The Impact of Technological Change on Work and Wages

Clair Brown and Ben Campbell[1]

I. The Issues

How technology affects work and pay has been an important topic in the study of labor markets and wage distribution. In this review article, we provide an overview of recent research in two particular areas: how technological change has affected wage and employment structures nationally, and how technological change has affected work at the establishment or plant level. With a few exceptions, we further limit our review to major empirical studies of United States data covering the 1980s and 1990s.[2]

This review seeks to identify the general consensus about the impact of technology on work and wages, as well as what is ~~still~~ controversial and what is still not known. Most recent studies have found that technological change has increased skill demand and has both supported and required new work practices, but ambiguities between findings at the national level and at the establishment level have led to two paradoxes. One is the paradox of productivity: the impact of new technology on productivity is much larger at the establishment or firm level than at the national level. The other is the paradox of wage inequality: wage increases for workers using advanced technology are much greater at the national level than at the establishment level, where wage dispersion appears to be occurring primarily across firms within industries. In order to explain these paradoxes, future research should focus on three major research issues: defining and measuring technology and productivity; conceptualizing and estimating the relationship between technological change, skill, and wages; and studying the impact of new technology on the firm's human resources (HR) or employment system.~~structure of employment globally.~~

In this review, we first discuss how technology affects wage structures. Then we look at studies of the impact of technological change on wages (and growing inequality), productivity, and employment. Then we review studies of the interrelationship of technology, human resource systems, and labor productivity. Finally, we summarize the findings and suggest future research topics.

II. Impact of Technology on Wage Structures: Basic Theory

We first present a simple supply and demand model that conceptualizes the impact of technological shifts on the demand for skilled workers for skills associated with education, such as problem solving, mathematical

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[2] Machin and Van Reenen (1998) show that despite some key differences, the impact of technological change on labor market outcomes is similar throughout the OECD countries.

knowledge, and the learning new technology. In a simple model with one product and two types of workers, high skilled (H) and low skilled (L), in I firms at time t with production function Y_{it} and productivity shift relationship N_{it}, then

$Y_{it} = f(N_{Lit}, N_{Hit},\ldots)$

$N_{jit} = \theta_{jit}L_{jit}$ for j = H or L, where θ_{jit} is a productivity shifter of the labor input L_{jit}.

The first order condition is

$f_{jt}(N_{Lit}, N_{Hit},\ldots) = w_{jt}/\theta_{ijt}p_t$ for j = H or L for all firms i, where p_t is market product price and w_{jt} is the market wage rate. Notice that in this simple market-clearing model, any use of productivity-enhancing technology by only one firm results in that firm reducing the price and capturing the market.

If we expand the model to include more than one market-clearing industry, then introduction of skill-biased technological change in industry i, $\theta_{Hit}/\theta_{Lit}$, can be classified by the three possible impacts on relative skills between two periods, 0 and 1:

High-skill bias: $\theta_{Hi1}/\theta_{Li1} > \theta_{Hi0}/\theta_{Li0}$

Low-skill bias: $\theta_{Hi1}/\theta_{Li1} < \theta_{Hi0}/\theta_{Li0}$

Neutral: $\theta_{Hi1}/\theta_{Li1} = \theta_{Hi0}/\theta_{Li0}$.

We complete the model with the two skill groups having constant supply in the short-run and upward sloping supply in the long-run, and aggregate demand for each skill group is the summation of demand across all industries.

