Technology and the Demand for Skills

by

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Working Paper No. 153

December 1995

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I would like to express appreciation to The Jerome Levy Economics Institute for financial support.

The U.S. economy has undergone major structural changes since 1950. First, there has been a gradual shift of employment from goods-producing industries to service-providing industries. Second, since the 1970s at least, the availability of new information-based technologies has made possible substantial adjustments in operations and organizational re-structuring of firms. This has been accelerated, in part, by sharply increasing competition from imports. Evidence from industry level case studies indicate that this restructuring is likely to have important consequences for the level and composition of skills required in the U.S. workplace (see Adler, 1986, and Zuboff, 1988).

The direction and extent of changes in skill levels over the longer run has, however, been more uncertain, with case studies often finding a deskilling of the content of production jobs and aggregate studies finding little change or at most a gradual upgrading in overall occupation mix (see Spenner, 1988, for a survey of this literature). These trends have considerable policy significance since they help determine education and training needs. One important result of this paper, for example, is that a growing mismatch has been occurring between skill requirements of the workplace and educational attainment of the workforce, with the latter increasing much more rapidly than the former.

The first section of this paper documents changes in aggregate skill levels of the workplace over the period 1950 to 1990. I rely mainly on the

Dictionary of Occupational Titles (DOT), which offers direct measures of the skill requirements of detailed jobs (see Rumberger, 1981, for example). Cognitive, interactive and motor skill indices from the fourth edition of the DOT (see U.S. Department of Labor, 1977) are linked to consistent employment matrices for Census years 1950, 1960, 1970, 1980, and 1990 (267 occupations by 64 industries).[1] I also use standard measures of workforce skills based on educational attainment. Comparisons in the trends of the two types of measures are highlighted in this section.

The second part of the paper investigates skill trends at the sectoral level. Here it will be clear that some industries have been more dynamic than others in both upgrading and downgrading skill requirements. Differences in skill change between goods and service industries receive special attention. Changes in aggregate skill levels result from both changes in skill requirements at the industry level and structural shifts in employment patterns across industries. The former is normally interpreted as deriving from changes in technology and the latter from shifting patterns of demand. The last part of section 2 provides a decomposition of changes in aggregate skill levels into these two components.

Section 3 of the paper analyzes the role of technological change in explaining the changing demand for skill. This deserves some comment. The notion that technological change may stimulate the demand for more skilled or better education labor emanates from the work of Arrow (1962) and Nelson and Phelps (1966). Arrow introduced the notion of learning-by-doing, which implies that experience in the application of a given technology or new technology in the production process leads to increased efficiencies over time. One implication of this is that an educated labor force should "learn faster" than a less educated group. Industries with more rapid rates of technological progress may thus favor workers will greater potential for learning.

In the Nelson-Phelps model, it is argued that a more educated workforce may make it easier for a firm to adopt and implement new technologies. Firms value workers with education because they are more able to evaluate and adapt innovations and to learn new functions and routines than less educated ones. In this model, too, technological change may stimulate the demand for skilled workers.

Several studies provide evidence (both direct and indirect) of a positive relation between the pace of technological activity and the demand for educated labor. Welch (1970) analyzed the returns to education in U.S. farming in 1959 and concluded that a portion of the returns to schooling results from the greater ability of more educated workers to adapt to new production technologies. Bartel and Lichtenberg (1987), using industry-level data for 61 U.S. manufacturing industries over the 1960-1980 period, found that the relative demand for educated workers was greater in sectors with newer vintages of capital. They inferred from this that highly educated workers have a comparative advantage with regard to the implementation of new technologies.

A related finding is reported by Mincer and Higuchi (1988), using U.S. and Japanese employment data, that returns to education are higher in sectors undergoing more rapid technical change. Another is from Gill (1989), who calculated on the basis of U.S. Current Population Survey data for 1969-1984 that returns to education for highly schooled employees are greater in industries with higher rates of technological change.

In section 3, regression analysis is employed to relate the change in skill indices to various measures of technological activity, including traditional measures of total factor productivity growth, as well as computer intensity, research and development intensity, and capital vintage. The regressions are performed at the industry level, for the period from 1970 to 1990.[2]

1. **Aggregate Skill Trends, 1950-1990**

A. Measures of Labor Skills.

Labor skills appear in a wide variety of dimensions. Jobs are defined by a set of tasks requiring some combination of motor skills (physical strength, manual dexterity, motor coordination), perceptive and interpersonal skills, organizational and managerial skills, autonomy and responsibility, verbal and language skills, diagnostic skills (synthetic reasoning abilities) and analytical skills (mathematical and logical reasoning abilities). Perhaps, the best source of detailed economy-wide measures of skill requirements for the period since 1960 is the fourth (1977) edition of the 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.[3] On the basis of this source, four measures of workplace skills are developed for each occupation, as follows:

1. General Educational Development (GED). On a scale of one to six, GED measures mathematical, language and reasoning skills and is taken directly from the DOT.

2. Substantive Complexity (SC). SC is a composite measure of skills derived from a factor analytic test of DOT variables by Roos and Treiman (Miller et. al., 1980: Appendix F). The results provided strong support for

the existence of such a factor: it was highly correlated with General Educational Development, Specific Vocational Preparation (training time requirements), Data (synthesizing, coordinating, analyzing), and three worker aptitudes - Intelligence (general learning and reasoning ability), Verbal and Numerical. Both GED and SC measure cognitive skills and are highly correlated across industries.

3. Interactive Skills (IS). IS can be measured, at least roughly, by the DOT "People" variable, which, on a scale of 0-8, identifies whether the job requires mentoring (0), negotiating (1), instructing (2), supervising (3), diverting (4), persuading (5), speaking-signaling (6), serving (7) or taking instructions (8). For comparability with the other measures, we have rescaled this variable so that its values range from 0 to 10 and reversed the scoring so that mentoring, the highest form of interactive skill, is now scored 10 and taking instructions is scored 0.

4. Motor Skills (MS). MS is measured by another factor-based variable from the Miller study (1980, p. 339). Also scaled from 0 to 10, this measure reflects occupational scores on motor coordination, manual dexterity and "things" - job requirements that range from setting up machines and precision working to feeding machines and handling materials. These traditional shop-floor skills have been the focus of much of the deskilling debate.

Another measure of workplace skills is derived from the 1970 Census of Population data:

5. 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. In a sense, this measure gives us a "constant educational requirements"

measure by occupation, in contrast to the actual educational attainment of workers in each occupation on a year-by-year or "current" basis. This is analogous to constant dollar versus current dollar output series. 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. We shall return to this point below.

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 1950, 1960, 1970, 1980, and 1990 on the basis of occupation by industry employment matrices for each of these years constructed from decennial Census data. There are 267 occupations and 64 industries. Since occupation and industry classifications have changed substantially with each census, we used Commerce Department compatibility tables for 1950-60, 1960-70 and 1970-80 to produced consistent matrices for 1950, 1960, 1970, and 1980. Fortunately, there were only very minor changes in classification between 1980 and 1990.

It should be emphasized at the outset that no attempt is made to account for changes in the skill content of specific occupations. Such a project would require a comparison of skill levels over successive editions of the DOT. Moreover, the last edition was published in 1977. There is some evidence that the skill content of some jobs do change over time. Hirschhorn (1986) notes the increasing importance of diagnostic skills and synthetic reasoning abilities with the use of programmable automation. Similarly, Zuboff (1988 pp. 75-76) writes that operators increasingly require a new kind of thinking, which "...combines abstraction, explicit inference, and procedural reasoning." However, the evidence from studies that have looked across all occupations suggests that there are changes in skill content in both directions, and the net effect is small (see Horowitz and Hernstadt, 1966, and Spenner, 1983, pp. 830-831).

Another point worth noting is that if the skill requirements of a job change substantially, then the U.S. Bureau of the Census classifies this as a new occupation. The number of occupations contained in the Census data has grown considerably over time -- particularly between 1960 and 1980, when the number increased from 277 to 505. It is probably not unreasonable, therefore, to assume that, on average, the skill levels of occupations have remained largely unchanged over the 1950-90 period.

