Technology and Skill Requirements: Implications for Establishment Wage Structures

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The concept of skill reflects the capacities and human capital that workers bring to jobs—what psychologists refer to as "knowledge, skills, and abilities"—and the specific demands that individual jobs make on workers who occupy them. Whether the demand for skills is changing is a vitally important question for public policy. Such changes help determine the distribution of income and the extent of technological unemployment; they also help determine whether relative skill shortages exist that may lead to a lack of competitiveness, especially in relation to other economies that possess the valued skills in more abundance.

An extensive literature has examined the causes of technological change and its effects on the demand for skills and the structure of wages. This article begins by reviewing this literature, which spans economics, sociology, and other social science disciplines that examine industrial behavior. It then makes use of an extensive establishment-level survey to examine the effects of organizational structure and investment activity on wages. The study finds that establishments that adopt new technologies pay production workers more than those that do not, and also pay them more relative to the pay of supervisors. Thus, the results suggest that recent changes in workplaces are increasing skill requirements for production workers. The article concludes with some comments on how this trend will play out in terms of labor market adjustments.

Factors Shaping Changes in Skill

The demand for skill in the economy is derived from the objective requirements associated with jobs. Changes in the demand for skill are the result of changes either in the requirements associated with individual jobs or in the distribution of employment across jobs that have different skill requirements. A vast literature in the social sciences, most prominently in sociology, argues that technology drives skill requirements. This literature uses the word technology to refer to broad changes in production systems, such as the industrial revolution or the adoption of the factory system.

One tradition argues that technological change has tended to increase skill requirements by eliminating noxious physical labor. The focus here is often on technological changes so massive and inexorable that their effects on employment can be treated as exogenous.[1] Many of the more contemporary studies in this area begin with the analysis from *Workforce 2000*, which concludes that the distribution of employment across occupations and industries in the United States is shifting toward higher-skilled work (U.S. Department of Labor 1987). Examinations of Census occupational data over time suggest, however, that the rate at which this shift has occurred has slowed from the 1960s to the 1980s (Howell and Wolff 1991). And further reanalysis of the data used in *Workforce 2000* indicates that the anticipated shifts in the future will not in fact increase skill demands by much (Mishel and Teixeira 1991).

The "upskilling" tradition tends to rely on forces external to the organization for its explanations and changes in the distribution of employment; the "deskilling" tradition relies on forces internal to the firm and changes within individual jobs.

Another and perhaps equally long tradition sees technological change operating to reduce the breadth of skills required from workers and, in particular, their control over the way jobs are performed.[2] The "deskilling" research argued that the types of technologies used and the way they were implemented were choice variables that management could exercise in ways that depended on the circumstances. Marglin (1974), for example, argued that deskilling was a conscious management decision taken to increase control over workers and make the management process easier. This thesis reached its best-known form in the work of Braverman (1974), who extended it to clerical and other nonproduction jobs.[3] Growing worker dissatisfaction with production jobs in the 1970s led to explicit public policy acknowledgments that narrow, deskilled jobs were part of the cause. For an example, see *Work in America* (U.S. Department of Health, Education, and Welfare 1973).

The "upskilling" tradition tends to rely on forces external to the organization for its explanations and changes in the distribution of employment for evidence. The deskilling tradition relies on forces internal to the firm (management strategy) and changes within individual jobs for its explanations. (See Attewell 1990 for a review of this literature.)

The third research approach is more empirically driven and asserts explicitly that technology is a choice variable and that the effect on skill may vary. Spenner (1983) described this research as the "mixed effects" position in terms of the net change it predicts in skill.[4] This middle position assumes that situational factors such as labor costs or employee bargaining power are important in determining the utility of any technology or system of work organization.

[1] Arguments about the benefits to workers of technology began with Adam Smith, then with the scientific socialists, and continued in studies of economic development. Kerr and coworkers (1960), for example, saw industrialization as liberating production workers by leading to more skilled jobs. Students of industrial technology such as Woodward (1965) argued that assembly line work was only a stop on the road toward automated, "continuous production" factories where workers would be freed from machine-paced tasks. Blauner (1964) argued that such technologies would actually lead to an increase in skill, for example, as workers performed a broader range of monitoring tasks. This thesis reaches its high point with Bell's (1973) arguments that knowledge-based jobs would replace production work in the economy of the future.

[2] Adam Smith's observations about the increasing division of labor and the narrowing of jobs that results can also be seen as part of the beginning of the deskilling argument. Durkheim (1893), Veblen (1914), and others were concerned about the dehumanizing effects of automation and factory production and the broader effects it would have on society. Scientific management as a theoretical argument for deskilling and assembly line production methods in basic industries led to widespread acceptance of the deskilling argument supported by research findings (Walker and Guest 1952; Bright 1966) and to a shift in research to examine the *consequences* of deskilled jobs (for example, Blauner 1964).

[3] In particular, Braverman (1974) argued that the shift in the distribution of occupations toward administrative and white collar jobs was not an indication that overall skill levels are rising, but instead was simply a manifestation of deskilled production work where the "mental" aspects had been removed.

[4] Most of these studies are cases, and many are historical. Hobsbawm (1964) describes, for example, how craft workers were able to use the techniques of organized labor (for example, controlling supply) to resist management efforts to deskill jobs. Edwards, Reich, and Gordon (1979) suggest that changes in skill have been the result of a complex process of bargaining between management and labor. Flynn's (1988) survey of hundreds of case studies of technological change finds considerable variance in the effects on employment and skill levels, lending support to the "mixed effects" hypothesis.

Other studies have examined changes in skill and looked beyond technology for their explanations. For example, Piore and Sabel (1984) argue that the saturation of industrial markets and greater international competition have forced employers to find smaller market niches that demand quicker reactions to changing markets and, in turn, a more flexible workplace where jobs are defined more broadly and workers have greater control over them. The result is to create jobs with more skill, broadly defined. In other words, changing product markets have made a form of work organization that was always available suddenly much more effective. Cappelli and Sherer (1989) find a broadening of responsibilities in such a firm,

Outside of production, little evidence is seen of high-performance work systems, even in organizations that have production-like aspects.

and Loveman (1988) finds evidence of a shift in manufacturing occupations toward greater skill that is consistent with the "flexible-specialized" hypothesis.[5]

Measuring Changes in Skill

Exactly how one should attempt to measure skill changes has been a vexing problem for the research efforts described above. Studies sometimes attempt to use measures of worker characteristics, such as average education levels, to assess whether skill requirements have changed. The problem with this approach is the considerable evidence that such worker characteristics vary independently from the demands of jobs (Berg 1970). One approach is to ask workers directly about the requirements of their jobs (Mueller et al. 1969), but an individual's perceptions of job characteristics do not necessarily relate well to actual job characteristics (Roberts and Glick 1981). Myles and Eno (1989) found that workers' self-reports of skill requirements in their jobs differed substantially from those provided by expert raters.