The overall impact of technological change on the employment and wages of the two skill groups in the short-run depends on the net effect of the scale or output effect (i.e., the impact on product demand and employment as p_t falls) and the substitution effect (i.e., the impact on the firm's relative demand for the two types of labor with the new technology). The net effect of the scale and substitution outcomes determines the impact of technology on labor market outcomes, and this is an empirical question. Although high-skill biased (often called skill-biased) technological change is technological change that increases the firm's demand for high-skilled workers relative to the demand for low-skilled workers, the overall impact on the demand for workers by skill is determined by the scale in addition to the substitution effects. Most studies reviewed below assume the substitution effect dominates the scale effect, and so skill-biased technical change leads to an increase in the relative demand for high-skilled workers. Under this assumption, an acceleration of skill-biased technological change will have the following impact in competitive labor and product markets in the short run:

- *Rising returns to skill.* If some firms experience a technological shock that increases their demand for high-skilled workers and consequently increases the demand for high-skill workers relative to the supply of high-skill workers in the economy (i.e., more than the technological shock increases the demand for low-skill workers relative to the supply of low-skill workers), then wages for high-skill workers increase relative to that of low-skill workers. The return to education (and inequality) will have increased, and even high-skilled workers in firms that do not experience a technological shock will receive higher wages in the short run. More simply, an increase in the level of capital/skill complementarity within a firm increases the firm's relative demand for skilled workers, which increases the national relative demand for high-skill workers and results in an increase in the market-clearing wage for high-skilled workers in the short run. However unless there is a constraint to workers acquiring the higher skill or education, the return to education should fall to the market rate in the long run.

- *Firms or industries that implement skill-biased technological change ("high-tech firms") will hire relatively more high-skilled workers than low-skilled workers.* However the net impact on high-skill and low-skill labor demand (employment) depends on the scale and substitution effects economy-wide. The impact on wages paid to high-skilled workers in high-tech firms compared to the rest of the firms depends on the impact on the total demand for skilled workers (supply constant). This is where our definition of skill becomes critical to the outcome. Since we defined skill as ~~synonomous~~synonymous with education, the returns to skill will not vary between high-tech firms and all firms, since they are operating in the same labor market.

However if we assume~~change our assumption so~~ that education and skill are no longer synonymous and~~, but~~ we define skill as embodying specialized knowledge (e.g., particular types of computer programs or specific fields of science and engineering), then firms adopting new technology that requires certain skills may have to increase pay in the short-run in order to attract the required high-skilled workers. Under the assumption of specialized skills, an acceleration of skill-biased technological change will have following impact in competitive labor and product markets in the short run:

- *Rising within group wage inequality.* Since the new technology increases the productivity of the high-skilled workers, the high-tech firms can increase the wages of these workers over the wages paid by firms that did not implement the new technology, at least in the short run. The returns to education will both increase and have a larger variance, and how long the workers with the high-tech skills can command a higher wage depends on how long it takes other workers to acquire these skills. We will also observe this outcome if skill-biased technological change is biased toward a skill or ability that is not observable or measurable but is randomly distributed throughout the population. Then within any subsection of the population, wage inequality will increase because members of the group with the unobserved skill will earn more relative to the members of the group without the skill. However we find it difficult to believe that some skill or ability~~ that has never before been rewarded in the labor market and~~ that is not observed (i.e., is not correlated with education, experience, or other skill variables) would suddenly become more valuable because of new technology.

If we further relax the assumption of competitive markets, so that industries vary by their market power and rents, then the impact of skill-biased technological change on wages becomes much more complex. The technology and wage relationship in this institutional model depends on the impact of technological change both on the size of the industry rent and on each skill group's ability to capture rent. If we assume that the market rent stays constant, a technological change that increases the relative demand for a skill group, especially if the skill group cannot be quickly expanded, should increase the bargaining power and wages of that skill group, either to the detriment of profits or the wages of the other-skilled groups. If market rents increase or decrease, then the wage outcomes must also reflect the larger or smaller pie, respectively, to be distributed. The studies reviewed below tend to implicitly assume competitive product and labor markets unless they explicitly assume product markets have rents that are shared with labor, which requires a rationing of jobs.