Educational attainment has also been employed to measure the skills supplied in the workplace. The usefulness of schooling measures is limited by such problems as variations in the quality of schooling both over time and among areas, the use of credentials as a screening mechanism, and inflationary trends in credential and certification requirements. Indeed, there is some empirical evidence that years of schooling may not closely correspond to the technical skill requirements of the jobs (see Rumberger, 1981, for example).

For comparison purposes, we have also constructed three measures of the actual educational attainment of the adult population or workforce in each of the Census years: (i) percent of the adult population ages 25 and over with a high school degree; (ii) percent of the adult population ages 25 and over with a college (B.A.) degree; and (iii) mean schooling of the workforce (see footnotes to Table 2 for sources and methods). These measures are based on economy-wide data (mainly household surveys) for the population but are not available on the industry level. Moreover, unlike EDUC-1970, these measures are based on current educational data for each of the Census year and may thus be interpreted as an indicator of workforce skills.

B. Broad Occupational Trends

I begin with general trends in the occupational composition of employment over the period 1950 to 1993. As shown in Table 1, some of the changes have been quite dramatic. Professional and technical workers doubled as a share of employment, from 8.6 percent in 1950 to 17.5 percent in 1993. Managers and administrators also increased substantially as a proportion of the work force, from 8.7 to 12.9 percent. Clerical workers grew as a share over the same period, from 12.3 to 15.6 percent. A much higher proportion of the labor force were also engaged as sales workers by 1993, with most of the increase apparently occurring during the 1980s.[4] The other major increase occurred for service workers (excluding private household workers), whose share rose from 7.8 to 13.1 percent.

The other occupational categories all declined as a share of employment. The proportion of the labor force employed as craftsmen fell from 14.2 to 11.2 percent and as operatives (that is, machine and transportation operators) from 20.4 to 10.4 percent. Nonfarm laborers (that is, unskilled workmen except those employed on the farm) declined from 6.6 percent of employment to 3.9 percent. Domestic servants and other household workers declined as a proportion of the employed labor force from 2.6 to 0.8 percent. Finally, farmers, farm managers, and farm laborers together fell from 11.8 percent of total employment to only 2.8 percent. In sum, the postwar period witnessed a sizable relative reduction in blue collar work and a corresponding increase in white collar jobs, particularly professional and technical positions.

C. Trends in Aggregate Skill Levels

The results portrayed in Figure 1 show that, with the exception of motor skills, changing employment patterns have had the effect of raising the skill requirements of jobs between 1950 and 1990. Of the five indicators of workplace skills, the average SC level in the economy as a whole had the highest growth, 16 percent over the four decades. GED and EDUC-1970 grew slower, at 9 and 8 percent, respectively, while IS increased by 7 percent. MS, on the other hand, showed a 2 percent decline over the 40 years.

Growth in workplace skills was dwarfed by increases in the educational attainment of the workforce and adult population, particularly as evidenced in the rescaled Figure 2. The fraction of the adult population (25 years of age and over) with a high school diploma or better more than doubled between 1950 and 1990, from 34 to 78 percent, while the proportion of adults who had completed at least four years of college more than tripled, from 6.2 to 21.3 percent. The mean schooling level of employed workers grew slower than these first two indicators, at 38 percent over the forty-year stretch, but at five times the rate of GED and EDUC-1970. Thus, the educational attainment of the population increased considerably faster than the educational requirements of the workplace in the postwar period.

Another striking result is the pronounced slowdown in the rate of growth for all 5 measures of workplace skills, with the exception of IS, between the 1960s and the 1980s, after a rapid acceleration between the 1950s and 1960s (see Table 2 and Figure 3). Skill growth was quite low during the 1950s. Between the 1950s and 1960s, it increased more than four-fold for SC, tripled for IS, more than doubled for both GED and MS, and rose by more than half for EDUC-1970. Skill growth peaked in the 1960s. Between the 1960s and 1980s, it fell off by half for SC and GED. The annual rate of growth in EDUC-1970 declined from 0.30 percent in the 1960s to 0.12 percent in the 1970s and 0.05 percent in the 1980s. The growth in MS, which was positive in the 1950s and

1960s turned negative in the 1970s and 1980s. The annual growth in IS fell from 0.27 percent in the 1960s to 0.18 percent in the 1970s but then rebounded to 0.25 percent in the 1980s.

Patterns of skill growth generally correlate with changes in the broad occupational composition of the labor force. The growth in SC, GED, IS, and EDUC-1970 over the four decades reflects the increasing share of professionals and managers in the workforce, while the decreasing share of craft workers and operatives in employment appears responsible for the postwar decline in motor skills. The decade-by-decade correspondence is a bit rougher. The peak growth in cognitive skills during the 1960s seems to be due to the particularly rapid increase in the share of professionals in the labor force over that period (3 percentage points). The decline in motor skills after 1970 seems to be attributable to the very sharp reduction in the fraction of operatives in the workforce dating from that year. The rebound in IS growth in the 1980s correlates with the large jump in the share of managers and administrators employed in the economy (about 2 percentage points).[5]

Figure 4 contrasts the growth in workplace skills with trends in the educational attainment of the population and the workforce. As noted above, the growth in educational attainment has been considerably greater than that of workplace skills. Here, we focus on the time pattern over the four decades. Of the three measures of educational attainment, only the mean education of the workforce has the same pattern as cognitive skills, with the rate of growth rising between the 1950s and 1960s and then falling off in the 1970s and again in the 1980s. However, interestingly, the difference in the growth in mean schooling is relatively small between the 1950s, 1960s, and 1970s, whereas it is much lower (by about two-thirds) in the 1980s.

The growth in the percent of adults with a high school education or more is highest in the 1950s, falls off somewhat in the 1960s, remains about the same in the 1970s, and then declines sharply in the 1980s. The growth in the proportion of adults with a B.A. or more declines somewhat between the 1950s and 1960s, peaks in the 1970s, and then falls off substantially in the 1980s. These results again emphasize the lack of correspondence between the growth in the demand for cognitive skills (as reflected in the direct skill measures) and the supply of such skills, as reflected in the educational attainment of the population.

2. **Skill Changes at the Industry Level**

There are striking differences in skill requirements among industries in the U.S. economy. These are shown in Table 3 for 9 major industrial groupings in 1970 (also see Figure 5). Mean substantive complexity (SC) scores ranged from a low of 3.6 in manufacturing to a high of 5.1 in finance, insurance, and real estate (FIRE, for short). SC levels were about a fifth higher in services than goods-producing industries. Median education levels (EDUC-1970) were about 10 percent higher in the service industries than the goods sectors. The highest EDUC-1970 was recorded in the other services sector, which includes a wide range of business and personal services, at 13.2 years, followed by FIRE (13.0 years) and the government sector (12.8 years). The lowest median education level was found in agriculture (10.3 years).

Interactive skills (IS) were almost twice as high in services as in goods-producing industries. The top three sectors in terms of IS were the same as for EDUC-1970: the other services sector, FIRE, and the government sector. Manufacturing had the lowest IS level. In contrast, motor skill (MS) levels were 14 percent higher in goods industries than service industries.

Not surprisingly, construction had the highest MS level, followed by manufacturing and mining. Wholesale and retail trade had the lowest MS score.

The addendum to Table 3 provides another bifurcation of jobs -- in this case, into production and non-production workers on the basis of the U.S. Bureau of Labor Statistics definition for the manufacturing sector. Production workers are blue-collar workers with the exception of service workers, while non-production workers include white-collar and service jobs. This division has been used in many recent productivity and earnings studies, such as Berman, Bound, and Griliches (1994), to distinguish between skilled and unskilled workers.

The results show that production workers score much higher than non-production workers in SC and IS but the difference in educational attainment is less pronounced. Moreover, as expected, production workers have substantially higher motor skills. Moreover, the standard deviation of skill scores is considerably higher among non-production than production workers, indicating that the former are a more heterogeneous group. These results suggest caution in using production versus non-production workers as a demarcation between skilled and unskilled jobs.

Some industries have also been more dynamic than others in both upgrading and downgrading skill requirements. Interestingly, SC scores have grown much faster in goods industries than service industries over the years from 1950 to 1990 -- 16 versus 10 percent (also see Figure 6). Mining led the way with a 32 percent increase, followed by construction (23 percent) and then manufacturing and FIRE (both at 20 percent). Agriculture and the trade sector experienced almost no change in SC levels.

