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Abstract. Whereas difficulties in measuring the output of service sectors have been well documented, input measures are reasonably accurate. Using U.S. input-output data for the period 1958-87 and a number of indices of skill and occupational change derived from the Dictionary of Occupational Titles and decennial census data covering the period 1960-1990, I find strong evidence that among all industries in the economy industry productivity growth is positively related to R&D intensity and knowledge spillovers from other industries but negatively related to major restructuring of technology, as reflected in changes in the occupational composition of industry employment. However, the degree of computerization and both the level and change in occupational skills are not significant, with the sole exception of the share of administrators and managers in total employment, which has a positive effect on productivity growth. Moreover, regressions among service industries by themselves yield very different coefficients than those among all industries -- in particular, knowledge spillovers and computerization have significant negative effects on productivity growth. I interpret the latter results to provide circumstantial evidence of mismeasurement of service output.

JEL Codes: O30, O32, O47, O51, C67

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1. Introduction

Difficulties in measuring the output of service sectors have been well documented in many studies. This has lead to corresponding difficulties in creating a reliable index of productivity in service industries. On the other hand, input measures are quite adequate in service sectors, as in other industries within the economy. Labor, capital, and material inputs are easily identifiable and measurable in services, and are, in principle, no different than in other industries. The basic problem, then, is how to measure productivity in an industry in which output is difficult to measure but inputs are relatively easily measured.[1]

Most recent attempts to obtain a better measure of productivity in service industries have aimed at improving the output measures. For example, in the banking industry, the number of checks processed or cleared per hour has been proposed as an output indicator; for the airline industry, passenger-miles; for legal services, the number of wills prepared or the number of real estate closings per year; and for the health industry, the number of procedures performed per year (see, for example, Bresnehan, Milgrom, and Paul, 1992; Dean and Kunze, 1992; Fixler and Zieschang, 1992; and Gordon, 1992). In almost all cases, the use of these direct indices of service output results in higher measured productivity growth than those based on conventional national accounting data.

There are problems in these approaches due to the fact that most services produce a composite output. Such approaches usually capture only one or several aspects of the output and often the least important parts of the industry's activity.[2] In the banking industry, for example, the most important activity in terms of revenue and manpower is the loan department and for this it is very difficult to arrive at a suitable index -- number of loan applications received, number of loans approved, dollar amount of loans approved, the interest rate charged and other fees generated, the default rate, and so on? In law firms, the chief revenue source are the complex legal cases taken on and the most suitable measure is, perhaps, hours billed -- a value added measure.

An alternative approach used in this study is to consider several indirect indicators of productivity growth in the service sector by examining changes in the input mix. The trick is to avoid using service output measures or price deflators in designing such indices. It should be noted at the outset that the indirect measures relate to the *growth rate* of productivity rather than to its level. Moreover, the indices developed provide circumstantial evidence rather than direct evidence on productivity movements.

Two approaches are used here. The first is based on changes in direct input-output coefficients. I utilize changes in the inter-industry coefficients and the capital-labor and materials-labor ratios as indices of productivity growth. Technological progress (total factor productivity or TFP growth) in goods-producing industries has historically been associated with not only a rising level of output per unit of input but also with a change in input proportions -- in particular, an increasing capital-labor and materials-labor ratio. Goods-producing sectors with low productivity growth, on the other hand, have typically been characterized by a relatively stable ratio of capital to labor as well as materials used per labor hour.

The second approach considers changes in the occupational composition of employment within service sectors. The justification is similar. In sectors with rapidly changing technology, we would expect to find substantial changes in the occupational make-up of the industry. Conversely, in sectors with stagnant technology, we would expect little change in employment composition.

A number of indices of occupational change are used here: (i) the change in the overall occupational composition of employment within an industry; (ii) the ratio of scientific and technical manpower to total industry employment; (iii) the proportion of knowledge workers in total employment; (iv) the proportion of professionals and technical labor in total employment; and (v) the proportion of managerial and administrative labor in total employment. A related indicator is changes in the average cognitive skill level of the workforce in an industry. Skill levels can be measured by the average level of educational attainment or Dictionary of Occupational Title (DOT) direct skill measures.

For the analysis of coefficient changes, I rely on U.S. input-output data for years 1958, 1967, 1977, and 1987. The analysis of changes in occupational composition will be based on data from the U.S. decennial Census of Population for 1960, 1970, 1980, and 1990.

The remainder of the paper is organized as follows. The next section (Section 2) develops the accounting framework. Section 3 describes the data sources and methods. Section 4 presents descriptive statistics and Section 5 the regression results. Concluding remarks are made in the last section.

2. **Accounting Framework**

Define:[3]

U = an input or "use" commodity-by-industry flow matrix, where u_{ij} shows the total amount of commodity i consumed by industry j.

V = an output or "make" industry-by-commodity flow matrix, where v_{ij}

shows the total output of commodity j produced by industry i.[4]

$x = V^T\mathbf{1}$ = (column) vector, showing the gross output of each commodity,

where a superscript T refers to the transpose of the indicated matrix, and

$\mathbf{1}$ = vector with unit entries.

Also, let:

$y = (V^T - U)\mathbf{1}$ = (column) vector of final demand by commodity.

e = (row) vector, showing total employment by industry.

k = (row) vector, showing total capital stock by industry.

To derive the corresponding technical coefficients, I will make use of the commodity technology model, where it is assumed that each commodity is produced by the same technology, irrespective of the industry of production. In this case, industries are considered independent combinations of outputs j, each with their separate input coefficients (a_{ij}). The commodity technology requirements (coefficient) matrix is given by:

(1) $A = U[V^T]^{-1}$ = matrix of interindustry technical coefficients,

where V is restricted to a square matrix (that is, there are as many industries as commodities).[5] Row vectors of labor and capital stock coefficients can be derived in analogous fashion:

$\ell = e[V^T]^{-1}$ = (row) vector of labor coefficients

$\kappa = k[V^T]^{-1}$ = (row) vector of capital coefficients.

In addition, let us define

n = total employment (a scalar) in the economy.

c = total capital stock (a scalar) in the economy.

w = the annual wage rate (a scalar), assumed constant across industries.

r = the rate of profit on the capital stock (a scalar), also assumed constant across industries.[6]

p = (row) vector of commodity prices, given by the Leontief equation:

$p = (w\ell + r\kappa)(I - A)^{-1}$

In the I-O framework, sectoral output is measured by gross commodity output x (alternately called gross domestic output or GDO), while the inputs consist of employment, fixed capital, and materials (intermediate inputs). The rate of TFP (total factor productivity) growth for sector j is defined as:

$$(2) \qquad \pi_j \equiv -(\Sigma_i p_i da_{ij} + wd\ell_j + rd\kappa_j)/p_j$$

where π is the corresponding row vector and "d" refers to the differential.[7] Since productivity growth rates are measured over discrete time periods rather than instantaneously, the average value share of p_i, w, and r over the sample period is used to measure π.[8]

Aggregate TFP growth, ρ, as

$$(3) \qquad \rho \equiv [pdy - wdn - rdc]/py.$$

This measure is directly analogous to equation (2), the index of sectoral TFP, except that intermediate inputs are netted out.

3. Data Sources and Methods

Our basic data source consists of U.S. input-output dollar flow tables, which were originally obtained from the Bureau of Economic Analysis on the 87-sector level for years 1958 and 1967 in single-table format, and on the 85-sector level for years 1967, 1977, and 1987 in the dual use-make table format. [9] The 1967, 1977, and 1987 data are available in separate make and use tables.[10] There were several adjustments required to make the four tables compatible, which are described in detail in Wolff (1997).[11]

All matrices are deflated to 1972 dollars using sectoral price deflators. Productivity growth rates for 1958-67 are calculated using the single-table basic framework (and making use of the 1967 single table data). Productivity growth rates for 1967-77 and 1977-87 are calculated using the use-make framework (and relying on the 1967 dual table data). Because of alignment difficulties between the various input-output years (several industries are collapsed in the 1987 table, in particular), productivity growth estimates are available for only 68 industries.