The impact of technical change should be visible not just in wage dynamics but also in employment dynamics.[3] If we now assume that technical change is implemented at the firm level and there are "high-tech" industries that are more likely to implement technical change, then shifts in employment demand will be observed between firms within industries, and between industries. Once again, if labor and product markets are competitive, the returns to general skills should not change and should not vary across industries. However in institutional models where wages vary by industry and labor market segment, the employment demand shifts will affect the returns to skills. In this review we will focus primarily on studies that examine the link between technologyemployment and wages and usually exclude employment shifts.[4]

To sum up, the overall impact of skill-biased technological change on relative wages of high-skill to low-skill workers depends on the underlying assumptions. In competitive markets with specialized skills, the impact of SBTC on relative wage depends on how quickly the supply of skilled workers respond to the changes in demand. The between-skill group wage gap will increase if the relative supply of high-skilled workers increases more slowly than the relative demand for high-skilled workers. If the overall relative demand for high-skill workers increases and so their wages increase, then we should expect the supply of high-skill workers to respond in whatever time period is required for workers, both new entrants and experienced workers, to acquire the higher skill. Any impact skill-biased technological change has on relative wages should be a disequilibrium situation that is resolved by a supply-side response. Only in the event of accelerating technological change, or decelerating relative supply of high-skilled workers would we expect this disequilibrium to continue for any period of time. Even under the condition of

[3] See Hamermesh (1993) and Vivarelli (1995) for an overview of the theory that relates the impact of technology to employment.

[4] See Chennells and Van Reenen (1998) for a comprehensive review of the micro-econometric evidence of the impact of technology on employment and wages. The empirical evidence tends to be anecdotal and focus on specific industries or firms.

accelerating technological change, however, workers would incorporate this acceleration into their expectations of technological change and adjust their supply decisions accordingly.

In an institutional labor market, where market rents and market power affect wage outcomes, skill-biased technological change can affect the size and distribution of market rents across firms as it creates new product markets. For example, technological innovations that led to the creation of the personal computer eventually resulted in a shift (and decline) in market rents from IBM to the multitude of PC makers. Simultaneously technological change can affect the distribution of these rents between capital and labor and within labor groups as it affects the structure of bargaining power.

III. Empirical Relationship Between Technological Change and Wages

Wage structures underwent a large shift in the 1980s and early 1990s that resulted in rising inequality. Analysis of the empirical trends from the 1980s gives us the following stylized facts:

- wage dispersion increased rapidly;
- the average returns to education and experience (often used as proxies for skill) increased;
- wage dispersion also increased within specific groups, including those with the same education, experience, race, or gender;
- the relative supply of college-educated workers increased (although the rate of growth decreased);
- changes in the relative demand for skilled workers were driven by within-industry changes instead of across-industry changes and by across-firm changes instead of within-firm changes.

Many researchers have argued that these trends are consistent with the story that an acceleration in technological change led to a change in labor market outcomes in the 1980s. Other researchers have argued that ~~these trends can be explained by other forces~~other forces can explain these trends.

Since studies of the impact of technology on wages cover~~is~~ a broad literature, we will focus our review on three key areas. First we look at studies that analyze changes in wages using only national individual-level data. Second we look at studies that analyze the impact that one specific technological change, computerization, has had on labor market outcomes. Third we look at research that augments individual-level data with industry-specific or plant-specific technology variables. ~~Fourth~~Then~~,~~ we discuss the problems with~~of~~ measuring technological change.

A. National Individual-Level Data

In the past two decades wage inequality in the U.S has grown as wage dispersion has increased by education and experience and in the residuals (unobserved heterogeneity). Here we look at research that uses Current Population Survey (CPS) data[5] to examine the relationship between technological change and four of the

[5] See appendix for a brief description of the major data sets used in the studies reviewed.

potential outcomes of technological change: increasing returns to skill, increasing overall wage inequality, increasing within-group inequality, and industry-specific wage changes. The primary goal of this literature is to document changes in U.S. wage structures in order to attribute the increased inequality to changes to one of four potential explanations:

- a decline in manufacturing employment (especially high wage manufacturing employment) that results from a variety of causes including changes in international trade, increasing levels of automation, and shifts in consumption demand.[6] [6] This increases inequality by putting downward pressure on the already relatively low wages of production workers as their relative demand falls;

- a decline in unionization. This increases inequality by reducing the wages of production workers as their bargaining power declines;

- a decline in the rate of *growth* of the college-educated population leads to growing inequality by decreasing their relative supply and pushing their wages higher;

- skill-biased technological change increases the demand for high-skill workers relative to low-skill workers, and causes the wage gap between the two groups to increase as described in our simple model.