The same is true for EDUC-1970 (where jobs are rated according to their 1970 educational requirements). EDUC-1970 grew by 6.0 percent in goods industries and 3.9 percent in services. Mining, again, was at the top of the list (8.7 percent increase), followed by FIRE (5.2 percent), and then agriculture and construction (both at 5.0 percent). Growth in educational requirements was lowest in the trade sector -- slightly negative over the period. The upgrading of SC and educational requirements in the goods industries reflects the more rapid growth in white-collar jobs than blue-collar ones, particularly from the industrial restructuring of the 1980s.

Interactive skills grew slightly more in services than goods industries. Growth was strongest in FIRE, at 11.2 percent, followed by other services (6.5 percent), and, surprisingly, mining (6.5 percent). Growth was weakest in agriculture, 0.6 percent.

Unlike the other measures in this table, motor skills requirements declined after 1950. This was true of every major industry except trade. While case studies have suggested that deskilling has occurred via the decline in the skill content of many blue-collar jobs, these industry results indicate that changes in occupation employment patterns within industry also contributed to a reduction in the demand for manual skills.

Substantive complexity, interactive skills, and motor skills represent three relatively independent dimensions of job skills. Looking at Figures 5 and 6, we can see quite clearly that industries that are strong in one dimension of skill need not be strong in the other dimensions as well. For example, while FIRE ranked highest in SC in 1970 it ranked second in IS but last in MS. Moreover, industries that grow rapidly in one skill direction did not necessarily grow in others. FIRE, for example again, had the highest growth in IS, ranked third highest in SC growth but recorded the lowest growth in MS. This stresses the importance of considering multiple dimensions of skills rather than a single one, such as educational attainment, that is used in most studies on this subject.

A. Industry Effects on Aggregate Skill Growth.

Changes in aggregate skill levels result from both changes in skill requirements at the industry level and structural shifts in employment patterns across industries. The former is normally interpreted as deriving from changes in technology and the latter from shifting patterns of demand.

Before presenting a formal decomposition, it is helpful to look at the broad changes in employment composition by industry over the postwar period (see Table 4). One of the most dramatic changes has been in agriculture, which accounted for 14 percent of employment in 1950 and only 3 percent in 1993. This relative decline has been going on for at least the last 100 years. In 1929, for example, the fraction of total employment accounted for by agriculture was 22 percent. The proportion fell to 14 percent in 1947, 8 percent in 1960, and 4 percent in 1978. The major decline in employment in the agricultural sector was from the exodus of owners of small farms and their families.

Another major change occurred in manufacturing, whose share of total employment fell by almost half, from 29 percent in 1950 to 16 percent in 1993. In absolute terms, employment in manufacturing peaked in 1980 at 20.3 million workers and has since fallen to 17.8 million in 1993. Much discussion has recently ensued over this development, which has been labelled by some as the "deindustrialization" of America. However, it should be noted that much of the decline in employment in manufacturing is due to the high (labor) productivity growth of this sector. In fact, manufacturing accounted for almost the same share of total output in the early 1990s as it did in the early 1950s.[6]

The share of employment in mining also declined rather precipitously between 1950 and 1993, from 1.7 to 0.5 percent. The share of employment in transport and public utilities also fell over this period, from 7.7 to 5.0 percent, while the proportion of workers in construction remained roughly constant, about 4 percent.

If the share of employment fell in agriculture, mining, manufacturing, and transport and utilities, where did it increase? The answer is the service sectors, which absorbed most of the growth of employment in the postwar period. The proportion of total employment in wholesale and retail trade increased from 18 to 23 percent, the percent in finance, insurance, and real estate from 3.6 to 5.8, the percent on government payrolls from 12 to 17, and the share in other services (personal and business) from 10 to 27 percent. In sum, two major developments characterized the postwar period. The first was the shrinking share of workers employed in agriculture and manufacturing, and the second was the shift of the work force out of goods-producing sectors into services.

Changes in overall skill levels are a result of changes in the skill levels of individual industries (through changes in occupational mix) and employment shifts among industries. We can formally decompose the change in overall job skill requirements into an industry and occupation effect, as follows. Let

M = the occupation-by-industry employment matrix, where m_{ij} shows employment of occupation i in industry j.

e = vector with unit entries.

$L = eM$ = (row) vector showing total employment by industry.

p = (row) vector showing the distribution of employment among industries, where

$p_j = L_j / \Sigma L_j$.

s = (column) vector showing the average skill level of each industry j.

σ = ps = the overall or economy-wide average skill level of employed workers.

Then, for instantaneous changes,

$$d\sigma = pds + (dp)s \ .$$

Since our data are for discrete time periods, we use the discrete form,

$$(1) \quad \Delta\sigma = p\Delta s + (\Delta p)s,$$

where $\Delta s = s^2 - s^1$, $\Delta p = p^2 - p^1$, and superscripts refer to time period. The results are based on average period weights, which provides an exact decomposition.

The results are shown in Table 5. During the 1950s, all the growth in Substantive Complexity (SC) was due to changes in the occupational composition of the work force within industry (by our interpretation, technological change). In fact, employment shifted slightly in favor of industries with below average SC levels. During the 1960s, the period of greatest overall growth in SC, both the occupational mix effect and the industry shift effect were positive and strong. If the industry shares of employment had remained unchanged, economy-wide mean cognitive skill levels would have grown by 0.15, over twice the increase of the 1950s. However, higher-skilled industries experienced greater than average employment growth (the industry shift effect), which accounted for an additional 0.12 increase in mean cognitive skills. During the 1960s, a bit over half of the growth in average SC was attributable to changes in occupational mix.

The contribution of the occupational mix effect fell off sharply between the 1960s and 1970s, from 0.150 to 0.068, and again between the 1970s and 1980s, from 0.068 to 0.038, while the industry shift effect fell off slightly. As a result, overall SC growth declined in the 1970s and again in the 1980s. Moreover, the industry shift effect, which accounted for less than half of overall SC growth in the 1960s, accounted for over 70 percent in the 1980s.

A very similar pattern is evident for our fixed educational requirements variable, EDUC-1970, and for interactive skills (IS) with regard to occupation effects. In both cases, almost all the growth in average skill during the 1950s was attributable to changes in occupational composition. Moreover, between the 1950s and 1960s, the occupational mix effect increased in importance (almost doubling for IS), and then fell off sharply in the 1970s and again in the 1980s.

There is a difference in the pattern of industry effects between EDUC-1970 and IS. In the case of the former, the industry shift effect fell off sharply between the 1960s and 1970s and again between the 1970s and 1980s, so that the growth in overall EDUC-1970 likewise fell off sharply. Moreover, the occupation mix effect was the dominant component of overall skill gain during the 1970s and 1980s. In the case of interactive skills, the industry shift effect became stronger after the 1960s, so that overall IS growth in the 1980s was about the same as in the 1960s. Moreover, the industry shift effect accounted for over 70 percent of the overall growth in IS in the 1980s.

Changes in motor skills (MS) show a very different pattern from the other three skill measures. The occupation mix effect was negative and of very similar magnitude in each of the four decades, reflecting the shift of employment within industry from blue-collar to white-collar jobs. The industry shift effect was positive and relatively strong in both the 1960s and 1970s, favoring industries with above-average motor skills and accounting for the positive increase in motor skills over these two decades. However, the industry effect turned negative in the 1970s and even more negative in the 1980s, reflecting the dramatic shift of employment toward service industries and accounting for the decline in overall MS growth in those two periods.

It is also interesting to note that over the entire 1950-90 period, changes in average SC and MS levels were about equally attributable to technological change (52 percent) and to shifting demand patterns (48 percent). However, about two-thirds of the upgrading in IS levels and over 70 percent of the increase in MED-EDUC were accounted for by the occupation mix effect.

3. **Technology and Skill Growth**

The literature cited in the introduction above suggests that there may be a strong correlation between skill growth and the pace of technological change. The analysis begins with some descriptive statistics, illustrated in Figure 7. I use two standard measures of productivity growth --- GDP per Full-Time Equivalent Employee (FTEE) and total factor productivity growth, measured using GDP for output and FTEE and gross capital stock for inputs.[7] Also shown on the diagram are the growth in SC, MS, and the mean education of the employed work force.