A popular data source for measuring the skill requirements of jobs has been the U.S. Department of Labor's *Dictionary of Occupational Titles* (DOT), now in its fourth edition, which is compiled by government job analysts who provide detailed descriptions of some 12,000 job titles. By examining changes in these titles in subsequent editions, one can measure changes in job requirements (for example, Horowitz and Herrstadt 1966; Spenner 1979). But serious drawbacks are associated with using the DOT in this manner, in addition to the fact that it is not updated regularly.[6]

An alternative approach is to estimate skill changes by examining shifts in the composition of occupations in the economy, the approach followed by *Workforce 2000* and discussed above.[7] The problem with all such studies is the difficulty in controlling for the content of jobs. It is not obvious that the respondents are really using common definitions and that the results are reliable. The current questions used for gathering information about jobs are far from ideal. The Current Population Survey, the source of data for many of these studies, asks respondents about their business or industry, the kind of work they do, and

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[5] Other studies in this period continued to emphasize the relationship between technology and skill. Hirshhorn (1984) suggests an argument similar to Bell's (1973) that new automated technologies will require higher-order mental and social skills from workers. Studies of the introduction of numerically controlled production machinery have suggested that the introduction of these machines is designed to reduce workers' skill (Noble 1977). Further, even where the mix of skills associated with numerically controlled jobs appears to grow, the changes may simply add more boring tasks and leave the content of the jobs degraded (Adler 1986). Again, studies in the "mixed result/it depends" tradition report a variety of changes in skill across situations, depending typically on contextual issues. (See the papers in Hyman and Streek (1988) and Zuboff (1988) for case-based examples and Kelley (1989) for a survey-based argument.) Overall, a National Academy of Sciences study (Cyert and Mowery 1987) concluded that changing technology was unlikely to increase skill requirements during the immediate future. See Levin, Rumberger, and Finnan (1990) for a similar conclusion.

[6] It is not clear that all of the entries were actually reanalyzed in subsequent editions, and there may have been a bias toward making the reports consistent over time. Further, by itself the DOT measure tells only what is happening to the content of specific jobs, not what is happening to average skill across a work force or an organization. For example, a given job such as drafting can be substantially deskilled by new technology while at the same time the composition of the design work force in a firm shifts from drafting jobs to higher-skilled engineering jobs. The overall skill level of the design function may rise because of this shift in its composition, even though the skill associated with some individual jobs is declining.

[7] Perhaps the best data source for compositional studies is the *Occupational Employment Statistics Survey* assembled by the Bureau of Labor Statistics (BLS). This survey examines 150 occupations in each industry with establishment-level surveys and reports the shift in employment across those occupations. The survey is actually conducted separately by each state, under the general guidance of, but not the control of, the BLS. The BLS takes the data from the states with little opportunity to check the reliability of the results or the methods used.

their most important activities at work, a relatively small amount of information by which to measure skills. Classification clerks then take these responses and code them into occupations. A number of tests are made for the reliability of the coding but not for the validity of the original responses. In about half the cases, employees believe that their occupation is something different than does their employer (Mellow and Snider 1985). At least half the time, then, one of the parties—employer or employee—is wrong in labeling an occupation.

Perhaps the most important problem with occupational data is that job titles do not always accurately reflect changes in skill requirements. Employees in less rigid organizations are sometimes rewarded with "promotions" and given higher job titles, even though their duties remain unchanged. Managers may also arrange such promotions to secure grade-based salary increases, especially when general salary increases are being restrained. (The practice is sometimes known in the compensation literature as "grade drift.") And as jobs get broader in scope, it becomes more difficult to match tasks and skills with specific job titles.

Finally, compositional studies do not indicate whether changes have been made in skill requirements within individual jobs, the reverse of the problem noted above in using the DOT. For example, the decline in aggregate skill levels associated with a shift in work force composition from quality control to assembly jobs may be offset if substantial upskilling of assembly jobs has occurred.

Spenner (1988; 1990) reviewed the research that has been based on aggregate data and concluded that the results have been mixed, at least through the 1980s—perhaps a small upgrading of content in the form of complexity, equivocal results for content in the form of autonomy, and not much change in composition. His conclusions suggest that "the poverty of quality data" (Spenner 1983) may be the main obstacle to obtaining better estimates of skill changes.

My own study of changes in skill requirements used a different set of data on 56,000 production workers over an eight-year period and found significant upskilling across the board for production jobs as measured by changes in Hay points, the job evaluation metric introduced by Hay Associates to measure job requirements. Some of the upskilling seems due to the fact that tasks associated with quality control and housekeeping have been pushed onto all the remaining jobs (the decline of employment in quality and housekeeping jobs is consistent with this interpretation). That is, not only has each job experienced upskilling but the overall distribution of production jobs has shifted away from less skilled and toward more skilled positions (Cappelli 1993).

Economic-Based Arguments

A different research stream has developed in economics on the question of skill levels. This research also focuses on the role of technology in driving skill changes. Here "technology" refers not to system or economywide developments but to firm-level decisions of the kind associated with production functions. In most cases, the analysis focuses on the effects of broad production decisions such as the level or type of capital spending. And, in contrast with the research cited above, the goal is less to assess skill changes than to explain where they occur and their effects on other aspects of operations.

Perhaps the most intriguing aspect of arguments about changing technology and skill requirements is their use in explaining changes in the wage structure.

One set of research in this tradition focuses on the complementarity between skills and firm production choices. For example, Bartel and Lichtenberg (1987) find that operations with more educated workers adopt new technologies sooner and that the decision to adopt new systems then increases further the demand for skill. Historical research finds that as early as the 1920s, more technologically sophisticated firms hired more educated workers (Goldin and Katz 1995). Other recent work (Bartel and Sicherman 1995) finds similar results for training, in that technological change increases training.