We describe four studies (Bound and Johnson, 1992; Levy and Murnane, 1992; Katz and Murphy, 1992; Juhn, Murphy and Pierce, 1993) that use CPS data from numerous years to document and analyze increased wage inequality (see Table 1). In the framework of our model, these studies attempt to use national-level data to examine the role of technological change, which occurs at the firm level. This literature is excellent at documenting changes in the U.S. wage structure and presenting potential explanations for the changes[7]. The studies all agree that wage inequality has increased as the returns to education and the returns to experience have increased. In addition, Katz and Murphy find that wage dispersion is growing within industrial sectors and within occupations; Juhn, Murphy, and Pierce show that dispersion within narrow education and experience classification groups has increased. Since the studies use the same data, it is not surprising that their basic results are similar. The researchers use different methodologies, which demonstrates that their results are robust. They agree that the first three potential explanations (decline in manufacturing, in unionization, and in growth of college-educated population) cannot explain the majority of the change in wage structures. However they erroneously conclude that changes in the demand for skilled labor must be driving the increase in wage inequality, and that these changes are consistent with the hypothesized effects

[6] The impact of technology on wages, productivity, and employment appears very similar to the impact of trade on labor market outcomes, and it is often difficult to separate the effects of the two phenomena. In this literature review we will not address the impact of trade on wages. Key articles in the literature are Baldwin and Cain (1997), Leamer (1996), and Wood (1995).[7] The impact of technology on wages, productivity, and employment appears very similar to the impact of trade on labor market outcomes, and it is often difficult to separate the effects of the two phenomena. In this literature review we will not address the impact of trade on wages. Key articles in the literature are Baldwin and Cain (1997), Leamer (1996), and Wood (1995).

of skill-biased technological change, which is not included as an explanatory variable. These studies argue the unobserved variable driving the inequality must be technological change. We do not find this to be a convincing argument, since other hypotheses, such as the unobservables represent changes in job-specific or firm-specific variables that are unrelated to technological change, are also consistent with these findings. More direct evidence of what is causing the increased inequality is needed.

Since the CPS does not contain any measures of technology or firm-level variables, it cannot be used alone to analyze the impact of technological change on labor market outcomes. The next line of literature takes a more narrow view and focuses on one specific example of technological change.

B. Impact of Computerization on Wages

This literature uses data that contain technology-use variables at the individual level in order to analyze the impact of technology on individual labor market outcomes. One of the potential impacts of skill-biased technological change is to augment workers' skills as they learn to use a new technology. Often this is observed as an increase in the returns to skill or education, even though the workers' skill inventory has actually enlarged. One skill that technological change may be biased toward is computer fluency. The basic methodology of this literature is to compare workers who use computers to those that do not in order to estimate the return associated with computer use. Since computer power became egalitarian and moved away from the mainframe and to the desktop in the late 1970s, which was concurrent with the take-off in wage inequality, computers are an excellent candidate for skill-biased technological change.

Krueger (1993) analyzes the returns to computer use using data from the CPS, which contains a variety of computer usage variables. He finds that the percentage of respondents who claimed that they use a computer at work increased from 24 to 37 percent of the workforce between 1984 and 1989. Fitting a log earnings function that includes a computer-use dummy variable, he estimates that workers who use a computer at work earn 10 to 15 percent more than those who do not. He concludes that a computer use premium could account for one third to one half of the increase in return to education. These results provide evidence that technological change can account for a large portion of the variation in wages between groups, but they offer no explanation for the growing within-group wage inequality.