Labor and TFP growth show a very similar time pattern. Both are strongest in the 1950s (1.7 and 1.1 percent per year, respectively), fall slightly in the 1960s, and then precipitously in the 1970s (to 0.7 and 0.2 percent per year, respectively), and then show a partial recovery in the 1980s (to 1.2 and 0.7 percent per year, respectively). In contrast, the growth in both SC and mean years of schooling of the workforce increases between the 1950s and 1960s and then declines in the 1970s and again in the 1980s. MS growth also increases between the 1950s and 1960s and falls off in the 1970s and 1980s, but in this case MS growth is negative in the latter two periods. On the basis of these decadal averages, there does not appear to be any clear correspondence between the growth in skill demand (or educational attainment) and the growth in productivity.

I next turn to regression analysis to analyze formally the relation between skill change and technological advance. Because of differences in industry classification schemes in the underlying data sources, I use 43 industries 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. A second sample, limited to the 30 goods-producing industries for a sample size of 60, is also used. 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 skill level 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 sales (R&D/Sales); (4) the ratio of computer programmers, computer systems analysts, computer specialists, n.e.c., and engineers to FTEE (CSE/FTEE); and (5) average annual growth rate of the ratio of gross capital stock to FTEE (K/L Growth), which may be interpreted as an indicator of the rate at which new vintages of capital are introduced into the industry.

Other control variables are introduced as well. Relative factor prices between capital and unskilled labor are used to control for the possibility of capital-skill complementarity. Capital intensity, measured as the ratio of capital to output, is also 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.

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.

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 skill change. Industries competing against imports and those competing in international product markets may be forced to upgrade skills faster in order to remain competitive.

Results are shown in Table 6 for the change in three skill dimensions, SC, IS, and MS. 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 growth in capital-labor intensity. The growth in both cognitive and interactive skills is strongly and positively linked to the rate of new investment, though the change in motor skills is not.

Both the rate of computerization (OCA/FTEE) and R&D intensity (R&D/Sales) have a significant positive effect on the change in interactive skills. Computerization also has a positive and significant relation to the growth in SC among goods industries only but not among all industries, whereas the coefficient of R&D intensity is positive and significant at the 10 percent level for the change in SC among all industries but insignificant among goods industries only. Neither variable has much measured effect on the change in motor skills but the ratio of computer specialists and engineers to employment (CSE/FTEE) bears a very significant negative relation to MS change.

TFP growth generally has a negative effect on skill growth, though the variable is significant in only two of the six specifications. This result suggests 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. If it becomes routinized, then it may not have to rely on expensive, highly trained labor nor on special production processes to supply its inputs.

Relative factor prices between capital and labor (as well as their change over time) fail to appear as significant determinants of skill change. Of the organizational variables, only the percent of employees in unions (%UNION) has any significant effect on skills. It has a negative and significant effect on the change in interactive skills among goods industries -- presumably, by retarding the substitution of higher skilled (managerial and administrative) workers for lower skilled (operative) workers -- and has a positive and significant effect on the growth in motor skills among all industries -- probably, by supporting craft workers and operative jobs.

Import competition does not appear to affect skill change. However, industries which export a high percentage of their output have a higher than average growth in interactive skills (at least among goods industries) and a faster growth in motor skills (among all industries). 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 upgrade craft and operative jobs in order to produce higher quality output for the international market place.

4. **Conclusion**

Between 1950 and 1990, all three indices of cognitive skills -- substantive complexity, general educational development, and median years of schooling measured in 1970, showed positive growth, as did interactive skills. Motor skills, on the other hand, experienced an absolute decline. Growth in all five workplace skill indices peaked in the 1960s. In the case of cognitive skills, this was due to both strong occupation and industry effects; in the case of interactive skills, this was due to a very strong occupation effect; while in the case of motor skills, this was accounted for by a very strong industry effect.

Skill growth was lower in the 1950s, 1970s, and 1980s in all five dimensions. The growth of cognitive skills fell between the 1960s and 1970s and again between the 1970s and 1980s, due mainly to declining occupation effects. This suggests that the bias in technological change toward workers with cognitive skills was strongest in the 1960s but fell rather sharply in the 1970s and again in the 1980s. Despite stories of radical industrial restructuring of the 1980s, occupation effects were at their lowest level in this period for cognitive skills. This result casts doubt on recent analyses which posit a particularly strong technological bias in favor of educated workers during the 1980s.

The growth in interactive skills fell sharply between the 1960s and 1970s but then recovered in the 1980s, due to a strong industry effect. The growth in motor skills turned negative in the 1960s and became even more negative in the 1980s, due mainly to the sharp shift in employment toward service industries.

Overall, there is no evidence of deskilling in the 1980s, except for motor skills. However, the rate of increase of cognitive skill levels slowed down in the 1970s and 1980s, though the rate of growth of interactive skills in the 1980s was almost the same as in the 1960s.

Changes in the educational attainment of both the population and the workforce outstripped changes in workplace skills. These results emphasize the lack of correspondence between the growth in the demand for cognitive skills (as reflected in the direct skill measures) and the supply of such skills, as reflected in the educational attainment of the population. Indeed, they suggest that in both the 1970s and 1980s, the educational system in the U.S. has been producing far more educated workers than the workplace can absorb.

Investigation into the factors that affect the demand for skills indicates that technological change, as measured by the growth in total factor productivity, seems to be de-skilling, though the results are relatively weak (the coefficients are generally not statistically significant). This result is consistent with product life cycle models, which emphasizes the constant pressure to routinize new technology so that becomes less reliant on skilled labor. However, the result appears to conflict with those of Mincer and Higuchi (1988) and Gill (1989), who found higher returns to schooling in industries undergoing more rapid technical change.

I do find that other dimensions of technological activity -- particularly, 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 substantive complexity and interactive skills. Bartel and Lichtenberg (1987) also found that new vintages of capital stimulate the demand for more educated workers. On the other hand, the ratio of computer specialists and engineers to total employment within an industry has a very significant negative effect on the growth in motor skills, suggesting that their efforts are aimed at reducing the skill requirements of production-line workers.

Unionization generally has a negative effect on interactive skills and a positive effect on motor skills, a result that may be due to the retarding effect of unions on the substitution of higher skilled (management) workers for lower skilled (operative) workers. While import penetration does not seem to affect skill change, export-oriented industries appear to upgrade both interactive and motor skills more rapidly than domestically-oriented industries.

Footnotes

* I would like to express appreciation to the Jerome Levy Economics Institute of Bard College for financial support.

[1] This part extends the analysis contained in Howell and Wolff (1991), which was based on actual Census employment matrices for 1960, 1970, and 1980 and a statistically constructed matrix for 1985.

[2] This section updates previous econometric analysis (Howell and Wolff, 1992), which was conducted on skill change from 1970 to 1985.

[3] For a discussion of some of the limitations of these data, see Miller et. al. (1980) and Spenner (1983).

[4] The data show an increase in the share of sales workers from 6 percent in 1977 to 12 percent in 1988. However, these numbers should be interpreted with some caution, because the Census Bureau changed its classification of sales jobs during the 1980s.

[5] Apparent anomalies are that interactive skills grew faster in the 1960s than the 1950s, whereas the share of managers in total employment grew faster in the earlier decade; and that motor skills had positive growth in the 1950s while the share of both craft workers and operatives in the labor force declined.

[6] If a sector's output share remains constant and its labor productivity growth is greater than average, then its share of total employment must, of consequence, fall. This mechanism is often referred to as the "unbalanced growth" effect. See Baumol, Blackman, and Wolff (1989), Chapter 6, for more discussion.

[7] The data source is the U.S. National Income and Product Accounts, supplied on diskette by the U.S. Bureau of Economic Analysis.