Still other research relies on changes in the distribution of employees across occupations to estimate changes in skill levels. Berndt and Morrison (1991) find that investments in certain kinds of physical capital (mainly office equipment) are associated with increased education among production workers and a shift toward presumably more highly skilled nonproduction workers. Berman, Bound, and Griliches (1994) argue that a measure of the level and rate of change in computer investments for manufacturing firms is a good proxy for the firms' overall technological change and explains the shift toward higher-skilled workers in some operations.

Perhaps the most intriguing aspect of arguments about changing technology and skill requirements is their use in explaining changes in the wage structure. The research on changes in wage structures, especially the rise in the returns to education, is too voluminous to review in detail here. Levy and Murnane (1992) survey it and conclude that "the most striking evidence of change in the demand for skill is the increase in the premium associated with formal education." Wallace and Kalleberg (1982), Davis and Haltiwanger (1990), and others find rising wage differentials between occupations and an increase in the premium for skill.

Several studies have attempted to see how these technology choices, broadly defined, affect wage outcomes. Mincer (1991) offers one of the first studies to argue that technology explains some of the increase in the returns to education over time. Bound and Johnson (1992) compare different explanations for changes in the overall structure of wages in the 1980s using changes in education levels of workers as a proxy for technology. They conclude that technological change was the most important factor in explaining changes in wage premiums in this period. Krueger (1993) finds that workers who use computers on the job, other things equal, earn about 10 to 15 percent more and that computer use may explain as much as half of the increase in the rate of return to education in the late 1980s. Dunne and Schmitz (1995) find that the use of advanced production technologies in manufacturing is associated with higher wages for both production and nonproduction workers.

Mishel and Bernstein (1994) question whether the conclusion can really be drawn that technological change, however defined, can explain changes in wage differentials during the 1980s. They argue that research showing relationships between technology and wages—that is, between levels—does not explain *changes* in wage differentials. In order to do this, one needs to show that there has been a change in technology, specifically, that the rate of introduction of technology was somehow greater in the 1980s. And, as noted earlier, the evidence does not suggest that this was the case. Indeed, the pace of change may even have declined somewhat (Howell and Wolff 1991).

Further, as the "mixed effects" research in sociology suggests, the introduction of specific pieces of technology may not have an obvious effect on skill levels. Some of the clerical occupations that have been subject to innovations in office equipment of the kind emphasized by Berndt and Morrison (1991), for example, have been deskilled (for example, typists, following word processing) while others have been upskilled (bank tellers after the introduction of automated teller machines, Cappelli 1993). And as Kelley (1986) demonstrated with programmable automation, the introduction of a given technology may have very different effects on the skills of the workers using it across establishments, depending on factors like the power of unions in those establishments. Finally, it is worth asking, as Mishel and Bernstein (1994) do, whether the assumption that average education levels are a good proxy for skill levels, used in much of this research, is adequate.

Work Organization Studies

Yet another approach to the issue of changing skill requirements looks neither at systemwide changes nor at production function choices associated with capital decisions. This approach focuses on "technology" in the sense of management technology and, in particular, decisions about how work might be organized within individual jobs. The common theme in models of new work systems is that they represent a contrast to Tayloristic work systems associated with scientific management. These changes in the organization of work alter the hierarchy and internal organization of jobs.

The contemporary debate about these new models of work in the United States began by identifying "high performance" (HP) work systems in the context of new production systems: High performance production systems were identified based on productivity outcomes, and the work systems demanded by them were identified, by definition, as high performance work. These production systems are most clearly associated with Japanese manufacturing and include techniques such as statistical process control, just-in-time (JIT) inventory systems, continuous improvement, and total quality management (TQM). This approach is, not surprisingly, the one taken by research projects that focus on production, such as MIT's World Motor Vehicle Project (MacDuffie and Krafcik 1992) or the study of manufacturing conducted by the National Academy of Sciences (1986).

The models of "lean" production basically argue that increased quality, productivity, and flexibility can be obtained by making better use of employees. In particular, responsibility and decision-making are transferred from administrative structures directly to employees or to their teams. These arrangements demand significantly more from employees than do work systems associated with scientific management, where tasks are narrowed and virtually all decision-making is in the hands of management.

These new work systems are associated with a series of specific work practices such as employee empowerment and participation in decision-making, where employees take over some tasks previously performed by supervisors, engineers, and staff specialists; teamwork, where autonomous or semi-autonomous teams take over some direct supervision and substitute for formal management structures; and job rotation/cross-training, where employees within teams swap tasks and become more interchangeable.

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Measuring the incidence of these work practices is yet another way to proxy whether skill requirements are rising. The important question here is how to define those practices—is it a set of practices or individual ones? how extensive should they be to count? and so on. Lawler, Mohrman, and Ledford's (1992) study of *Fortune 1,000* firms in 1987 and again in 1990 provides extensive breakdowns of practices. Twenty-five percent have no employees involved in job redesign; 13 percent have a majority of the work force in quality circles, and 22 percent in some other participation group; 12 percent have a majority of employees receiving team-based incentive pay; and 68 percent have more than a majority of employees involved in cross-training.

Osterman's 1992 survey (1994) reports that about one-third of firms have some significant level of the practices associated above with high performance work. Forty percent have a majority of the workers in the "core" of their production process in teams and 26 percent in job rotation. Bassi's (1992) survey finds that one-half of non-manufacturing firms and three-quarters of manufacturing firms have undergone some reorganization of work along the lines of these practices, although very few had made substantial changes yet. A just-released survey conducted by the Census for the National Center on the Educational Quality of the Workforce (EQW) finds that between 20 and 30 percent of establishments surveyed had some combination of these practices (EQW 1995).

Work Organization Outside of Production

By definition, the techniques of high performance *production* systems are associated with production work, and not all of these techniques apply directly to other industries. The equivalent study to the one noted above using Hay data for clerical jobs finds no consistent pattern; some clerical occupations show increases in skill while others experienced decreases (Cappelli 1993).

One important attribute of these high performance systems is the increased flexibility needed to handle variations in products. Situations that do not demand change—indeed, may punish it—may not make great use of these techniques. HP production techniques are used little in industries like transportation, distribution, or public utilities, perhaps because reliability and consistency are the prime considerations there. Indeed, the work systems in these industries are often referred to as "high reliability" systems.