In response to Krueger, DiNardo and Pischke (1997) examine data from the West German Qualification and Career Survey, which contains demographic variables and extensive data on job tasks respondents perform at work, including computer-use, telephone-use, pencil-use, hand tool-use, and work performed-while-sitting. First DiNardo and Pischke recreate Krueger’s estimate and confirm that the German data support the estimate of a 10 to 15 percent computer-use premium. They then repeat the estimation including dummies for other work tasks. Surprisingly, they find that using a pencil at work returns a wage premium of similar magnitude to that for using a computer. This result leads them to argue that there is some type of selection or rationing of workers in those jobs using office equipment, and that Krueger's assumption of technology as the causal factor should be questioned.

In the same spirit as DiNardo and Pischke, Handel (1998) uses new data from supplements to the CPS to estimate the return to computer usage. He has data on the performance of eight key job tasks, including using a computer, writing text to be read by others, and using math. Handel fits a series of log wage regressions that include a set of dummies for frequency of undertaking eight job tasks. He finds that the return associated with each of the skills are of similar magnitude. Like DiNardo and Pischke, he argues that the similarity in the estimated return to very different job tasks occurs because the estimates are picking up some unobserved variable that is correlated with all of the job tasks. His findings show that the estimated return to computer use which~~which~~ does not control for this underlying variable will be significantly upward biased.

Entorf and Kramarz (1997) use French data to examine if users of new technology are more highly paid because they are inherently more skilled than non-users or if the technology makes them more productive. Their data include workforce characteristics and implementation and use of new technologies, such as use of a micro-computer, machine tools with numerical command, or robots. They find that computer-based technology typically is used by workers who were already more highly paid than their peers, and who then become even more highly paid with experience in the new technology. They estimate that using a computer-related technology increases a workers wages by six percent for the first year, and then by one to two percent annually until the wage premium tops out at an average of 16 percent, which is similar to Krueger's estimates for U.S. workers. Their estimates show that skill differentials are driven primarily by years of experience on the new technology rather than strictly by use of the new technology.

These studies examine the growth of between-group inequality, but do not offer insight into within-group phenomena. However, as shown by Juhn, Murphy, and Pierce (1993), within-group wage variation comprises a larger portion of the increase in inequality than between-group variation. Potentially using more control variables, and hence finer groupings, might explain most of the changes in inequality and eliminate the distinction of between-group and within-group inequality.

More problematic is the absence of analysis that indicates why, or under what conditions, technological change increases wages. Measurement that is not grounded in theory may be difficult to interpret and may be consistent with several interpretations. The articles consistently find that workers who use computers earn more than

[7] For more in this line of literature see Murphy and Welch (1992a) and (1992b), and Gottschalk (1997).

workers who do not. The studies reviewed above attempt to analyze changes in wage inequality by examining changes in return to skill associated with technological change. According to our simple supply and demand framework, these studies need to relate technological change to a short-run ~~iincrease~~increase in the relative demand for skilled workers (market-~~=~~clearing model) or to a shift in firm-~~specofic~~specific rents and their distribution. They find a correlation between wages and technology, but can not complete the chain of causality linking the two.

The next set of studies combine the strengths of the two previous lines of literature. They use large industry- and plant- specific data sets that cover national samples, which allow for shifts in skill demand and provide proxies for the measurement of technology.

C. Industry and Plant-Level Data

Industries and plants that have experienced an acceleration of skill-biased technological change should display greater changes in labor market outcomes than industries and plants that have experienced less skill-biased technological change (*cet par*). Studies use industry and plant level data in order to proxy for skill-biased technological change with an observable technology variable, such as R&D intensity or investment in high-tech capital. Although these variables are crude in their measurement of technological change, they contain enough variation to proxy for technological effects.