The 85 industries are divided into two groups, goods and services. The goods industries include: agriculture (1-4)[12], mining (5-10), construction (11-12), manufacturing (13-64), transportation (65), communications (66-67), and utilities (68). Services include: trade (69), finance, insurance, and real estate (70-71), government services (78, 79, and 82), and all other services (72-77 and 84). It should be stressed that I include communications, transportation, and utilities in the goods sector because for the purposes here they have relatively easily measured output and are more like the other goods industries than services from this standpoint.

Employment data for 267 occupations and 64 industries are obtained from the decennial Census of Population for years 1960, 1970, 1980, and 1990. Since occupation and industry classifications have changed substantially with each census, I used Commerce Department compatibility tables for 1960-70 and 1970-80 to produced consistent matrices for the four years. Fortunately, there were only very minor changes in classification between 1980 and 1990 (see Wolff, 1996a, for more details on the construction of these matrices).

The measure of cognitive skill is based on the fourth (1977) edition of the Dictionary of Occupational Title (DOT). For some 12,000 job titles, it provides a variety of alternative measures of job-skill requirements based upon data collected between 1966 and 1974.[13] I use as an index of cognitive skill the measure Substantive Complexity (SC), which is a composite (factor analytic) measure of skills developed by Roos and Treiman (Miller et. al., 1980: Appendix F), reflecting the educational and training time requirements of the job, as well as the needs for synthesizing, coordinating, and analyzing data and the general learning, reasoning, verbal, and numerical ability of the job. This measure is developed for each of the 267 occupations (see, Wolff, 1996a, for more details).

Another measure of cognitive skills, which is derived from the 1970 Census of Population data, is Median Years of Schooling-1970 (EDUC-1970). Median years of schooling is computed for each occupation in 1970 on the basis of actual schooling attainment reported by respondents in the 1970 Census of Population. If the actual skill requirements of each occupation remain constant over time, then EDUC-1970 serves as an indicator of the changes in the educational requirements of the workplace.

Average industry skill scores are computed as a weighted average of the skill scores of each occupation, with the occupational employment mix of the industry as weights. Computations are performed for 1960, 1970, 1980, and 1990 on the basis of the occupation by industry employment matrices.

Another dimension of occupational skills is based on the number of "knowledge producers" in an industry. The basic data are again from the U.S. Decennial Censuses of 1960, 1970 1980, and 1990. In the classification schema, professional and technical workers have generally been classified as knowledge workers, depending on whether they are producers or users of knowledge. The line is somewhat arbitrary at points, and judgment calls have been made. 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 (see, Wolff, 1996b, for more details).

4. **Descriptive Statistics**

A. Trends Productivity Growth

Before presenting the regression analysis, it is helpful to see what the conventionally measured productivity growth figures are for the various sectors of the economy. As shown in Panel 1 of Table 1, the annual rate of labor productivity growth for the entire economy fell from 1.8 percent per year in 1958-67 to 0.9 percent per year in 1967-77 and then to 0.7 percent per year in 1977-87.

In the goods industries, there was generally a slowdown in labor productivity growth between the 1958-67 and 1967-77 periods and then a modest recovery in the 1977-87 period. This was true for all sectors except nondurable manufacturing, whose productivity growth rate remained strong throughout the three periods and utilities, where productivity growth was exceptionally high in the first two periods and then fell to virtually zero in the third. Altogether, labor productivity growth in the goods-producing industries (including communications, transportation, and utilities), averaged 2.5 percent per year in the 1958-67 period, fell to 1.7 percent per year in the 1967-77 period, and then recovered slightly to 1.9 percent per year in the 1977-87 period.

The pattern is very different for the service industries. Labor productivity in wholesale and retail trade was strong in the 1958-67 period (2.0 percent per year), turned negative in the next period, and then rebounded in 1977-87 (1.5 percent per year). In both finance, insurance, and real estate (FIRE, for short) and in general services, labor productivity growth dropped between 1958-67 and 1967-77 and then turned negative in the 1977-87 period. For the government sector, labor productivity growth remained virtually zero between 1958 and 1987. Overall, labor productivity growth in services fell from 1.2 percent per year in 1958-67 to 0.46 percent per year in 1967-77 and to 0.35 percent per year in 1977-87. As a result, the gap in annual labor productivity growth between the goods sectors and the service sectors widened, from 1.25 percentage points in 1958-67 to 1.50 percentage points in 1977-87.

Panel 2 shows the corresponding results for TFP growth,. TFP growth for the total economy was very strong in the 1958-67 period, averaging 1.5 percent per year, and then fell sharply to 0.3 percent per year in 1967-77 and, unlike labor productivity growth, showed no recovery in the 1977-87 period. In the goods sector as a whole, TFP growth averaged 2.1 percent per year in 1958-67, fell sharply to 0.6 percent per year in 1967-77, and then rebounded to 1.0 percent per year in 1977-87. In contrast, in services, annual TFP growth fell from 0.9 percent in the first period to 0.2 percent in the last two periods.

Time trends in TFP growth for the individual sectors are, in general, quite similar to the overall pattern for their group. All goods-producing sectors experience a slowdown in TFP growth between the 1958-67 and 1967-77 periods and all except mining, nondurable manufacturing, communications, and utilities show a recovery in the 1977-87 period. TFP growth in all four service sectors turned from positive to negative between the 1958-67 and 1967-77 periods and with the exception of trade declined even further in the 1977-87 period.

By both measures, productivity growth appears to be much lower in services than in goods-producing industries. Moreover, the disparity has generally widened over time, between 1958 and 1987. Indeed, in the 1958-67 period, both labor productivity and TFP growth in the service industries were quite "respectable", about one percent per annum. However, by the 1977-87 period, productivity growth in services was virtually zero. Several economists have contended that the apparent poor performance of services in more recent years is due to increasing problems in the measurement of their output over time, not due to actual changes in productivity. I now construct some related measures of technological activity to investigate this issue.

B. Measures of Technological Activity.

Several measures of technological activity are developed that do not directly rely on sectoral output measures. The first is the growth in the ratio of capital to labor, shown in the top panel of Table 2. If labor productivity growth is, in reality, higher in goods industries than services, part of this might be accounted for by a larger increase in the capital-labor ratio. Some support is provided for this argument. Over the entire 1958-87 period, the capital-labor ratio grew by 2.4 percent per year in goods industries and 1.5 percent per year in services. However, the capital-labor ratio actually increased faster in services than in goods industries in the 1958-67 period and at about the same rate in the 1977-87 period. Moreover, capital-labor growth was higher in trade and in FIRE than in manufacturing.

A similar argument applies to the ratio of total intermediate inputs to labor.[14] Over the entire 1958-87 period, the rate of growth in this ratio was greater in the goods sector than in the service sector, but the difference was not great (2.3 versus 1.8 percent per year). Moreover, this ratio grew much faster in services than in the goods-producing sector in the 1977-87 period. Another "anomaly" is that the rate of increase in the ratio of total intermediate inputs to labor over the 1958-87 period was about the same in trade and general services as in manufacturing.

Table 3 shows two indicators of investment activity. The first of these is investment in office, computing, and accounting equipment (OCA) per full-time equivalent employee (FTEE). In the 1977-87 period, the one where purchases of OCA were by far the greatest, FIRE led the way, at $1,068 (in 1987 dollars) per FTEE, followed by mining ($523), utilities ($464), durables manufacturing ($266), and communications ($226). As a whole, the service sector has been investing more intensively in computer equipment than the goods sector, but this was largely due to the very heavy investments made by FIRE. The trade and general service sectors were actually below average in terms of OCA investment per FTEE.