One of the more curious findings, however, is that little evidence is seen of work practices associated with high performance production systems even in organizations that have production-like aspects. The processing of transactions in the back offices of financial services and related industries, for example, looks very much like an assembly line, and in fact more people are employed in these industries than in manufacturing. Yet there appears to be little, if any, evidence that HP production practices or even specific HP work practices are being used in these operations. Indeed, the management focus in these facilities seems to be quite strongly in the opposite direction—to automate employees out of the process altogether.[8]

It is not obvious that there is a common trend in service jobs. In health care, for example, anecdotal evidence suggests that the biggest development has

[8] Preliminary findings from a study of transaction processing at the Wharton School's Financial Services Center finds virtually no evidence of HP production practices.

been the deskilling of jobs along the lines of Taylorism: Many of the simple tasks traditionally performed by nurses are now being transferred to lower-skilled workers. In customer contact jobs in retailing and hospitality, some efforts are being made to "empower" workers by giving them more authority to solve problems. Overall, there appears to be a clear trend toward high performance work in production-oriented jobs because it is associated with a new production process. It is not clear that this movement will make equal progress elsewhere.

Do These Arrangements Raise Skills?

Whether these new models of work organization are changing skills—and if so, in what way—is a central issue in a number of public policy arguments. Advocates assume that they raise skill requirements substantially and that the introduction of these systems may well require significant upgrading of work force skills (National Center on Education and the Economy 1990; U.S. Congress, Office of Technology Assessment 1990). Closer inspection suggests that the changes in skill demands may not be so obvious. Consider, for example, the issue of individual worker autonomy, a key concept of participative work systems thought to raise skill demands. As Klein (1989) observes, just-in-time inventory systems that eliminate buffers of materials or intermediate products between work groups make those groups highly interdependent. Changes in the production arrangements within any individual group can change their work pace, causing either shortages or pileups of material downstream. Because the overall flow of work across *all* teams in the assembly process must be absolutely consistent, the autonomy that any individual team has to make changes in work organization is tightly constrained.

As Adler (1993) discovered at the New United Motor's (NUMMI) joint venture between Toyota and General Motors, the principle of continuous improvement requires that the performance of individual tasks be completely routinized, so that the work teams can discover whether minute changes in tasks lead to an improvement in performance. In this sense, continuous improvement in work processes is like a laboratory experiment where everything is held constant except the one change being investigated. For employees, individual tasks appear to be every bit as rigidly defined as under scientific management. They do not have the individual autonomy that demands higher skills.

Lean production essentially eliminates some jobs and pushes their tasks onto production workers. Some of those tasks, such as housekeeping, make few demands on skills. Other tasks such as coordinating job design changes across teams demand considerably higher skills, especially behavioral skills such as communication and negotiation, and group dynamics skills. Adler notes that many of the tasks previously performed by industrial engineers, such as job analysis and redesign, are now being pushed down to the production teams.[9]

Research Questions

The literature from various fields reviewed above points toward several important issues under the general heading of skills and the economy. Perhaps the most fundamental question is, what factors determine why skill requirements appear to be rising in some sectors or establishments? Answers to this question may help address the more general issue as to whether some average trend in skill levels exists in the economy as a whole or in broad sectors within it, a trend that might require a response either from public policy or from the private sector. And the final question, which follows from the above, is whether changes in skill requirements might help explain some of the changes in the structure of wages—particularly, rising wage differentials for skilled versus less skilled workers—in the economy as a whole.

The EQW National Employer Survey

A recent establishment-level survey of employment practices conducted by the U.S. Bureau of the Census for the National Center on the Educational Quality of the Workforce (EQW) may help address some of the above questions. The EQW National Employers Survey (designed by Lisa Lynch in collaboration with EQW Co-Directors Robert Zemsky and Peter Cappelli) was administered by the U.S. Bureau of the Census as a telephone survey in August and September 1994 to a nationally representative sample of private establishments with more than 20 employees. The survey represents a unique source of information on how employers recruit workers, organize

[9] It is also important to remember that while these skill requirements are rising for production workers, they often start at a low base. It is certainly possible, therefore, that workers already have the skills to meet the increasing skill demands represented by these new systems.

work, invest in physical capital, and utilize education and training investments. It is structured to provide information on all categories of incumbent workers, not just new hires or those in core occupations.

The survey oversampled establishments in the manufacturing sector and establishments with over 100 employees. Public sector employees, not-for-profit institutions, and corporate headquarters were excluded from the sample. Although the survey excluded establishments with fewer than 20 employees (which represent approximately 85 percent of all establishments in the United States), the sampling frame represents establishments that employ approximately 75 percent of all workers. This is because while most establishments are small (fewer than five employees), most workers are employed in larger establishments. We concentrated on those establishments employing the most employees. The target respondent in the manufacturing sector was the plant manager and in the nonmanufacturing sector was the local business site manager. The survey was designed to allow for multiple respondents so that information could be obtained from establishments that kept financial information, for example, in a separate office—typically at corporate headquarters, for multi-establishment enterprises. Computer Assisted Telephone Interviewing (CATI) was used to administer each survey, which took approximately 28 minutes to complete.

Research suggests several factors that might be contributing to rising skill requirements at the establishment level: management structure, union coverage, computer use, R&D investment, and new work systems like TQM.

The sampling frame for the survey was the Census Bureau's SSEL file, one of the most comprehensive and up-to-date listings of establishments in the United States. Of the 4,633 eligible establishments contacted by Census, 1,275 refused to participate in the survey. This represents a 72 percent response rate, which is substantially higher than that of many similar establishment surveys. The usual reason given by employers for not participating was that they did not participate in voluntary surveys or they were too busy to participate. Probit analysis (described in Lynch and Black 1995) of the characteristics of nonrespondents indicates no significant pattern at the 2-digit industry level in the likelihood of participating in the survey. The only businesses more likely not to participate were manufacturing establishments with more than 1,000 employees, which represent 0.1 percent of the sample. Of the 3,358 establishments that participated in the survey, not all respondents completed all parts of the survey by the interview cutoff date of October 1, 1994. The final number of surveys in which all parts of the survey were completed was 1,621 for establishments in the manufacturing sector and 1,324 establishments in the nonmanufacturing sector. This represents a 64 percent overall "completed" survey response rate. The results presented below refer to this final sample of 2,945 establishments. (See the Appendix for more details on the response rates, the distribution of establishments by industry, and the distribution of establishments by employer size, weighted and unweighted.)