We describe three studies (Berman, Bound, and Griliches, 1994; Allen, 1997; Brown and Campbell, 1999) that examine industry-level data (see Table 2). Berman, Bound and Griliches proxy for skill-biased technological change with investment in computers and R&D intensity and find that industries with these markers of technological change have increased employment of high-educated labor. Allen uses industry-level data on R&D intensity and stock of high-tech capital as proxies for technological change. He finds that wage differentials are closely related to the technology proxies, which account for 30 percent of the increase in the educational premium. The Sloan "Conference on Industry Studies of Wage Inequality" document ~~Industry Centers find~~ that wage structure dynamics differ in both magnitude and direction across the Sloan industries.[8] For example, Brown and Campbell using semiconductor plant-level data find that the use of new automation and IT systems appears to go with a worsening of career ladders for higher skilled workers at semiconductor plants, and this is the opposite of the result expected with SBTC. This indicates that the impact of technological change on skill demand, including education and the speed of knowledge depreciation, is a complex relationship that must be explored in more detail.

We describe three studies (Davis and Haltiwanger, 1991; Doms, Dunne, and Troske, 1997; and Jensen and Troske, 1997) that use plant level data with industry controls from the Longitudinal Research Database (LRD) to study changes in wage distributions over the period 1963-1986 (see Table 3). The LRD includes only the manufacturing sector of the U.S. economy, which covers less than 20% of total U.S. employment. However the impact of technology on employment and wages should be more pronounced in the manufacturing sector where, for example, automotive line operators are replaced by robots and computer programmers. Davis and Haltiwanger's key finding is that the majority of the wage variance in U.S. manufacturing is attributable to between-plant differences, which they (erroneously) assume must reflect differences in the rate of technology change. Using the LRD data base combined with R&D intensity to measure technological change, Jensen and Troske find that, once technology is accounted for, most of the increase in demand for skilled labor can be attributed to unobserved factors. Doms, Dunne, and Troske show that establishments using more of a set of advanced technologies employ relatively more skilled workers and pay higher wages than companies using fewer of the advanced technologies. However, they also find little relationship between adoption of new technologies and employment shifts toward non-production workers. Their analysis shows that plants adopting new technology have more non-production workers both before and after the adoption.

Building on the previous studies are Autor, Katz and Krueger (1998), who represent the latest thinking in the mainstream, and Mishel and Bernstein (1998), who represent the dissenting view (see Ttable 4). In light of DiNardo and Pischke's study, Autor, Katz, and Krueger re-examine the impact of computers on both supply and demand in the labor market and provide an analysis of relative demand shifts. They combine census and CPS individual-level data with industry-level proxies of technological change, including National Income and Product Accounts data on office computing and accounting machinery per worker and National Science Foundation data on R&D intensity. They find that the relative demand for college educated workers grew faster in 1975-1990 than in 1940-1975, which is consistent with acceleration of skill-biased technological change. However, the growth rate of the supply of high-skilled workers accelerated in the 1970s, and so the skill premium did not increase until the 1980s. They find that technological change proxies can explain most of the increased shift in demand toward college graduates in the 1980s, which occurred primarily within industries, and that industries with larger investment in computer equipment increased demand for college graduates more quickly. Overall they estimated that the implementation of computer technology may account for 30 to 50 percent of the increase in relative demand for skilled workers.

Mishel and Bernstein present very different findings than Autor, Katz, and Krueger. They combine CPS individual data with proxies for technological change--computer stock accumulation data from the BEA and share of scientists in each industry calculated from the CPS. They argue that, given a constant growth rate for supply and demand, skill-biased technological change must be accelerating in order to be causing an increase in wage inequality. Analyzing the impact of the acceleration of technological change on several points in the wage distribution,

[8] "Conference on Industry Studies of Wage Inequality" Madison, Wisconsin March 26-27, 1999.~~Sloan Industry Centers -~~

rather than only the mean, Mishel and Bernstein find that the relative demand for college graduates in the 1970s is not significantly different from the relative demand in the 1980s. ~~Furfthermore~~Furthermore technological change was more favorable to the bottom of the male wage structure in the 1980s than in the 1970s. These results are not consistent with the hypothesis that an acceleration in technological change led to the increase in inequality in the 1980s or 1990s. They argue that the key components underlying changes in wage inequality are factors such as trade, industry shifts, immigration, and institutional factors.