The second indicator is total investment in equipment, machinery, and instruments (including OCA) per FTEE. It should be noted at the outset that total equipment investment was more than ten times greater than OCA investment, even in the 1977-87 period, which probably explains why computerization by itself has not had much effect on overall productivity growth. The goods industries invested much more heavily than the service sector in equipment per FTEE -- about double overall. The leading sectors were all goods producers -- utilities, communications, and mining.

Another indicator of the rate of technological activity is the degree to which the interindustry coefficient structure shifts over time. For this, I employ an index of similarity. First define:

(4) $$s^t_j = a^t_{ij} / \Sigma_i a^t_{ij},$$

which shows the input (in constant dollars) from industry i to industry j as a share of the total sum of interindustry inputs (all in constant dollars) into sector j. Then, the standard similarity index for industry j for two time periods t1 and t2 is given by:

(5) $$SI^{12} = \frac{\Sigma_i \; s^{t1}{}_j \cdot s^{t2}{}_j}{[\Sigma_i \; (s^{t1}{}_j)^2 \cdot \Sigma_i \; (s^{t2}{}_j)^2]^{1/2}}$$

The index SI is the cosine between the two vectors s^{t1} and s^{t2} and varies from 0 -- the two vectors are orthogonal -- to 1 -- the two vectors are identical.[15] The index of dissimilarity, DI, is defined as:

(6) $$DI^{12} = 1 - SI^{12}$$

where a greater value of the index DI indicates more dissimilarity between the two vectors.

Results for DI are shown in Table 4. The communications sector was by far the most dynamic in terms of shifting its input structure over the period 1958 to 1987 (a DI value of 0.54), and particularly for the period 1977-87. The second most dynamic sector was general services (0.26), followed by durables manufacturing (0.20), utilities (0.18), and transportation (0.15). However, overall, goods industries experienced more change in their interindustry coefficient structure than services, particularly in the 1977-87 period.

Panel 2 presents measures of the dissimilarity index DI based on changes in occupational structure over each decade. it should first be noted that the degree of overall occupational change was greater in the 1980s (DI equals 0.10) than in the 1960s (0.06) and much greater in these two periods than in the 1970s (0.02). These results confirm anecdotal evidence about the substantial degree of industrial restructuring during the 1980s.

Moreover, though the degree of occupational change was greater in the goods sector than the service sector, the difference was relatively small (0.20 versus 0.16 over the period 1960-90). The three sectors that experienced the greatest occupational restructuring over the three decades were communications (0.26), utilities (0.23), and general services (0.23). Occupational change was particularly low in agriculture (0.03), construction (0.08), and transportation (0.09).

I use two other technological variables. The first of these is $RDSALES_j$, the amount of R&D expenditure in constant dollars per constant dollar of net sales in sector j. The data are obtained from National Science Foundation (various years). These data have historically been available only for the manufacturing sector.[16] As shown in Table 5, RDSALES in manufacturing has remained relatively constant over time, at least in comparison to the wide fluctuations in labor productivity and TFP growth. Indeed, the weighted average of RDSALES for overall manufacturing shows a slight dip between the 1958-67 and 1967-77 periods but almost no change between the latter period and 1977-87. The ratio of R&D to sales was considerably higher in durable manufacturing than nondurables (almost a factor of three) and in the 1977-87 period ranged from a low of 0.4 percent in food products to a high of 18.3 percent in aircraft.

The second is an index of direct technological spillovers from supplying to purchasing sector, given by:

$$TFPIND_{jt} \equiv \Sigma_i \, a^{\circ}_{ijt} \cdot \pi_{it},$$

which is a measure of sector j's indirect knowledge gain from technological change in its supplying sectors. The matrix A° is identical to the A matrix except that the diagonal is set to zero to prevent double-counting of TFP growth. It is assumed that the information gained from supplier i's TFP is proportional to its importance in sector j's input structure. In Wolff (1997), this variable was found to be highly significant in explaining industry TFP growth.

As shown in Table 6, TFPIND for the economy as a whole followed the same trend as overall TFP growth, falling sharply between the 1958-67 and 1967-77 periods and then recovering slightly in the last. This is not surprising since TFPIND is a weighted average of TFP growth rates of individual industries. However, what is surprising is that whereas TFPIND for the goods sector as a whole also conformed to this pattern, TFPIND for services fell between both the first and second and the second and third period as well (turning negative in the latter). This is due to the fact that service industries tend to buy from each other and that goods industries also tend to buy from each other. Also, as a result of this, TFPIND was generally higher in goods industries than service industries.

C. Measures of Skill Level

Tables 7 and 8 show various indices of "brain-power" by industry. The first of these is the ratio of knowledge workers to total industry employment. The service industries as a group were more intensive in their use of knowledge workers than the goods sector but the leading sector was communications (21.8 percent in the 1980s), followed by the government sector (16.1 percent), general services (15.6 percent), and FIRE (15.4 percent). The increase in the share of knowledge workers in total employment between 1960 and 1990 was about the same for services as for the goods industries.

The ratio of scientists, computer analysts, engineers, and technicians tot total employment was much greater in the goods-producing sector than in services (5.2 versus 2.4 percent in 1990) and the ratio grew faster in the goods sector than in services over the three decades. In contrast, the total number of professional and technical workers as a share of total employment was more than twice as great in services as in goods industries in 1990 and grew faster in services than goods-producing industries between 1960 and 1990. The share of managers and administrators in total employment was greater in services but it grew faster in the goods sector.

As shown in Table 8, cognitive skill levels (SC) were, on average, higher in the service sector than the goods sector. In 1990, employees in FIRE had the highest average SC score (5.36), followed by general services (4.91), communications (4.86), and the government sector (4.68). The growth in mean SC was about the same in services as in the goods industries between 1960 and 1990. The pattern is very similar for the Med.Educ-70 (Median Education-1970) score. The average Med.Educ-70 score was higher in services than the goods sector and was led by general services (13.4 in 1990), followed by FIRE (13.2), communications (13.0), and government (12.9). The percentage change in this score over the three decades was also about the same in the goods and service sectors.

5. **Regression Analysis**.

I now turn to regression analysis to sort out the influences of these various technological indicators on measured productivity growth among industries. There are three main questions of interest. First, which, if any, of these factors is found to have a significant effect on measured productivity growth? Second, is the goodness of fit better among goods-producing industries alone in comparison to all industries, including services? Third, do the regression results differ substantially between goods-producing and service industries, and, if so, does this difference throw any light on measurement problems in service output?

The dependent variable in the regressions is the rate of TFP growth. The independent variables include the technological indicators described above, such as the ratio of OCA investment to FTEE, the ratio of total equipment investment to FTEE, the occupational change index, RDSALES, TFPIND, scientific and technical manpower as a proportion of total industry employment, and both the level and change in average industry skill scores.

The basic estimating equation is:

$$(7) \qquad TFPGRT_j = b_0 + b_1 \, RDSALES_j + b_2 \, TFPIND_j + b_3 \, TECHACT_j + \epsilon_j$$

where $TECHACT_j$ is one of the other indices of technological activity in the industry and ϵ_j is a stochastic error term. It is assumed that the ϵ_{jt} are independently distributed but may not be identically distributed. The regression results reported in Tables 9, 10, and 11 below use the White procedure for a heteroscedasticity-consistent covariance matrix. The constant b_0 is usually interpreted as the pure rate of technological progress.