The National Employers Survey (NES) is used below to examine the factors that predict whether skill requirements are increasing for production workers at the establishment level and then to explore how the characteristics associated with rising skill requirements affect the wages of production workers and their supervisors, the first level of management in most organizations. The research reviewed above suggests several possible factors that might be contributing to rising skill requirements at the establishment level. From the sociological traditions, especially the "mixed effects" approach, come arguments about management structure and union coverage (raising skills), and arguments about size and structure affecting skills. From the economics-based research on skills complementarity comes the argument that innovation should be higher when education levels in the work force are higher, further increasing skill demands. From the production-function-oriented research comes the argument that computer use and research and development investments are raising skill levels. And from the work organization research come arguments about how new work systems that involve programs like total quality management (TQM) and employee participation raise skill requirements.

The NES asks a very simple and straightforward question of each establishment: Have the skills required to perform production jobs adequately risen over the past three years? Because the question asks about perceptions, it is subject to all kinds of error at the level of the individual respondent; the criteria that respondents use to aggregate the different changes going on in the workplace into an overall conclusion about skill changes will surely differ across individuals. But it is difficult to see a priori how errors of this kind would vary with establishment characteristics. And it is worth noting that other measures of skill change, such as occupational titles, have their own measurement problems, as noted above.

The fact that the question asks about a change in skill levels suggests that ideally we would like to have information about changes in establishment practices, data that we do not have, unfortunately. On the other hand, many of these practices are essentially new; widespread computer use among regular employees, for example, is quite a recent phenomenon, as are most of the work systems examined here.

We begin the analysis with an equally straightforward logit model examining the responses as to whether skill requirements have risen. Controls are included for industry at the 2-digit level, establishment size, whether it is part of a multi-establishment operation, and the percentage of the work force accounted for by production and supervisory employees. (Appendix Table A-4 contains summary statistics for all variables included in the regressions.)

In particular, we are interested in seeing whether skill requirements have risen where the education levels of production and supervisory employees (the groups most directly affected by technology changes of the kind described here) have risen; whether the use of computers, the presence of research and development operations, and capital lead to rising skill requirements; whether skill requirements are rising where TQM programs and self-managed teams are in place, where the ratio of production workers to supervisors is greater, and where the organization is "flatter"—as measured by the number of levels of management.[10] The argument concerning the latter two variables is that they measure changes that essentially push tasks down onto the more numerous, lower-level employees, raising the skill requirements of their jobs.

Hypotheses concerning the influence of union representation are more ambiguous. The "mixed effects" literature suggests that unions may help lower-level employees prevent their jobs from being deskilled. But employers also appear to treat unionized establishments very differently, for example, underinvesting in the kinds of new techniques that might otherwise raise skills.

Table 1

Logit Results for Establishments Reporting Rising Skill Requirements for Production Jobs

Variable	Parameter	Standard Error
Intercept	.85	.28
TQM Program	.15	.03
Percent of Nonmanagerial Workers in Self-Management Teams	.001	.006
Ratio of Employees to Their Supervisors	.0002	.0007
Number of Management Levels	−.008	.010
Log Capital Stock/Total Sales	.03	.009
R&D Center Present	.12	.03
Percent of Managers Using Computers	.0007	.0005
Percent of Nonmanagerial Employees Using Computers	.001	.0005
Percent of Employees with Less than One Year of Tenure	−.0005	.0009
Education of Production Workers (years)	−.025	.018
Education of Supervisors (years)	.02	.01
Percent of Employees Unionized	−.0007	.0005

R^2 = .17
$\overline{R}^2$ = .14
F = 5.146
Prob > F = .0001

The results presented in Table 1 are generally supportive of the hypotheses. For example, computer use is associated with rising skill requirements (not quite approaching conventional significance levels for managerial computer use) as are capital levels and research and development operations. TQM programs and self-managed teams also raise skill requirements. The presence of unions seems to lower skill requirements, although the effect is very small and estimated imprecisely. Perhaps the most surprising result is that while skills are rising where supervisors are more educated, they appear to be rising more where education levels of production workers are *lower*.

Part of the complication in understanding these education results is that the dependent variable measures only whether skill requirements are rising, not whether they are high or low, in contrast to the skills complementarity research, which attempts to measure levels of technology. So, for example, the skill levels at

[10] Supervisors are defined as the first level of management.

establishments with uneducated production workers could be rising very quickly, precisely because they start from a low base. In other words, these establishments are playing catch-up with more sophisticated establishments. The relationship between rising skills and higher education levels of supervisors is perhaps easier to see. Given that supervisors serve important training and teaching functions, it is important that they be more educated when efforts are under way to raise the skill requirements of the workers they supervise. Interpreting the magnitude of these relationships in a practical way is difficult, given the categorical nature of the dependent variable.

The next issue to examine is how some of these same factors that raise skills might affect the structure of wages in these establishments. One way to think about this relationship is as a system of equations, where establishment practices with respect to technology, broadly defined, drive increases in skill requirements and, in turn, wages. But there are several reasons for examining the reduced form, where potential relationships between practices and wages are considered directly. First, the average level of skill requirements is more likely to be related to wage levels than is the increase in skills, the dependent variable examined above, and we do not have a measure of average skill levels. Second, the establishment practices considered here may have effects on wages other than through skill levels. They may demand more effort, for example, or generate stress that requires commensurate compensation. The variable measuring skill increases is included in the analysis, however, to see how rising skill requirements affect wages.

For production workers, wages are higher where teams and TQM are used and where organizations are flatter, and where capital is more intensive.

Another potential issue is that wage levels may affect the choice of practices. This is perhaps most obvious with capital decisions like computer purchases, where capital could be substituted for labor, depending on relative prices. It is less obvious for these other practices, where the effects on labor are not at all clear. For example, does a TQM program increase or decrease total labor requirements or change the mix of workers by skill? Where wages affect the choice of practices, the relationship may well be recursive, as Bartel and Lichtenberg (1987) argue in a similar context—practices drive wages, which then affect the choice of practices, and so on. In that case, more straightforward, single-equation ordinary least squares techniques may be sufficient.[11]

Simple OLS estimates relating establishment practices to wages are presented for production workers, for supervisors, and for the differential between the two. The same set of independent variables is used as in the skill requirements equation, and for similar reasons—practices that demand more from employees should lead to higher wages for production workers. The one exception is that we also include the variable measuring whether skills have risen for production workers in the equation.

Given that the work organization practices in particular are aimed primarily at production workers, we might expect their effect on supervisors to be different from the effect for production workers. The complication in framing hypotheses about supervisors is that they often serve two very different roles. On the one hand, they are teachers and monitors of employees, serving as a substitute for lower-quality workers; on the other, they also serve as lead workers, contributing side-by-side with production employees and functioning as complements when the ability of their workers increases. To illustrate, having more educated production workers may reduce the monitoring tasks of supervisors but may increase the standards to which supervisors have to perform in their own tasks.