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Table 1

The Percentage Distribution of Employment by Occupational Group, 1950-1993[a]

Occupational Group	1950	1960	1970	1977	1988	1993
Professional, Technical, and Kindred	8.6	10.8	13.8	14.6	16.1	17.5
Administrators and Managers except Farm	8.7	10.2	10.2	10.3	12.4	12.9
Clerical	12.3	14.5	17.4	17.7	15.9	15.6
Sales	7.0	6.5	6.1	6.2	12.0	11.9
Craft & Kindred	14.2	12.9	12.8	13.1	11.9	11.2
Operatives	20.4	18.6	18.2	15.7	11.3	10.4
Laborers, Nonfarm	6.6	6.0	5.0	5.3	4.2	3.9
Private Household	2.6	3.3	2.0	1.3	0.8	0.8
Service except Private Household	7.8	9.3	10.5	12.7	12.6	13.1
Farmers & Farm Managers	7.4	4.0	2.1	1.5	3.0	2.8
Farm Laborers	4.4	3.9	1.8	1.5		
Total	100.0	100.0	100.0	100.0	100.0	100.0

a. Sources: U.S. Bureau of the Census, Historical Statistics of the U.S.: Colonial Times to 1970, Bicentennial Edition, Part 2, Washington, D.C., 1978; U.S. Bureau of Labor Statistics, Handbook of Labor Statistics 1978, 1979; U.S. Bureau of Labor Statistics, Handbook of Labor Statistics 1989, 1990; and U.S. Bureau of the Census, Statistical Abstract of the United States, 1994.

Table 2

Annual Rate of Change of Workplace and Workforce Skills, Total Economy, 1950-1990

(percent)

Skill Dimension	1950-60	1960-70	1970-80	1980-90	1950-90
A. Workplace Skills					
Substantive Complexity (SC)	0.16	0.68	0.38	0.31	0.38
General Educational Development (GED)	0.15	0.35	0.18	0.18	0.22
Interactive Skills (IS)	0.09	0.27	0.18	0.25	0.20
Motor Skills (MS)	0.03	0.07	-0.13	-0.23	-0.06
Median Year of Schooling, 1970 (EDUC-1970)	0.19	0.30	0.12	0.05	0.16
B. Workforce Skills					
Percent of Adults with 4 years of HS or more[a]	2.62	2.14	2.17	0.74	1.92
Percent of Adults with 4 years of College or more[a]	3.00	2.74	4.35	1.32	2.85
Mean Years of schooling Employed Workers[b]	0.91	1.10	0.83	0.31	0.79

a. Source: Kominski and Adams (1994), Table 18. Adults refer to persons 25 of age and over.

b. Source: U.S. Bureau of Labor Statistics (1993), Labor Composition and U.S. Productivity Growth, 1948-90, Table 8, p. 11. Figures are for the private business sector. Mean schooling is calculated by weighting educational attainment of workers by hours of work.

Table 3

Mean Skill Scores by Major Industry in 1970
And Percentage Change over 1950-90

	Mean Skill Score, 1970				Percentage Change, 1950-90			
	SC	MS	IS	EDUC-1970	SC	MS	IS	EDUC-1970
Agriculture	3.62	5.09	1.73	10.3	0.2	-1.4	0.6	5.0
Mining	3.90	5.44	1.56	11.7	32.0	-2.2	9.6	8.7
Construction	4.13	6.00	1.46	11.4	23.1	-0.8	6.3	5.0
Manufacturing	3.57	5.56	1.38	11.9	20.4	-2.1	5.6	4.3
Transportation, communications and public utilities	3.69	5.41	1.94	12.0	13.1	-2.3	3.0	2.2
Wholesale, retail trade	3.82	4.66	2.21	12.1	1.0	4.2	0.3	-0.1
Finance, insurance, and real estate	5.09	4.79	2.91	13.0	20.4	-5.4	11.2	5.2
Other Services	4.66	5.01	3.38	13.2	11.9	-2.5	6.5	5.9
Government	4.38	5.12	2.51	12.8	9.9	-1.6	4.6	1.8
Goods Industries[a]	3.68	5.55	1.52	11.7	15.7	-0.6	4.2	6.0
Service Industries[b]	4.37	4.88	2.84	12.8	10.2	0.4	5.4	3.9
Total	4.07	5.17	2.27	12.3	16.5	-2.5	8.1	6.8
Addendum[c]								
Production Workers	3.03	5.75	1.09	11.07				
	(1.53)	(1.19)	(1.26)	(0.87)				
Non-Production Workers	4.73	4.80	3.01	13.08				
	(2.03)	(1.83)	(2.07)	(1.89)				

a. Goods-producing industries are defined as: (1) agriculture; (2) mining; (3) construction; (4) manufacturing; and (5) transportation, communications and public utilities.

b. Service industries are defined as: (1) wholesale and retail trade; (2) finance, insurance, and real estate; (3) other services; and (4) government services.

c. Production workers include craft workers, operatives, and laborers. Non-production workers include all others. The standard deviation is shown in parentheses.

Table 4

Percentage Distribution of Employment by Major Industry, 1950, 1970, and 1993[a]

	1950	1970	1993
Agriculture	13.7	4.7	2.7
Mining	1.7	0.8	0.5
Construction	4.5	4.8	4.0
Manufacturing	29.1	26.1	15.7
Transportation, communications and public utilities	7.7	6.1	5.0
Wholesale and retail trade	17.9	20.2	22.8
Finance, insurance, and real estate	3.6	4.9	5.8
Other Services	10.2	15.5	26.7
Government	11.5	16.9	16.6
Total	100.0	100.0	100.0

a. Source: Council of Economic Advisers, Economic Report of the President, 1994.

Table 5

Decomposition of the Change in Overall Skill Levels
Into An Occupation Mix and Industry Shift Effect, 1950-1990

		Decomposition[a]		Percentage Decomposition	
Period	Change in Average Skill Level ($\Delta\sigma$)	Occupation Mix Effect ($p\Delta s$)	Industry Shift Effect [$(\Delta p)s$]	Occupation Mix Effect ($p\Delta s$)	Industry Shift Effect [$(\Delta p)s$]
A. Substantive Complexity (SC)					
1950-60	0.060	0.068	-0.008	113.9	-13.9
1960-70	0.267	0.150	0.118	56.1	43.9
1970-80	0.156	0.068	0.088	43.4	56.6
1980-90	0.134	0.038	0.096	28.6	71.4
1950-90	0.617	0.324	0.293	52.5	47.5
B. Motor Skills (MS)					
1950-60	0.016	-0.018	0.034	-114.0	214.0
1960-70	0.038	-0.017	0.056	-45.1	145.1
1970-80	-0.068	-0.019	-0.049	28.5	71.5
1980-90	-0.114	-0.012	-0.102	10.2	89.8
1950-90	-0.128	-0.067	-0.061	52.2	47.8
C. Interactive Skills (IS)					
1950-60	0.019	0.027	-0.007	136.6	-36.6
1960-70	0.060	0.053	0.007	87.9	12.1
1970-80	0.040	0.024	0.016	59.8	40.2
1980-90	0.059	0.016	0.042	27.8	72.2
1950-90	0.178	0.120	0.059	67.1	32.9
D. Median Education, 1970 (EDUC-1970)					
1950-60	0.220	0.206	0.014	93.6	6.4
1960-70	0.362	0.242	0.120	66.9	33.1
1970-80	0.148	0.081	0.067	54.5	45.5
1980-90	0.064	0.041	0.023	64.1	35.9
1950-90	0.794	0.570	0.224	71.8	28.2

a. See Equation 1 of the text.

Table 6

Regressions of Skill Change on Technology and Other Variables[a]

	Dependent Variable					
	Change in Substantive Complexity (SC)		Change in Interactive Skills (IS)		Change in Motor Skills (MS)	
Independent Variables	All Industries	Goods Only	All Industries	Goods Only	All Industries	Goods Only
Constant	0.047* (1.71)	0.074*** (2.87)	0.074** (2.28)	0.150*** (5.07)	-0.013 (0.48)	-0.030 (0.86)
TFP Growth	-0.929 (1.50)	-1.019* (1.74)	-0.613 (1.57)	-1.020*** (3.32)	-0.287 (0.96)	-0.304 (1.29)
Ln(OCA/FTEE)	0.012 (1.22)	0.032** (2.53)	0.017* (1.83)	0.019** (1.92)		
R&D/Sales	0.011* (1.71)	0.004 (0.59)	0.010** (2.58)	0.0077** (2.03)		
Ln(CSE/FTEE)					-0.040*** (4.66)	-0.027*** (2.78)
K/L Growth	1.963*** (3.34)	1.909*** (3.11)	1.209*** (2.78)	1.126** (2.26)	-0.291 (0.57)	0.262 (0.80)
%UNION			-0.061 (1.11)	-0.159*** (2.97)	0.166** (2.30)	0.073 (1.11)
IMP/GDO				-0.078 (1.15)		
EXP/GDO				0.490* (1.70)	0.528* (1.68)	0.402 (1.41)
DUM8090			0.0018** (1.91)	0.0042*** (2.97)	-0.0016* (1.69)	-0.0014* (1.69)
R^2	0.24	0.38	0.39	0.67	0.31	0.33
Adjusted R^2	0.20	0.33	0.34	0.61	0.26	0.26
Std. error	0.14	0.11	0.088	0.059	0.097	0.063
Sample Size	86	60	86	60	86	60

a. The "all industries" 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 "goods only" sample is limited to the 30 goods-producing industries for a sample size of 60. 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/Sales: ratio of expenditures on research and development to industry sales (source: National Science Foundation, <u>Research and Development in Industry</u>, 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) K/L Growth: average annual growth rate of the ratio of gross capital stock to FTEE (source: NIPA on diskette).