The sample is a pooled cross-section time-series data set consisting of 68 industries and 3 time periods (1958-67, 1967-77, and 1977-87). From Griliches (1980), the coefficient of RDSALES is interpreted as the rate of return of R&D, under the assumption that the (average) rate of return to R&D is equalized across sectors. Time dummies for the periods 1967-77 and 1977-87 are introduced to allow for period-specific effects on productivity growth not attributable to R&D or the other technological indicators. A dummy variable identifying the 10 service industries is also included to partially control for measurement problems in service sector output. The regressions are also run separately among the 58 goods-producing industries and among the 10 service industries.

The first set of regression results, for all industries, is shown in Table 9. In specification (1), which includes only RDSALES, TFPIND, and a service dummy variable (SERVDUM) as independent variables, both RDSALES and

TFPIND have positive coefficients and are significant, at the five and one percent level, respectively. The coefficient of SERVDUM is negative, as expected, but not significant here. The goodness of fit, as measured by the adjusted-R^2 ($\bar{R}^2$), is only 0.076. When dummy variables are added in for the two time periods (DUM6777 and DUM7787), neither is statistically significant and the $\bar{R}^2$ statistic declines (results not shown).

In specifications (2)-(4), OCAFTEE (investment in OCA, in 1987 dollars, per FTEE) and DIOCCUP (the dissimilarity index based on changes in the occupational composition of employment within the industry) are included as independent variables along with RDSALES and TFPIND. Both variables have negative coefficients. However, OCAFTEE is not statistically significant, whereas DIOCCUP is significant at the 10 percent level when included by itself but not significant when included with OCAFTEE. The two other technology variables -- DIACOEFF (the dissimilarity index based on total interindustry coefficients) and EQUIPFTE (investment in equipment, machinery, and instruments, in 1987 dollars per FTEE), -- have negative but insignificant coefficients.

In Table 10, I add in the various indicators of the degree of "brainpower" within industry. Four of the indices -- KNOWLAVG (the share of knowledge workers in total industry employment, averaged over the period), PROFAVG (the share of professional and technical workers), SCAVG (the average substantive complexity or cognitive skill score of the industry, averaged over the period), and MEDUCAVG (the average median education-1970) -- are each statistically insignificant (see specifications 5 to 9). In two cases, the coefficients are actually negative (though insignificant). The change in these variables (as well as their annual growth rate, which is not shown) is each statistically insignificant, though their coefficients are generally positive. The major exception is ADMINAVG (the share of managerial and administrative workers in total employment), which has a positive coefficient that is significant at the five percent level. However, the change in the share of managerial and administrative workers has a negative coefficient, though it is insignificant. The evidence seems to suggest that, with the exception of managerial workers, the presence of high cognitive skill workers is not particularly beneficial to the productivity growth of an industry.[17]

Another interesting result is that the coefficient of TFPIND remains highly significant and its coefficient value remains virtually unchanged even with the inclusion of these skill variables. On the other hand, RDSALES becomes less significant and its coefficient value falls somewhat. The reason for this is that there is a positive correlation between the level of R&D expenditures of an industry and the industry's average skill level (correlation coefficients of 0.34 between RDSALES and KNOWLAVG, 0.37 between RDSALES and PROFAVG, and 0.34 between RDSALES and MEDUCAVG), reflecting the scientists and engineers employed in R&D activity. However, the correlation between RDSALES and ADMINAVG is slightly negative (-0.09). It is also of interest that the adjusted-R^2 statistic falls somewhat with the addition of these skill variables, again with the exception of ADMINAVG and ADMINCHG.

When the sample is restricted to goods industries only (Table 11), the coefficient estimates and significance levels of the two major technological variables -- RDSALES and TFPIND -- remain virtually unchanged, as shown in specification (10). However, none of the other technological variables is significant, including OCAFTEE, DIOCCUP, DIACOEFF, and EQUIPFTE, though they all still generally have negative coefficients (see specifications 11 and 12, for example). It is also of interest that when DIOCCUP is added to the regression, RDSALES remains significant, though at the 10 percent level (result not shown) but when any of the skill measures are added, with the exception of ADMINAVG, RDSALES becomes insignificant. The reason is that among goods industries by themselves, the correlation between RDSALES and the various skill measures is quite strong (a value of 0.54 between RDSALES and PROFAVG and 0.51 between RDSALES and MEDUCAVG, for example).

None of the "brainpower" variables is significant, except ADMINAVG, which is positive and significant at the 10 percent level (see specifications 11 and 12). Also of interest is that the goodness of fit of the various regression forms has not improved when the sample is restricted to goods-producing industries.

The regression results for the service industries by themselves, using conventionally measured TFP growth, are very different than those for the goods industries. As shown in specifications 13-15 of Table 11, the coefficient of TFPIND is now negative and generally significant at the ten percent level. The coefficients of both OCAFTEE and DIOCCUP are negative and significant at the one or five percent level in every case.[18] The adjusted-R^2 statistic is much higher for the service industry regressions than the goods industry regressions -- in the range of 0.20 - 0.26 compared to 0.07 - 0.09.

Of all the skill variables, only ADMINAVG has a positive and significant coefficient (at the five percent level). PROFAVG is significant at the five percent level but has a negative coefficient. None of the other skill level variables is significant.

6. **Conclusion and Interpretation of Results**

The regression results from the all-industry sample has provided some rather striking results. First, computerization (OCAFTEE) does not appear to exert a positive effect on productivity growth. Indeed, its coefficients have generally been negative (though not significant). My results differ from those reported by Brynjolfsson and Hitt (1997), Lehr and Lichtenberg (forthcoming), and Gera, Gu, and Lee (forthcoming), who generally find positive and significant coefficients on their computerization variables. There seem to be three reasons. First, Brynjolfsson and Hitt and Lehr and Lichtenberg use firms as their unit of observation whereas I use industry (Gera, Gu, and Lee also use industry data). Second, the sampling frames are different. In particular, my sample accords a greater weight to service industries. In particular, finance and insurance are marked outliers with, by far, the highest levels of computerization and among the lowest in terms of TFP growth -- a result I had commented on in earlier work (see Wolff, 1991). Third, and perhaps most importantly, I use pooled time-series and cross-section data, where the other three papers rely only on firm or industry cross-sectional data. Since my figures show a huge increase in computerization (OCAFTEE) over time, from 1958 to 1987, and a slowdown in productivity growth over the same period, the regression results fail to yield a significant coefficient on OCAFTEE. However, when I restrict the sample to the 1977-87 period (and also to goods industries), I do find a positive and significant (at least at the 10 percent level) coefficient on OCAFTEE.

Second, major restructuring of technology, as reflected in changes in the occupational composition of employment (DIOCCUP), seems to have a retardant effect on productivity growth. The first two sets of results might reflect the high adjustment costs associated with the introduction of new technology. The paradigmatic shift from electromechanical automation to information technologies might require major changes in the organizational structure of companies before the new technology can be realized in the form of measured productivity gains (see, David, 1991, for greater elaboration of this argument). Some confirmation of this hypothesis is provided by Brynjolfsson and Hitt, for example, who find that computerization has a positive effect on firm-level productivity only as long as there are concomitant changes in firm organization.

Third, "brainpower," as reflected in the various measures of worker skill, does not appear beneficial to productivity growth. The lone exception is the presence of administrators and managers (though not necessarily their growth over time), which is positively related to industry productivity growth. The likely rationale for this result is that many professional workers, such as lawyers, accountants, advertising personnel, and brokers, are involved in activities that inherently rent-seeking in nature or "unproductive" and do not increased measured output. For example, a study by Murphy, Schleifer, and Vishny (1991) reported cross-country regression results showing that per capita GDP growth is *negatively* related to the number of lawyers per capita of a country. However, managers should, in principle, be concerned with improving firm efficiency and lowering unit costs -- activities which would show up as higher measured productivity growth. However, overall, the results generally support the view that "brainpower" -- whether human or artificial -- has not greatly boosted measured productivity growth in the U.S. economy.