An interesting question is the extent to which the practices measured by the independent variables demand more of the skills and abilities that trade in labor markets, suggesting that higher-quality workers should be needed, or require greater effort and attention of the kind that commands higher wages as a compensating differential. Traditional wage equations

[11] The kind of practices outlined here may be associated with better organizational performance, which in turn makes it possible to pay higher wages through some kind of rent-sharing model. These practices may generate such performance themselves, or better performance produced through some other means may provide resources that make possible both these practices and higher wages. We hope to estimate the extent to which rent-sharing is involved in these results in subsequent models by including controls for establishment performance.

Table 2
Regression Results for Log Average Annual Pay for Production Workers

Variable	Parameter	Standard Error
Intercept	9.10	.17
TQM Program	.05	.02
Percent of Nonmanagerial Workers in Self-Management Teams	.001	.0004
Ratio of Employees to Their Supervisors	−.0005	.0005
Number of Management Levels	−.01	.006
Log Capital Stock/Total Sales	.01	.006
R&D Center Present	.02	.02
Percent of Managers Using Computers	.0008	.0003
Percent of Nonmanagerial Employees Using Computers	.0006	.0003
Percent of Employees with Less than One Year of Tenure	−.005	.0006
Education of Production Workers (years)	.05	.01
Education of Supervisors (years)	.008	.007
Percent of Employees Unionized	.002	.0003
Skills Rising for Production Jobs	.05	.02

R^2 = .17
$\bar{R}^2$ = .14
F = 5.146
Prob > F = .0001

of the kind presented here that control for education may well ignore effects on wages caused by demanding more skilled workers.

The results for the wage equations are generally stronger than for the skills regression (Table 2). For production workers, wages are higher where teams and TQM are used and where organizations are "flatter" (that is, have fewer management levels). Wages are also higher where capital is more intensive, but having an R&D operation seems to have little effect. The use of computers by both production workers and managers is associated with higher wages for production workers. The magnitude of these effects is much smaller than Krueger's (1993) finding, however, and management's use of computers appears to have a somewhat larger effect on production worker wages than does computer use by production workers. It may well be that when supervisors are working directly with computers, they have less time to serve as monitors and teachers, and higher-skilled production workers are required as a result.

The results are somewhat different for supervisory wages (Table 3). Despite the fact that teams in production work generally transfer tasks from supervisors to employees, the presence of teamwork among production workers appears to raise supervisor wages. The new role that supervisors play in such settings (for example, "coach," not "boss") may be sufficiently challenging to command greater pay. Flattening the organization also raises supervisor pay, presumably because it pushes more tasks down to supervisors. But a wider span of control (the production worker to supervisor ratio) has no effect, suggesting that the monitoring function traditionally proxied by the span of control may not be all that important in determining supervisor pay.

Perhaps the most interesting results are that supervisor pay is higher when production workers are more educated and make greater use of computers. These results also seem to suggest that supervisors may serve more as complements for the skills of production workers than as substitutes.

The estimates of the ratio of production to supervisory pay within the same establishment speak more directly to issues of inequality, at least inside organi-

Table 3
Regression Results for Log Average Annual Pay for Supervisors

Variable	Parameter	Standard Error
Intercept	9.78	.17
TQM Program	.02	.02
Percent of Nonmanagerial Workers in Self-Management Teams	.0009	.0004
Ratio of Employees to Their Supervisors	−.0003	.0004
Number of Management Levels	−.01	.006
Log Capital Stock/Total Sales	.007	.005
R&D Center Present	−.008	.02
Percent of Managers Using Computers	.0003	.0003
Percent of Nonmanagerial Employees Using Computers	.0007	.0003
Percent of Employees with Less than One Year of Tenure	−.004	.0006
Education of Production Workers (years)	.02	.01
Education of Supervisors (years)	.02	.007
Percent of Employees Unionized	.001	.0003
Skills Rising for Production Jobs	.05	.02

R^2 = .17
$\bar{R}^2$ = .14
F = 5.146
Prob > F = .0001

Table 4

Regression Results for Log of Ratio of Average Annual Pay for Production Workers to Supervisors' Pay

Variable	Parameter	Standard Error
Intercept	−.68	.15
TQM Program	.03	.02
Log Capital Stock/Total Sales	.007	.005
Percent of Managers Using Computers	.0004	.0002
Percent of Employees with Less than One Year of Tenure	−.001	.0005
Education of Production Workers (years)	.03	.009
Education of Supervisors (years)	.01	.006
Percent of Employees Unionized	.0008	.0002
Skills Rising for Production Jobs	.05	.02

R^2 = .17
$\bar{R}^2$ = .14
F = 5.146
Prob > F = .0001

zations. Because supervisors earn more than production workers on average, an increase in the ratio of production to supervisory pay can be seen as reducing the wage differential between the two occupations. We might expect that work practices like TQM would reduce pay inequality, because they raise the skill requirements of production workers—and their pay—more than they raise those of supervisors.

The results in Table 4 suggest that TQM programs reduce the differential between production and supervisory employees.[12] Perhaps the most interesting finding, however, is that increased computer use by management reduces the differential in pay between production and supervisory employees. Again, such computer use appears to identify working arrangements where the supervisors are serving as complements for skilled production workers. Among the control variables reported here, the average education level for production workers has the expected effects on the ratio, although the positive relationship with supervisor education is a surprise. Unions, which represent production workers but not supervisors, reduce the wage differential, while worker turnover increases the gap between production and supervisory pay. Together, the results in Table 2 and 3 might suggest that the introduction of computers and new work practices may increase inequality within occupations (comparing establishments that use them with those that do not) but reduce inequality between occupations within establishments where they are introduced.

Conclusions

The results described above suggest that technology has an important impact on changes in skill requirements within establishments and on the structure of wages within those establishments. Management practices—especially decisions on work organization—may be as much a source of that influence as are capital spending, computer use, and R&D.

Overall, these results seem to support the general argument that changes in the workplace are increasing skill requirements, at least for production workers. But the conclusions about the structure of wages may be somewhat different from those of previous studies, at least in part because there are many different dimensions on which to evaluate whether wage structures have changed. Specifically, many of the practices associated with new workplace technology, broadly defined, do lead to higher wages for production workers. These practices may well increase the inequality of wages between production workers in establishments that have these practices and workers in establishments that do not. On the other hand, at least some of these practices seem to reduce the wage differential between production workers and supervisors within the same establishments.