6) %UNION: share of employees covered by union contracts (<u>1970</u>: Freeman and Medoff, 1979; <u>1980</u>: Kokkelenberg and Sokell, 1985).

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

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

9) DUM8090: dummy variable which equals one for the 1980-90 period 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 Mean Skill Score by Type and Year

1950–1990 [Index, 1950 = 100]

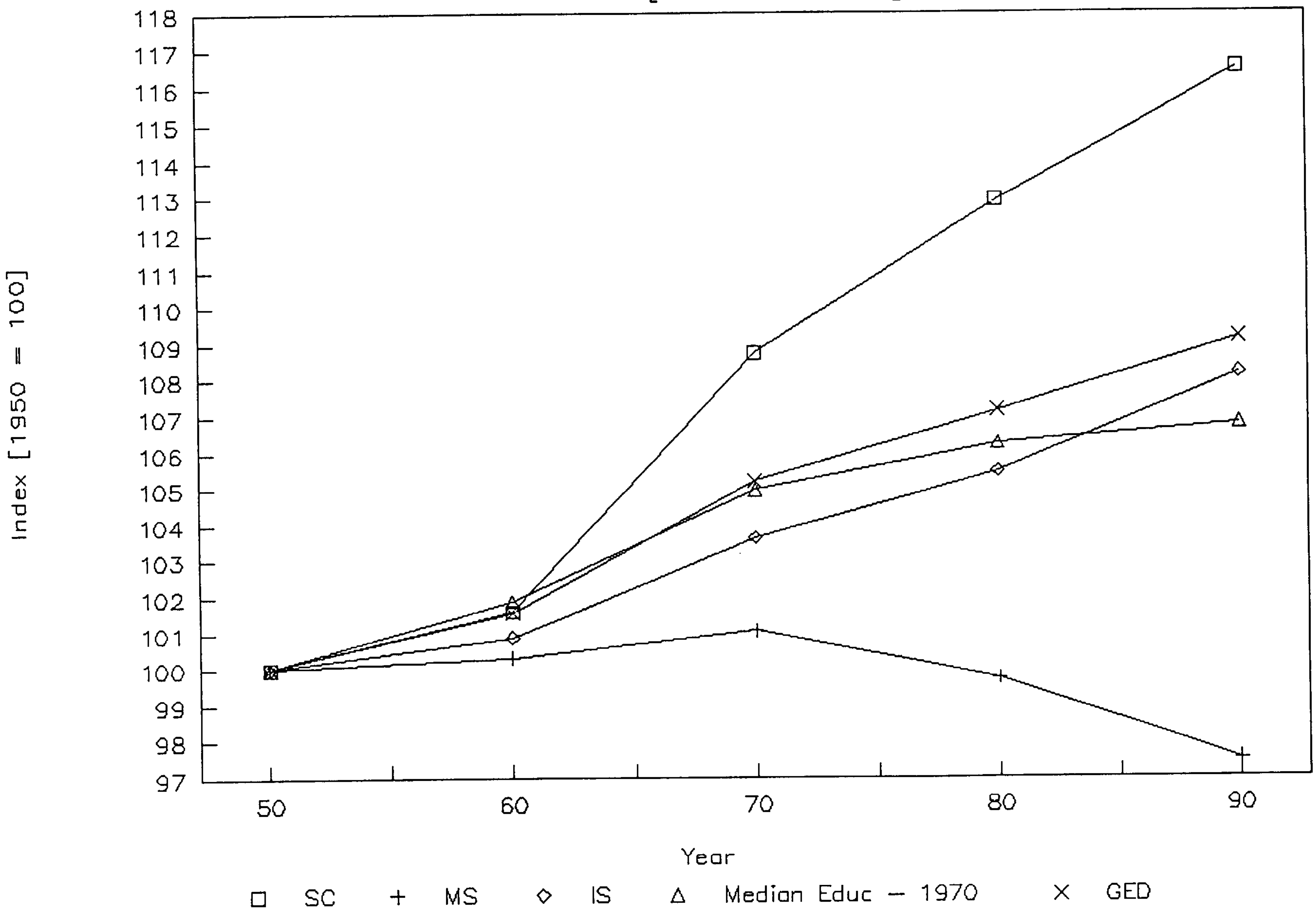

Fig 2 Actual Educ. Attainment & Skills,

1950–1990 [Index, 1950 = 100]