It still remains to resolve whether the poorer productivity performance of services is due to the fact that output is harder to measure in services or to the fact that productivity in services has very different determinants than productivity in goods industries. The regression results differ rather substantially between the goods-industry sample and the service industry sample. Productivity in services seems to suffer much more than in goods industries from computerization and technological restructuring (as reflected in OCAFTEE and DIOCCUP, respectively) and from the presence of high skilled workers than that of goods-producing industries.

It should be recalled from Section 4 that the aggregate performance of services in terms of both labor productivity and TFP growth was reasonably strong in the 1958-67 period. Moreover, both services and goods industries suffered major declines in productivity growth in the 1967-77 period. The major difference between the two sectors is that while productivity growth recovered in goods industries in the 1977-87 period, it failed to do so in services. The distinguishing features of service industries in the latter period were both its high rate of computerization and its rapid amount of employment restructuring.

The rather marked difference in regression results between the goods-producing and the service industry samples does, I believe, provide circumstantial evidence of mismeasurement of service output. It seems likely that "brainpower" - whether human or artificial -- is associated with a more heterogeneous output (or a greater variety of products), making output harder to measure. This, in turn, would suggest that the quality of service output is becoming harder to measure because of increasing heterogeneity.

The high degree of computerization found in finance, for example, has been responsible for the creation of a bewildering array of new financial products. The same appears to characterize the insurance industry and business services. Moreover, professional workers, such as lawyers, are often involved in the production of customized services, making their output very difficult to measure. The fact that both the computerization variable (OCAFTEE) and the share of professional workers in total employment (PROFAVG) have significant negative coefficients in regressions restricted to service industries but not in regressions involving goods industries is consistent with this argument. Moreover, the increasing magnitude of these two variables, particularly OCAFTEE, in service industries over time may likewise explain why the downward bias in measuring service output has itself risen over time.

A similar case can be made for the degree of employment restructuring (DIOCCUP). Rapid changes in employment mix in services, such as finance and business services, may also be associated with greater heterogeneity of products and increasing difficulties in measuring output. Likewise, the purchase of inputs which are themselves undergoing rapid technical change (reflected in TFPIND) may also lead to the provision of a new set of services by the industries which purchase such inputs. These two arguments would be consistent with the findings of significant negative coefficients for DIOCCUP and TFPIND in service industry regressions but not in goods-producing industry regressions. Likewise, the fact that the degree of employment restructuring increased substantially between the 1970s and 1980s would create increasing difficulties in measuring service output.

A simple experiment provides additional support to this argument. If one were to use the regression coefficients derived from goods-producing industry sample to predict TFP growth in service industries (based on their actual values for the independent variables), one would find that the predicted values of service industry TFP growth are almost universally greater than their actual measures. Moreover, the error (the difference between predicted and actual TFP growth) generally increases over time, between the 1958-67 and 1977-87 periods.

These results, however, should not be interpreted to mean that service sector productivity growth, even if correctly measured, will be as high as that in goods-producing industries. As we have argued elsewhere (bee Baumol, Blackman, and Wolff, 1989, Chapter 6), it is likely that services which are basically labor activities, such as haircutting, medicine, business services, and teaching, are inherently limited (that is, stagnant) in the degree to which they can increase the amount of output produced per hour of labor input. However, it still appears that for many of these service industries, the official national income and product account measures of output have led to an understatement of the actual increase in their productivity.

Footnotes

[1] In practice, this might not be altogether true since services are more poorly covered by government statistical surveys than goods industries, particularly manufacturing. Moreover, the relative abundance of good industries (again, notably manufacturing) in both national accounting and input-output data and the relative paucity of services also suggest greater measurement error in service inputs in comparison to inputs into goods-producing industries.

[2] An exception is the work on service sector productivity reported in McKinsey Global Institute (1992).

[3] The time subscript is dropped for notational convenience.

[4] In the traditional one-matrix input-output framework, the V matrix is implicitly treated as a diagonal matrix.

[5] An alternative formulation is possible through the industry technology model, where it is assumed that each industry has the same input requirements per dollar of output for each commodity which it produces and that the market shares for each commodity are fixed among industries. As documented in ten Raa and Wolff (1991), the industry technology model is unfortunately characterized by several serious analytical difficulties, so that I use only the commodity technology model here. However, actual estimates of industry TFP growth differ are very similar in the two models, since there are very few secondary products recorded on the 85-sector level. See ten Raa and Wolff (1991) for more details.

[6] It is implicitly assumed that the government sector receives a shadow rate of return r on its capital stock.

[7] The use of Leontief prices rather than market prices in measuring industry TFP growth makes relatively little difference in the actual empirical

estimates of TFP growth. Moreover, there is a strong correlation between industry TFP growth estimated by equation (2) and more standard TFP growth estimates based on national accounting output measures such as gross product originating or GDP and labor and capital inputs. For the 1963-77 period, I calculated a correlation coefficient between these two measures of 0.96 for 76 sectors and a rank correlation of 0.98. See Wolff (1994) for more details.

[8] In input-output data, there are many cells with zero values, so that the more usual logarithm transformation would not be applicable.

[9] See, for example, U.S. Industry Economics Division (1974), for a discussion of methodology and for a listing for the sectors. The single-table format relies on the so-called BEA transfer method. See Kop Jansen and ten Raa (1990) for a discussion of this method and its associated methodological difficulties.

[10] A description of the 1967 tables can be found in U.S. Interindustry Economics Division (1974); of the 1977 tables in U.S. Interindustry Economics Division (1984), and of the 1987 tables in Lawson and Teske (1994).

[11] Also see Wolff (1997) for details on data sources and methods.

[12] Sector numbers refer to the standard BEA 85-sector classification scheme. See, for example, U.S. Interindustry Economics Division (1984) for details.

[13] For a discussion of these measures as well as some of their limitations, see Miller et. al. (1980).

[14] It should be noted that this index is partially "contaminated" by the use of price deflators for service sector inputs.

[15] This index is also partially "contaminated" by the implicit use of sectoral price deflators for inputs from the service industries.

[16] Recently, there have been some estimates of R&D expenditures compiled for various service industries. However, they are currently available only for the 1990s and do not yet exist for the period 1958-1987.

[17] The remaining "brainpower" indicator -- the share of scientists, computer analysts, engineers, and technicians in total industry employment -- is also insignificant in both the level and change form.

[18] RDSALES is not included because by construction its value is zero for service industries. It should also be noted that the coefficient of TFPIND is positive and insignificant when OCAFTEE is omitted.

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Table 1
Labor and Total Factor Productivity (TFP) Growth By Major Sector, 1958-87[a]

(Average annual growth in percentage points)

	1958-67	1967-77	1977-87	1958-87
	1. Labor Productivity Growth			
A. Goods Industries				
Agriculture, forestry, and fisheries	2.91	-0.13	3.06	1.91
Mining	5.61	-1.04	0.06	1.41
Construction	0.64	-3.27	-1.27	-1.37
Manufacturing, Durables	3.02	2.47	2.87	2.78
Manufacturing, Nondurables	2.89	3.40	2.68	2.99
Transportation	3.15	1.21	1.44	1.89
Communication	5.48	4.69	4.83	4.98
Electric, gas, and sanitary services	5.44	5.32	-0.10	3.49
B. Service Industries				
Wholesale and retail trade	1.97	-0.23	1.47	1.04
Finance, insurance, and real estate	1.87	0.42	-0.77	0.46
General Services	0.99	0.72	-0.46	0.40
Government and government enterprises	0.25	0.08	0.19	0.17
Aggregated Sectors				
Total Goods	2.45	1.74	1.85	2.00
Total Services	1.20	0.46	0.35	0.65
Total Economy (GDP)	1.79	0.91	0.69	1.11
	2. Total Factor Productivity Growth			
A. Goods Industries				
Agriculture, forestry, and fisheries	-1.26	-2.23	3.38	0.00
Mining	2.13	-0.13	-3.07	-0.44
Construction	0.52	-4.23	-0.40	-1.43
Manufacturing, Durables	2.74	1.46	1.96	2.03
Manufacturing, Nondurables	2.42	2.06	1.76	2.07
Transportation	3.49	1.08	1.86	2.10
Communication	2.98	2.54	2.54	2.68
Electric, gas, and sanitary services	3.61	3.55	-0.29	2.25
B. Service Industries				
Wholesale and retail trade	0.99	-1.35	0.15	-0.11
Finance, insurance, and real estate	0.16	-0.50	-2.11	-0.85
General Services	0.11	-0.15	-0.72	-0.26
Government and government enterprises	0.25	-0.43	-0.17	-0.13
Aggregated Sectors				
Total Goods	2.14	0.62	1.04	1.24
Total Services	0.88	0.16	0.19	0.39
Total Economy (GDP)	1.49	0.28	0.34	0.68

a. See equation (2) for the definition of sectoral TFP growth and equation (3) for the definition of overall TFP growth.