A movement toward workplace practices that raise skill requirements and wages will benefit workers, but it may also create a new equilibrium in the labor market with some potentially undesirable consequences for employers—delays in filling positions and increased wages for skilled jobs that may damage an establishment's competitiveness.[13] As with most

[12] Other insignificant coefficients from the regressions are not reported here but are available upon request.

[13] *Workforce 2000* (U.S. Department of Labor 1987) focused the attention of both employers and policymakers on the issue of a potential mismatch between the skills of the labor force and the demands of employers in the years ahead. Complaints by employers of difficulties in finding workers with adequate basic skills, despite a plentiful supply of applicants, was one of the major forces that led to another U.S. Department of Labor investigation, the Secretary of Labor's Commission on Workforce Quality and Labor Market Efficiency (1989). A recent report by the U.S. Congress, Office of Technology Assessment (1990) also argues that a mismatch between the existing labor force and skill requirements will occur as manufacturing, in particular, shifts to the flexible-specialized production techniques described by Piore and Sabel (1984).

developments, however, it is difficult to guess at the precise general equilibrium effects of such changes on the economy as a whole. For example, the changes in the distribution of employment across occupations that might result could alter the income distribution in other ways. Employers might respond to higher wages by substituting capital for labor and redesigning jobs to have lower skill requirements. This should expand the supply of applicants and address the relative shortage of skilled workers in the long run, but it may also create less challenging jobs that pay less. The National Center on Education and the Economy (1990) and Kane and Meltzer (1990) both conclude from interviews that many employers have responded to a relative shortfall/rising wages for skilled workers by "deskilling" jobs.[14] Studies like the one by the Office of Technology Assessment present the worrisome possibility that the products of these deskilled production systems will not be of the quality necessary to compete internationally. The potential consequences of rising skill requirements are therefore complex, and it may not be obvious how best to accommodate them.

[14] The rising wage differentials associated with skill and education noted above suggest that deskilling must not be the dominant trend in the economy, although it may be particularly important in some sectors and may in part offset what would otherwise be even greater increases in skill differentials.

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Appendix

Appendix Table A-1
EQW National Employer Survey Response Rates[a]

	Percentage	Number of Cases
Manufacturing Sector		
Completed + All Partials[b]	75.0	1,831
Completed + Workplace Partials	70.4	1,728
Completed Interviews	66.0	1,621
Nonmanufacturing Sector		
Completed + All Partials[b]	69.4	1,516
Completed + Workplace Partials	66.2	1,445
Completed Interviews	60.6	1,324

[a]Empirical analysis of the determinants of the probability of refusing to participate in the survey showed no significant impact of establishment size or industry on the probability of responding for the nonmanufacturing sector. For manufacturing, establishments in the largest size category (1,000 employees or more) were slightly more likely to refuse to participate in the survey than establishments in all other size categories.

[b]Since all interviews had to be completed by the end of September 1994, some of the surveys were not completed. The survey allowed for multiple respondents and was divided into two main sections: establishments' sales and financial information, and employment practices. The bulk of the survey's questions were contained in the employment practices section of the survey. Therefore, the final sample includes some partial interviews. Our analysis focuses on both the completed and the workplace partial interviews.

Source: The EQW National Employer Survey, The National Center on the Educational Quality of the Workforce.

Appendix Table A-3
Distribution of Sample by Establishment Size

Number of Employees at Establishment	Unweighted Percentage	Weighted Percentage
20–49	17	53
50–99	15	23
100–249	19	14
250–999	29	8
1,000 or more	20	2

Total unweighted observations = 3,173

Source: The EQW National Employer Survey, The National Center on the Educational Quality of the Workforce.

Appendix Table A-2
Distribution of Sample by Industry

	Unweighted Percentage	Weighted Percentage
Manufacturing		
Food and Tobacco (SIC 20, 21)	5	2
Textile and Apparel (SIC 22, 23)	4	2
Lumber and Paper (SIC 24, 26)	6	2
Printing and Publishing (SIC 27)	5	2
Chemicals and Petroleum (SIC 28, 29)	6	1
Primary Metals (SIC 33)	6	2
Fabricated Metals (SIC 34)	5	2
Machinery & Computers, Elec. Machinery, and Instruments (SIC 35, 36, 38)	6	4
Transportation Equip. (SIC 37)	6	1
Misc. (SIC 25, 30, 31, 32, 39)	6	2
Nonmanufacturing		
Construction (SIC 15–17)	5	7
Transportation (SIC 42, 45)	4	3
Communication (SIC 48)	2	2
Utilities (SIC 49)	4	1
Wholesale Trade (SIC 50, 51)	5	11
Retail Trade (SIC 52–59)	4	34
Finance (SIC 60–62)	4	4
Insurance (SIC 63, 64)	4	2
Hotels (SIC 70)	5	2
Business Services (SIC 73)	4	7
Health Services (SIC 80)	4	8

Total unweighted observations = 3,173
Source: The EQW National Employer Survey, The National Center on the Educational Quality of the Workforce.

Appendix Table A-4
Means and Standard Deviations of Variables Used in Regressions

Variable	Unweighted Mean	Standard Deviation
Percent of Managers Using Computers	75.2	30.4
Percent of Nonmanagerial Employees Using Computers	37.5	34.3
Percent of Nonmanagerial Workers in Self-Management Teams	12.9	25.9
Number of Management Levels	2.6	1.6
TQM Program? (1 = yes)	.55	.50
Ratio of Employees to Their Supervisors	18.6	20.6
Percent Supervisors	8.9	5.5
Percent Production Workers	58.6	22.6
Firm Size:		
20–49	.12	.32
50–99	.18	.39
100–249	.20	.40
250–1,000	.32	.47
Multi-Establishment Firm? (1 = yes)	.67	.47
Log of Capital Stock/Total Sales	−1.4	1.7
R&D Center Present? (1 = yes)	.58	.49
Skill Rising for Production Jobs? (1 = yes)	.66	.47
Education of Production Workers (years)	12.1	.9
Education of Supervisors (years)	13.3	1.5
Percent of Employees with Less than One Year of Tenure	13.9	14.9
Percent of Employees Unionized	20.3	32.6

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Discussion

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I would like to begin by reviewing what I think we know and do not know about technological change and its implications for the structure of wages. I will then go on to discuss the specific research reported in Peter Cappelli's paper.