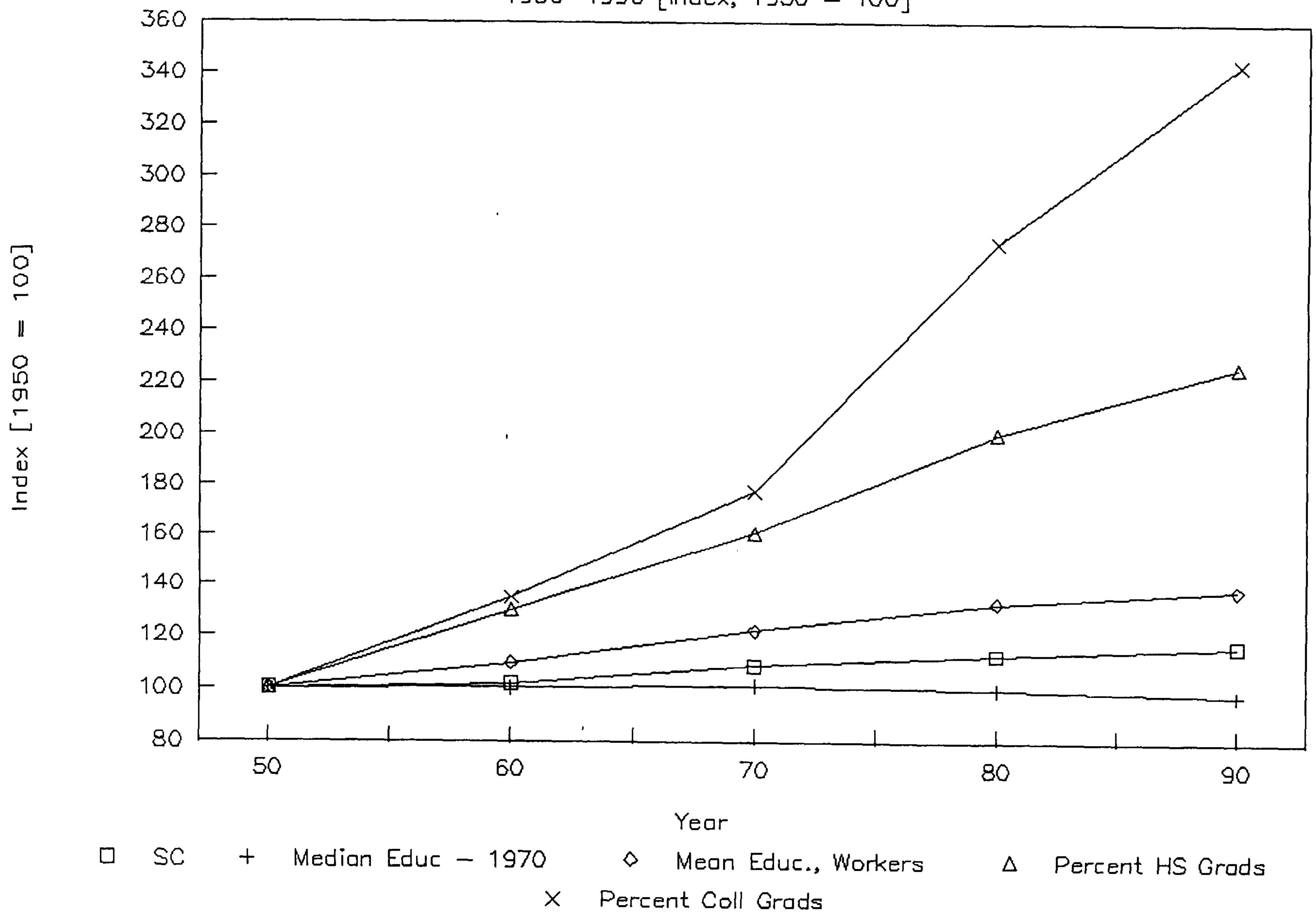

Fig 3 Growth in Workplace Skills

By Decade, 1950–1990

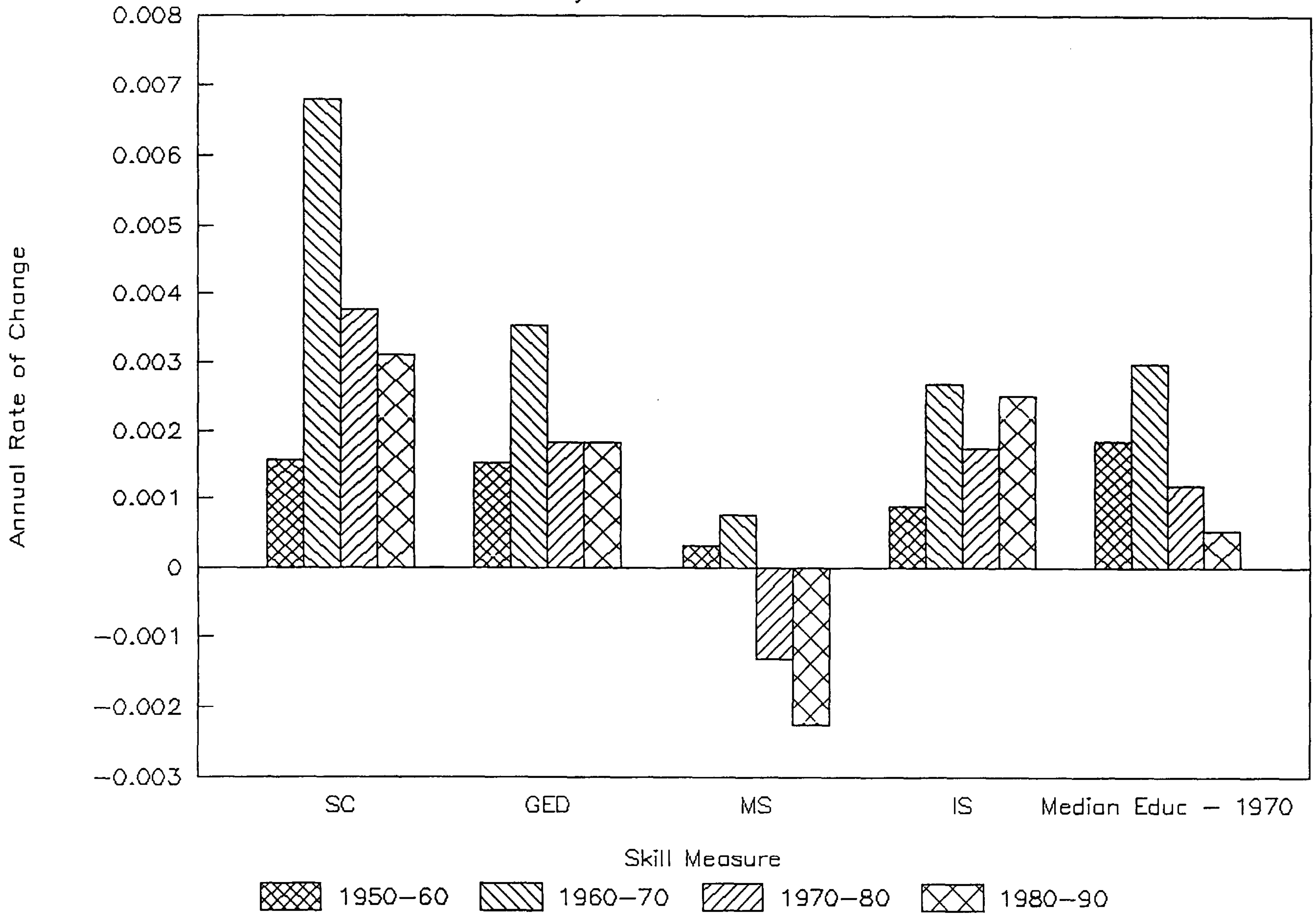

Fig 4 Growth in Workplace and Workforce

Skills by Decade, 1950–1990

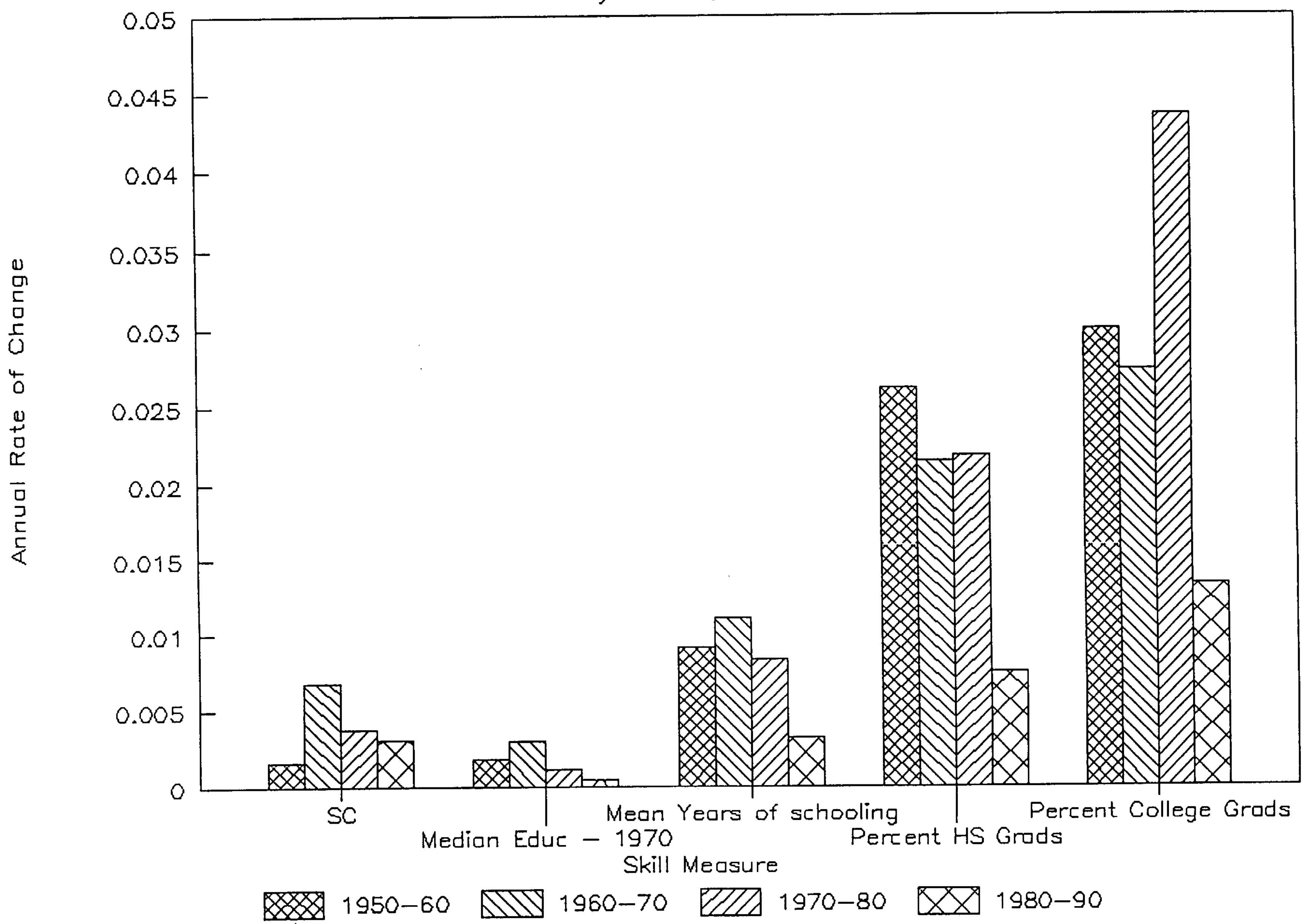