Table 2
Growth Rates of the Capital-Labor and Interindustry Inputs-Labor Ratios
By Major Sector, 1958-87[a]

(Average annual growth in percentage points)

	1958-67	1967-77	1977-87	1958-87
	1. Capital / Labor Ratio			
A. Goods Industries				
Agriculture, forestry, and fisheries	5.51	11.98	-2.33	5.04
Mining	1.12	1.80	7.55	3.57
Construction	7.26	0.95	-2.36	1.77
Manufacturing, Durables	0.53	2.34	2.94	1.99
Manufacturing, Nondurables	2.26	2.47	1.90	2.21
Transportation	-0.48	1.45	-1.99	-0.33
Communication	4.85	4.63	3.10	4.17
Electric, gas, and sanitary services	1.93	5.44	-3.39	1.31
B. Service Industries				
Wholesale and retail trade	4.28	2.55	3.28	3.34
Finance, insurance, and real estate	3.64	5.12	3.91	4.25
General Services	4.86	0.37	0.72	1.88
Government and government enterprises	1.10	0.31	0.62	0.66
Aggregated Sectors				
Total Goods	2.49	3.30	1.30	2.36
Total Services	2.66	0.84	1.12	1.50
Total Economy	2.38	1.76	0.85	1.64
	2. Interindustry Inputs / Labor Ratio			
A. Goods Industries				
Agriculture, forestry, and fisheries	4.95	9.51	-0.34	4.70
Mining	2.06	4.31	3.91	3.47
Construction	4.13	-0.34	1.67	1.74
Manufacturing, Durables	3.02	0.93	2.15	2.00
Manufacturing, Nondurables	2.96	1.37	0.85	1.68
Transportation	2.98	3.60	1.85	2.80
Communication	5.73	3.58	10.73	6.71
Electric, gas, and sanitary services	4.10	1.64	-2.75	0.89
B. Service Industries				
Wholesale and retail trade	1.94	1.00	2.79	1.91
Finance, insurance, and real estate	0.86	-0.10	1.38	0.71
General Services	2.89	-1.15	3.41	1.68
Government and government enterprises	1.21	-0.32	3.70	1.54
Aggregated Sectors				
Total Goods	3.70	1.88	1.39	2.28
Total Services	1.90	-0.06	3.53	1.78

a. Capital is based on gross capital stock, labor on employment, and interindustry inputs are in constant (1972) dollars.

Table 3
Investment in Office, Computing, and Accounting Equipment (OCA)
And Total Machinery, Equipment, and Instruments per FTEE, 1958-87[a]

(1987$, Period Averages)

	1958-67	1967-77	1977-87	1958-87
	1. Investment in OCA / FTEE			
<u>A. Goods Industries</u>				
Agriculture, forestry, and fisheries	0.1	0.9	5.0	2.1
Mining	14.9	24.3	522.5	245.8
Construction	4.2	3.5	10.8	6.7
Manufacturing, Durables	17.7	30.9	265.5	116.9
Manufacturing, Nondurables	12.0	19.4	120.1	54.2
Transportation	20.0	17.7	117.3	57.4
Communication	22.6	25.6	226.2	109.4
Electric, gas, and sanitary services	21.5	16.6	464.1	208.4
<u>B. Service Industries</u>				
Wholesale and retail trade	9.3	16.3	171.5	85.5
Finance, insurance, and real estate	73.4	186.5	1,067.6	587.2
General Services	15.7	15.8	155.6	93.3
Government and government enterprises	NA	NA	NA	NA
<u>Aggregated Sectors</u>				
Total Goods	13.1	20.2	170.6	76.4
Total Services (except government)	20.1	39.1	279.6	155.0
Total Economy (except government)	16.0	29.2	231.8	115.6
	2. Investment in Machinery & Equipment / FTEE			
<u>A. Goods Industries</u>				
Agriculture, forestry, and fisheries	3,816	6,875	5,134	5,143
Mining	7,416	11,769	14,401	11,600
Construction	2,290	2,540	1,504	2,027
Manufacturing, Durables	1,841	2,580	3,089	2,540
Manufacturing, Nondurables	2,258	3,291	3,825	3,145
Transportation	4,931	7,058	6,117	6,013
Communication	9,140	14,314	18,253	14,429
Electric, gas, and sanitary services	11,658	18,970	21,309	17,872
<u>B. Service Industries</u>				
Wholesale and retail trade	957	1,349	1,934	1,512
Finance, insurance, and real estate	2,796	4,691	8,766	6,202
General Services	1,682	2,056	1,991	1,928
Government and government enterprises	NA	NA	NA	NA
<u>Aggregated Sectors</u>				
Total Goods	3,060	4,509	4,880	4,191
Total Services (except government)	1,433	2,054	2,834	2,292
Total Economy (except government)	1,995	3,340	3,732	2,613

a. Source for Investment Data: Bureau Of Economic Analysis, Department of Commerce, Diskette of Detailed Investment by Industry. Source for FTEE: Bureau of Economic Analysis, National Income and Product Accounts, diskettes.

Table 4
Dissimilarity Indices (DI) of Interindustry Technical Coefficients
And the Distribution of Occupational Employment, 1958-87

	1958-67	1967-77	1977-87	1958-87
	1. Dissimilarity Index (DI) for Interindustry Coefficients[a]			
A. Goods Industries				
Agriculture, forestry, and fisheries	0.001	0.018	0.023	0.003
Mining	0.050	0.045	0.066	0.070
Construction	0.013	0.033	0.020	0.055
Manufacturing, Durables	0.010	0.040	0.103	0.204
Manufacturing, Nondurables	0.012	0.021	0.014	0.041
Transportation	0.077	0.037	0.030	0.147
Communication	0.039	0.073	0.416	0.544
Electric, gas, and sanitary services	0.005	0.139	0.081	0.183
B. Service Industries				
Wholesale and retail trade	0.009	0.035	0.072	0.130
Finance, insurance, and real estate	0.023	0.041	0.028	0.074
General Services	0.023	0.157	0.046	0.264
Government and government enterprises	0.068	0.046	0.021	0.112
Total Goods	0.014	0.030	0.039	0.084
Total Services	0.017	0.020	0.020	0.068

	1960-70	1970-80	1980-90	1960-90
	2. Dissimilarity Index (DI) for Employment			
A. Goods Industries				
Agriculture, forestry, and fisheries	0.001	0.001	0.017	0.025
Mining	0.025	0.020	0.045	0.152
Construction	0.025	0.005	0.053	0.075
Manufacturing, Durables	0.039	0.014	0.096	0.147
Manufacturing, Nondurables	0.050	0.023	0.088	0.126
Transportation	0.024	0.014	0.048	0.089
Communication	0.061	0.043	0.128	0.262
Electric, gas, and sanitary services	0.169	0.053	0.105	0.231
B. Service Industries				
Wholesale and retail trade	0.019	0.029	0.078	0.162
Finance, insurance, and real estate	0.117	0.033	0.080	0.139
General Services	0.091	0.029	0.047	0.231
Government and government enterprises	0.054	0.042	0.045	0.106
Total Goods	0.061	0.014	0.110	0.199
Total Services	0.056	0.026	0.077	0.161
All Industries	0.056	0.019	0.095	0.162

a. Interindustry inputs are in constant (1972) dollars.