I believe it is fair to say that we *know* with reasonable certainty that, over the past two decades, technological changes have raised skill requirements and that, as such, technological change has been an important contributor to the growing gap in wages between skilled and less skilled workers. In his review of the direct evidence on skill requirements, Cappelli emphasizes that such evidence is open to various interpretations, largely because of data limitations. I basically agree with this point. However, the most compelling evidence on the nature of the technological change over the past two decades comes, I believe, from indirect evidence. Despite the fact that the relative cost of skilled labor has been rising, relative utilization has also been rising (Bound and Johnson 1992; Katz and Murphy 1992; Murphy and Welch 1993). This is true whether one looks at the educational or the occupational distribution of the work force. Most of the shifts towards higher skills appear to occur within an industry (Berman, Bound, and Griliches 1994) and even within a plant (Bernard and Jensen 1994). The shifts are occurring not just in manufacturing, where foreign outsourcing might explain them, but in all sectors of the economy (Murphy and Welch 1993). From a neoclassical perspective, it is easy to explain such shifts as a result of technological change, but it is hard to explain them as a result of other factors.

I do not intend to claim that technological change will always be "biased" towards more skilled labor. Both history and the recent past offer clear examples of the opposite. For example, computer technology has led to a decrease in the demand for skilled draftsmen. However, the evidence mentioned above suggests that, certainly within the last few decades and probably for most of this century, on net, technological change has favored the more skilled.

We know with reasonable certainty that technological change has been an important contributor to the growing gap in wages between skilled and less skilled workers.

While we can be reasonably certain that technological change has increased the skill requirements in the overall economy, there is a lot we do not know. We do not know much about the nature of the innovations involved or the nature of changes in the skill requirements of jobs. What is more, I do not believe that we will learn much about the nature of the changes using the kinds of data sets that have been used successfully to document the rise in skill premia. The Current Population Survey (CPS) has asked questions of individuals about computer utilization on the job, while the Census of Manufactures asks questions about computer investments, but such data are too crude to give us much insight into the actual nature of the changes that are occurring.

If we are to learn more, we need to turn to a combination of case studies and special surveys. Case studies can be extremely informative and interesting, and they are the best way to find out about what has been occurring in the context of specific industries. However, the obvious limitation of case studies is that one can never be sure how representative they are. This is where the special survey can be useful. It is from this perspective that I read Cappelli's paper. Cappelli's tabulations are based on a new survey of the workplace, the Educational Quality of the Workforce (EQW) National Employers Survey. The data, containing information on recruitment strategies, workplace organization, and skill requirements, are representative of private establishments nationwide with more than 20 workers.

We do not know much about the nature of the innovations involved in technological change or the nature of changes in the skill requirements of jobs.

In his analysis of the EQW data, Cappelli reports on the association between various explanatory factors and changes in both the skill requirements for production jobs and the wages of production workers and their immediate supervisors. While other interpretations of the wage equations are possible, I suspect that the right way to explain them is to assume that they reflect variation across establishments in terms of the skill level of the workers. More direct measures of skills would have been useful; but in lieu of such measures, I think it reasonable to assume that, in the context of a reasonably high degree of mobility across establishments and industries, higher wages are closely associated with higher skills.

It is tempting, but mistaken, to use Cappelli's wage equation results to make inferences about the effects of various factors on the distribution of wages in the overall economy. It is easiest to make this point within the context of a specific example. Cappelli finds that computer utilization is associated with higher wages among production workers. More specifically, the wages for production workers tend to be higher in establishments where the utilization of computers is the norm. However, this result says nothing about the overall effect of computers on production worker wages. In fact, it is entirely possible that while those who work with computers are paid a premium, the introduction of computers (more broadly, the micro chip) has led to a substitution of machines for humans, a decline in the demand for production labor, and, as a result, a decline overall in the wages of production workers.

It is worth noting that by limiting his analysis to production workers and their immediate supervisors, Cappelli is missing an important part of the action. The fraction of the work force in production or nonsupervisory jobs has been declining dramatically, and this shift away from production or nonsupervisory work is a very important part of the skill upgrading that has been occurring in the U.S. economy. This comment should not be seen as a criticism of what Cappelli has done. Others, including myself, have focused on the shift away from production work but have largely ignored changes in the nature of production work itself. Thus, Cappelli's work should be seen as complementary to the tabulations that others have done. It is important, however, to bear in mind the limited focus of Cappelli's tabulations when interpreting them.

I will not review Cappelli's findings in any great detail, but do want to comment on a few of them. He finds that the use of computers is associated with higher wages or skills. This result mirrors other results in the literature, although here Cappelli finds this result for production, nonsupervisory workers. Krueger (1993), using the CPS, found an association between the use of computers and wages, but his sample included all workers. In my own work (Berman, Bound, and Griliches 1994), I have found investments in computers to be positively associated with the shift away from production work, but that study ignored changes that were occurring in production work itself. Thus, Cappelli's finding is newer than it might appear from a superficial reading of the literature.

The EQW includes a variety of measures reflecting the organization of the workplace (for example, Total Quality Management or TQM). A variety of researchers have speculated that recent changes in the organization of the work place are likely to have increased the skill requirements of the typical production or nonsupervisory job. The tabulations Cappelli reports represent the first statistical evidence supporting this notion that I know of.

While Cappelli is interested in studying changing skill requirements, the EQW data are not ideal for this purpose, being cross-sectional rather than longitudinal. Thus, for example, we find out that computer utilization and TQM are associated with higher wages, but we cannot be sure that changes in either were associated with increases in wages or skill requirements. Cappelli can do little about this problem within the context of the EQW data; and before having much confidence in his findings, he cautions, we need to have them confirmed with longitudinal data.

Perhaps most discouraging to me about Cappelli's paper is the fact that, despite the focus of the EQW employers' survey, the variables he uses continue to be very much "black boxes." What was it about the introduction of computers or TQM into the workplace that entailed enhanced skill requirements among production workers? To a large extent this limitation may characterize any survey, though narrowly targeted surveys (for example, the Census "Survey of Advanced Technologies" in selected manufacturing industries) may suffer less from this problem. However, I suspect that a better understanding of the effect of human resources management practices or advanced technology on skill requirements may necessitate detailed longitudinal case studies of the sort recently completed by Ichniowski, Shaw, and Prennushi (1995) on the steel industry.

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