Fig 5 Mean Skill Score by Industry 1970

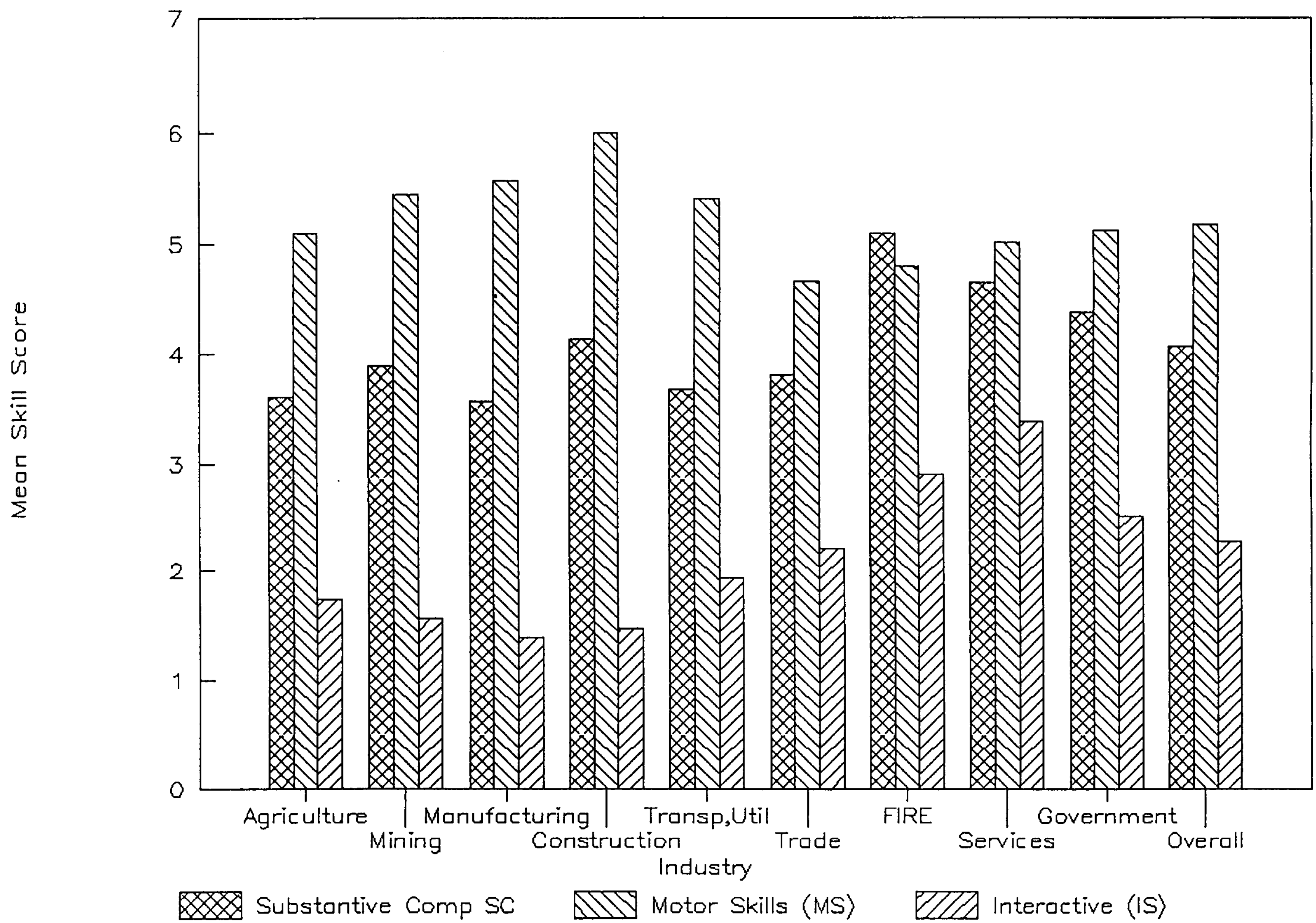

Fig 6 Percentage Increase in Industry

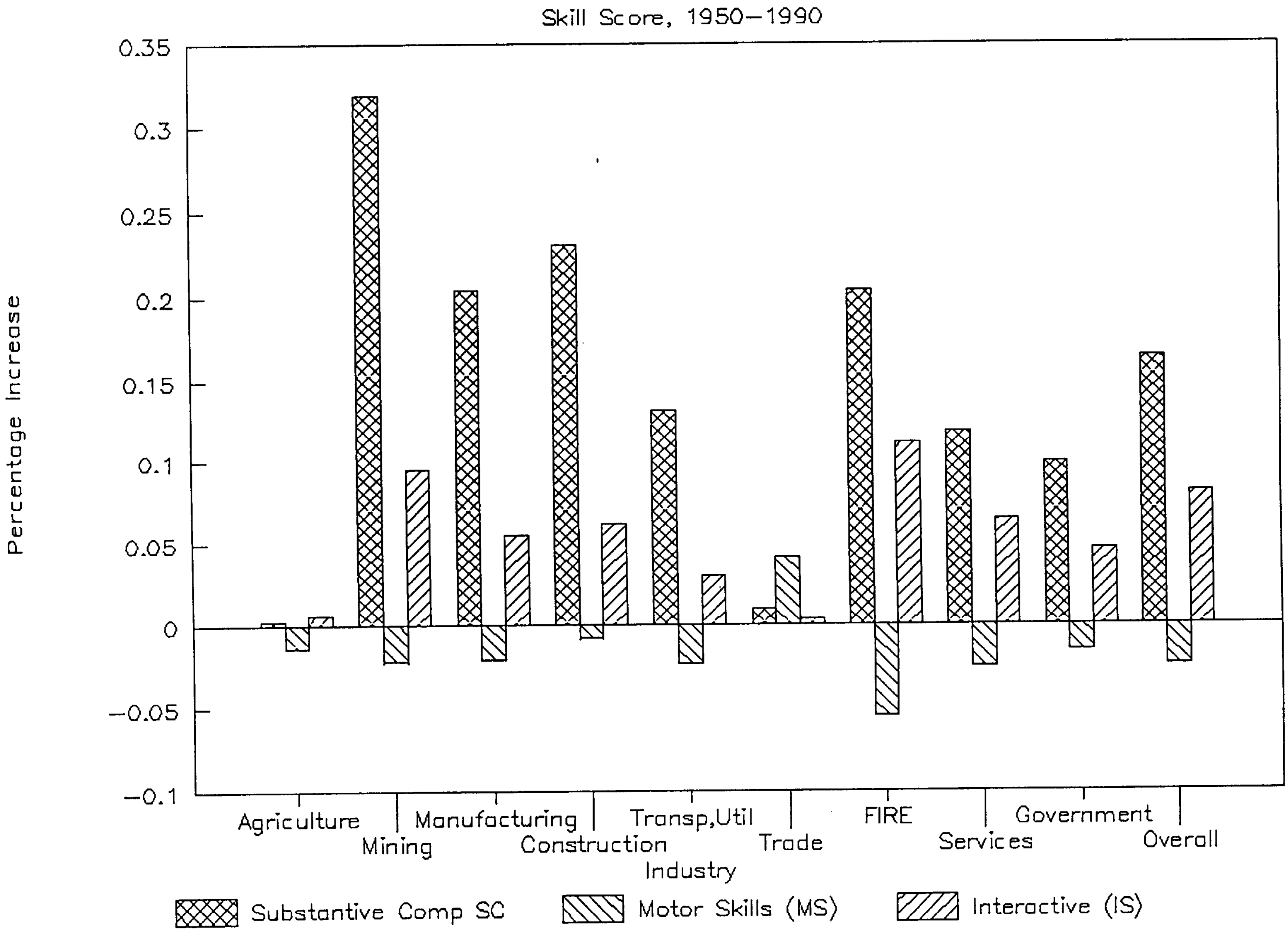

Fig 7 Growth in Skills, Education, and
Productivity by Decade, 1950–1990