Table 5

The Ratio of Research and Development Expenditures to Sales (RDSALES)
For Manufacturing Industries, 1958-1977

(figures are in percent)

	1958-67	1967-77	1977-87	1958-87
Manufacturing, Nondurables				
Food products	0.39	0.44	0.40	0.41
Tobacco products	0.68	0.76	0.48	0.64
Textiles, apparel, fabrics	0.48	0.45	0.40	0.44
Lumber, wood products, furniture	0.46	0.65	0.76	0.62
Paper and paper products	0.17	0.88	1.00	0.68
Printing and publishing	0.68	0.76	0.48	0.64
Chemicals and allied products	3.97	3.32	3.41	3.56
Petroleum refining, related products	1.02	0.77	0.67	0.82
Rubber and miscellaneous plastics	2.04	2.31	2.22	2.19
Footwear, leather, leather products	0.68	0.76	0.48	0.64
Glass, stone and clay products	1.61	1.59	1.33	1.51
Miscellaneous manufacturing	0.68	0.76	0.48	0.64
Manufacturing, Durables				
Primary iron and steel	0.66	0.64	0.63	0.64
Primary nonferrous metals	0.97	1.02	1.00	1.00
Fabricated metal products	1.43	1.21	1.32	1.32
Engines, turbines, and machinery	2.10	2.20	2.18	2.16
Computer and office equipment	11.19	11.73	11.40	11.44
Service industry machinery	2.10	2.20	2.18	2.16
Appliances; electric equipment	7.19	6.11	5.71	6.34
Motor vehicles	2.91	3.38	3.94	3.41
Aircraft and parts	23.76	15.82	15.28	18.29
Other transportation equipment	1.05	1.22	0.85	1.04
Scientific instruments	6.15	5.52	7.05	6.24
Ophthalmic and photographic equipment	6.38	6.64	6.83	6.61
Ordnance and accessories	1.43	1.21	1.32	1.32
Unweighted Average				
Manufacturing, Nondurables	1.35	1.33	1.27	1.32
Manufacturing, Durables	4.48	3.95	3.87	4.10
Manufacturing, Total	3.11	2.80	2.73	2.88
Weighted Average[a]				
Manufacturing, Nondurables	1.06	1.14	1.09	1.09
Manufacturing, Durables	4.00	3.59	3.66	3.75
Manufacturing, Total	2.44	2.36	2.35	2.38

a. Weighted by gross output (GDO).

Table 6

Knowledge Spillovers between Sectors as Measured by the Rate of TFP Growth of Supplying Sectors (TFPIND), 1958-1977[a]

(figures are in percent)

	1958-67	1967-77	1977-87	1958-87
A. Goods Industries				
Agriculture, forestry, and fisheries	0.26	0.07	0.06	0.13
Mining	0.30	-0.01	0.04	0.11
Construction	0.51	0.11	0.18	0.27
Manufacturing, Durables	0.48	-0.03	0.16	0.20
Manufacturing, Nondurables	0.48	0.10	0.27	0.28
Transportation	0.24	-0.01	-0.03	0.06
Communication	-0.18	0.28	0.06	0.05
Electric, gas, and sanitary services	0.14	-0.20	-0.03	-0.03
B. Service Industries				
Wholesale and retail trade	0.19	0.20	-0.20	0.06
Finance, insurance, and real estate	0.13	0.09	-0.11	0.04
General Services	0.29	0.26	-0.03	0.17
Government and government enterprises	0.47	-0.25	0.14	0.12
Total Goods	0.44	0.03	0.17	0.21
Total Services	0.29	0.12	-0.03	0.13
All Industries	0.42	0.05	0.14	0.20

a. Figures are unweighted averages of individual industries within each major sector.

Table 7
Knowledge Workers and Related Workers as a Share of Industry Employment
By Major Sector in the U.S., 1960-90

(figures are in percent)

	1960	1970	1980	1990	Change 1960-90
1. Knowledge Workers / Total Employment					
A. Goods Industries					
Agriculture, forestry, and fisheries	0.9	2.3	3.4	3.6	2.7
Mining	7.6	10.5	12.6	14.8	7.3
Construction	7.2	7.7	7.6	10.1	2.9
Manufacturing, Durables	7.5	10.2	10.5	12.3	4.9
Manufacturing, Nondurables	6.4	8.1	8.9	11.1	4.8
Transportation	4.9	5.1	5.6	6.2	1.3
Communication	11.1	13.4	17.4	21.8	10.7
Electric, gas, and sanitary services	8.4	9.3	11.3	14.5	6.1
B. Service Industries					
Wholesale and retail trade	7.9	7.0	9.3	10.7	2.8
Finance, insurance, and real estate	10.6	10.6	12.1	15.4	4.8
General Services	11.1	12.5	13.7	15.6	4.5
Government and government enterprises	11.8	13.9	15.5	16.1	4.3
Aggregated Sectors					
Total Goods	6.1	8.3	9.0	10.9	4.7
Total Services	9.9	10.5	12.2	14.0	4.2
All Industries	8.0	9.6	11.0	12.9	4.9
2. Scientists, Computer Analysts, Engineers, & Technicians / Total Employment					
Total Goods	3.4	5.0	5.3	5.2	1.7
Total Services	1.3	2.0	2.5	2.4	1.1
All Industries	2.3	3.3	3.6	3.3	1.0
3. Professional and Technical Workers / Total Employment					
Total Goods	5.8	8.4	9.2	9.7	3.8
Total Services	16.0	20.2	21.6	22.0	6.1
All Industries	11.0	15.1	16.8	17.8	6.8
4. Managers and Administrators / Total Employment					
Total Goods	5.1	5.9	6.9	9.0	3.9
Total Services	12.5	10.6	12.6	13.9	1.5
All Industries	8.8	8.5	10.4	12.2	3.4

Table 8
Average Skill Scores By Major Sector in the U.S., 1960-90

	1960	1970	1980	1990	% Change 1960-90
	1. SC (Substantive Complexity)				
A. Goods Industries					
Agriculture, forestry, and fisheries	3.67	3.62	3.59	3.69	0.7
Mining	3.52	3.90	4.05	4.21	19.7
Construction	3.90	4.13	4.19	4.24	8.8
Manufacturing, Durables	3.50	3.75	3.79	3.92	12.0
Manufacturing, Nondurables	3.01	3.30	3.46	3.65	20.9
Transportation	3.17	3.32	3.38	3.27	3.0
Communication	4.13	4.39	4.62	4.86	17.9
Electric, gas, and sanitary services	3.78	3.97	4.17	4.49	18.8
B. Service Industries					
Wholesale and retail trade	3.85	3.82	3.94	4.02	4.2
Finance, insurance, and real estate	4.83	5.09	5.17	5.36	11.1
General Services	4.27	4.66	4.80	4.91	15.0
Government and government enterprises	4.22	4.38	4.54	4.68	10.9
Aggregated Sectors					
Total Goods	3.46	3.68	3.78	3.90	12.7
Total Services	4.15	4.37	4.52	4.64	11.8
All Industries	3.81	4.07	4.23	4.37	14.9
	2. Med.Educ-70 (Median Education-1970)				
A. Goods Industries					
Agriculture, forestry, and fisheries	10.19	10.34	10.49	10.65	4.5
Mining	11.42	11.69	11.89	12.04	5.4
Construction	11.17	11.38	11.43	11.46	2.6
Manufacturing, Durables	11.81	12.00	12.05	12.07	2.2
Manufacturing, Nondurables	11.44	11.65	11.76	11.86	3.7
Transportation	11.56	11.71	11.76	11.63	0.6
Communication	12.66	12.80	12.92	12.96	2.4
Electric, gas, and sanitary services	11.92	12.02	12.19	12.42	4.2
B. Service Industries					
Wholesale and retail trade	12.10	12.09	12.13	12.07	-0.2
Finance, insurance, and real estate	12.73	13.00	13.07	13.15	3.3
General Services	12.68	13.23	13.36	13.42	5.8
Government and government enterprises	12.71	12.79	12.90	12.94	1.8
Aggregated Sectors					
Total Goods	11.40	11.69	11.78	11.81	3.5
Total Services	12.46	12.76	12.87	12.91	3.6
All Industries	11.94	12.30	12.45	12.51	4.8

