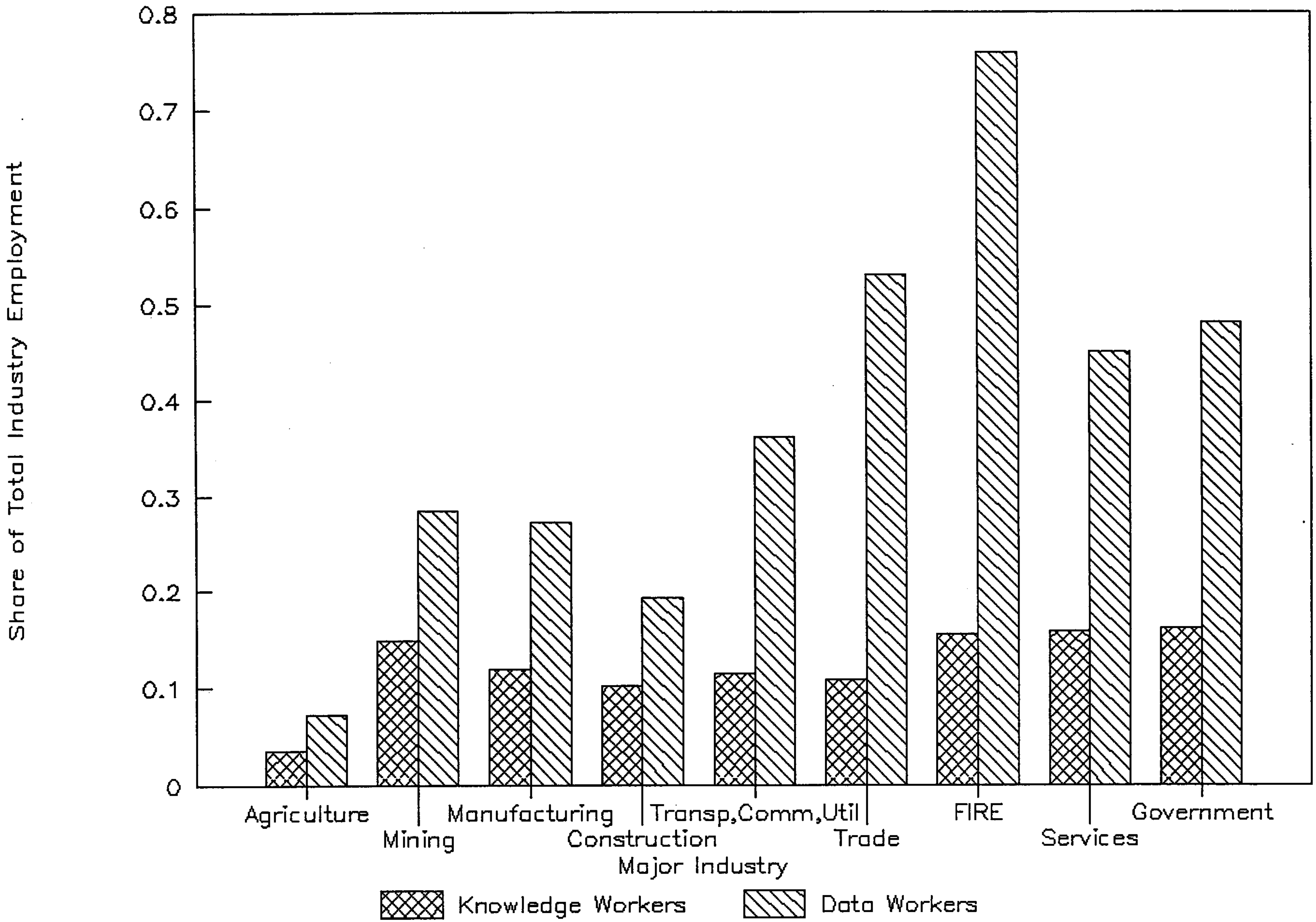

Fig 3 Change in Share of Info Workers

in Total Employ and Tech. Indices