Table 9
Regressions of Industry TFP Growth (TFPGRT)
On Technological Variables: All Industries[a]

Independent Variables	Specification (1)	(2)	(3)	(4)
Constant	0.0002	0.0029	0.0051**	0.0048*
	(1.44)	(1.58)	(2.17)	(1.95)
RDSALES	0.072**	0.073**	0.068*	0.069*
	(1.99)	(1.97)	(1.81)	(1.82)
TFPIND	0.924***	0.896**	0.960***	0.966***
	(2.77)	(2.45)	(2.82)	(2.61)
OCAFTEE		-0.052		-0.027
		(0.79)		(0.38)
DIOCCUP			-0.042*	-0.035
			(1.71)	(1.21)
SERVDUM	-0.0052	-0.0082*	-0.0057	-0.0086*
	(1.23)	(1.75)	(1.37)	(1.85)
R^2	0.089	0.122	0.113	0.138
$\bar{R}^2$	0.076	0.104	0.095	0.116
Std Err σ	0.0147	0.0144	0.0146	0.0143
Sample Size	204	198	204	198

a. Estimated coefficients are shown below the respective independent variables and the absolute value of the t-statistic is shown in parentheses. The White procedure for a heteroscedasticity-consistent covariance matrix is used in the estimation.

* Significant at the .10 level (two-tailed test).
** Significant at the .05 level (two-tailed test).
*** Significant at the .01 level (two-tailed test).

Key:

TFPGRT: Annual rate of growth of total factor productivity.

RDSALES: Ratio of R&D expenditure in constant dollars to GDP in constant dollar

TFPIND: A weighted sum of the annual rates of TFP growth of supplying industries, where the weights are given by the interindustry input coefficients.

SERVDUM: Dummy variable for the 10 service industries.

OCAFTEE: Investment in OCA, in 1987 dollars, per FTEE

DIOCCUP: Dissimilarity Index based on 267 occupations by decade.

KNOWLAVG: The ratio of knowledge workers to total employment, period average

KNOWLCHG: The change in the ratio of knowledge workers to total employment over the period.

PROFAVG: The ratio of professional and technical workers to total employment, period average

PROFCHG: The change in the ratio of professional and technical workers to total employment over the period.

ADMINAVG: The ratio of administrative and managerial workers to total employment, period average

ADMINCHG: The change in the ratio of administrative and managerial workers to total employment over the period.

SCAVG: Average SC (substantive complexity) score by industry, period average

SCCHG: The change in average SC (substantive complexity) score by industry over the period

MEDUCAVG: Average Med.Educ-1970 score by industry, period average

MEDUCCHG: The change in average Med.Educ-1970 score by industry over the period

Table 10

Regressions of Industry TFP Growth (TFPGRT)
On Technological and Skill Variables: All Industries[a]

Independent Variables	Specification (5)	(6)	(7)	(8)	(9)
Constant	0.0045*	0.0054**	0.0001	0.0055	-0.0059
	(1.71)	(2.12)	(0.06)	(0.70)	(0.26)
RDSALES	0.067*	0.069*	0.065*	0.061	0.054
	(1.76)	(1.73)	(1.83)	(1.48)	(1.23)
TFPIND	1.036***	0.904**	1.170***	0.845**	0.897**
	(2.76)	(2.47)	(3.19)	(2.28)	(2.39)
DIOCCUP	-0.044*	-0.041*	-0.054**	-0.044**	-0.043*
	(1.68)	(1.66)	(2.52)	(2.05)	(1.92)
Average Skill	0.0095	-0.0046	0.0906**	-0.0003	0.0009
	(0.47)	(0.30)	(2.20)	(0.15)	(0.40)
Change in Skill	-0.0321	0.0261	-0.0334	0.0091	0.0098
	(0.42)	(0.41)	(0.52)	(1.40)	(1.13)
SERVDUM	-0.0059	-0.0056	-0.0105**	-0.0059	-0.0069
	(1.23)	(1.26)	(2.08)	(1.22)	(1.40)
R^2	0.116	0.115	0.142	0.122	0.120
$\bar{R}^2$	0.089	0.088	0.115	0.095	0.093
Std Err σ	0.0146	0.0146	0.0144	0.0146	0.0146
Sample Size	204	204	204	204	204
Skill Measures	KNOWLAVG KNOWLCHG	PROFAVG PROFCHG	ADMINAVG ADMINCHG	SCAVG SCCHG	MEDUCAVG MEDUCCHG

a. See footnotes to Table 9 for key.

* Significant at the .10 level (two-tailed test).
** Significant at the .05 level (two-tailed test).
*** Significant at the .01 level (two-tailed test).

Table 11

Regressions of Industry TFP Growth (TFPGRT) on Technological And Skill Variables: Goods and Service Industries Separately[a]

Independent Variables	Goods Industries Only (10)	(11)	(12)	Service Industries Only (13)	(14)	(15)
Constant	0.0024	0.0024	-0.0010	0.0237***	-0.0082	0.1090
	(1.41)	(0.92)	(0.31)	(3.97)	(0.68)	(1.61)
RDSALES	0.072**	0.037	0.063*			
	(1.99)	(1.05)	(1.77)			
TFPIND	0.928***	1.071***	1.145***	-3.759*	-0.396	-4.102*
	(2.64)	(2.80)	(2.97)	(1.86)	(0.19)	(1.91)
OCAFTEE				-0.375***	-0.272**	-0.325***
				(5.22)	(2.75)	(5.42)
DIOCCUP		-0.032	-0.038	-0.220**	-0.189**	-0.209***
		(1.03)	(1.28)	(2.43)	(2.68)	(3.48)
Average Skill		0.0226	0.0860*	-0.0426**	0.1753**	-0.0074
		(1.25)	(1.86)	(2.21)	(2.15)	(1.43)
Change in Skill		0.0003	-0.0070	0.1819	-0.1330	0.0197
		(0.01)	(0.10)	(1.01)	(1.16)	(1.15)
R^2	0.081	0.105	0.118	0.424	0.394	0.381
$\bar{R}^2$	0.072	0.078	0.092	0.264	0.225	0.209
Std Err σ	0.0130	0.0129	0.0129	0.0195	0.0200	0.0202
Sample Size	174	174	174	24	24	24
Skill Measures		PROFAVG PROFCHG	ADMINAVG ADMINCHG	PROFAVG PROFCHG	ADMINAVG ADMINCHG	MEDUCAVG MEDUCCHG

a. See footnotes to Table 9 for key.

* Significant at the .10 level (two-tailed test).
** Significant at the .05 level (two-tailed test).
*** Significant at the .01 level (two-tailed test).