Both of these key articles analyze the connections among technological proxies, demand shifts, and wages over a long time period. Two key differences in methodology seem to drive their contradictory findings. Autor, Katz, and Krueger account for shifts in the growth of the supply of workers, while Mishel and Bernstein do not. Mishel and Bernstein examine the impact of wages on a more detailed representation of wage distribution, while Autor, Katz, and Krueger examine only the means. It is possible that these two studies are consistent, and an avenue of future research is to combine these two methodologies and repeat the analysis accounting for many points on the wage distribution and for changes in the structure of demand.

While the majority of the literature examining the impact of technological change on wage structures has found that technology has indeed had a major impact on labor market outcomes, there is a growing voice that contends otherwise. DiNardo and Pischke (1997), Handel (1998), and Mishel and Bernstein (1998) all argue that the impact of technology is overstated. DiNardo and Pischke and Handel look at more detailed data than previously available, and Mishel and Bernstein look more deeply into the traditional data and examine a longer time period. They argue that the story of the impact of accelerated technological change on wage structures in the 1980s may be wrong.

Combining industry-level technology data and individual-level labor market data allows an analysis of the impact of technology on wages and provides information on the mechanisms through which technology affects wages. Most of the studies show that wage structures are changing between plants and within industries and indicate that technology plays a role in the evolution of wage structures. They connect technology to changing skill demand and then to changes in wages. However we are still left with relative wage growth for skilled labor that is unrelated to technological change.

D. Measurement Issues

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A key problem in this literature is the technology measurement issue. How to define and measure technology is a complex issue that largely determines the limitations as well as results of a study. Our study of semiconductor fabrication (Brown and Campbell, 1999) provides an example of the wide range of new automation and information technologies that have been introduced and the many types of work activities that have been modified or eliminated as operations by the new technology. We have identified at least four distinct ways that microelectronics have been used to automate the work process: automation of materials handling; automation of operations; automation of scheduling and process control; and automation of data collection and analysis. Notice that this list of new technology does not include the technology used in the actual processing of wafers, such as photolithography, which has undergone dramatic shifts as the line width~~s~~ shrinks. The shifts in automation and information technology have a greater impact on the employment system than shifts in process technology.

Researchers lacking specific technological change variables have been forced to utilize proxy variables. The two most common proxies for technological change are quantity of computer stock and R&D intensity. Mishel and Bernstein (1998) use measures of capital, including “office, computing, and accounting equipment” per full-time equivalent worker. This measure may be a good proxy for technology in a service industry like banking where automation has occurred in computing activities and business services. This measure may not be a good proxy in manufacturing. In our semiconductor example, this measure includes expenditures for the computers that run the data, scheduling and control systems but excludes expenditures for equipment that moves materials or automates operations.

R&D intensity, as measured by percent of the workforce engaged in R&D activities or R&D expenditures as a percentage of revenues, is used by the BLS and OECD to classify industries as “high tech” (Allen, 1997). This measure may do a poor job of capturing technological change, since the relationship between R&D and new technology depends on the success of the investments and the length of period until implementation takes place. In addition, some companies are able to buy or appropriate new technology from external sources without R&D expenditures.

Researchers must be careful using proxies for technological change at the national level. Finding a technological change indicator that consistently captures the change in all industries is a challenge at best, an impossibility at worst.

IV. Technological Change, Human Resource Systems, and Productivity

Next we turn to research that has been conducted at the firm level to study the direct mechanisms through which technological change affects work, pay, and productivity. We divide the research into three areas. First we review studies that explore the nature of technological change and how technology affects work and wages. Second we review studies that analyze the relationship between the use of new technology and human resource (HR) systems, which are the firm's practices that govern the use of labor. We exclude studies that focus on the impact of technology on organization and do not include explicit analysis of HR systems.[9] The third group includes studies of the impact of technology on labor productivity and firm performance. We intentionally place the discussion of productivity within the human resources section, since the impact of technological change on productivity is found to vary by the HR system.

A. Technological Change and the Impact on Work and Wages

Earlier research on the impact of technology focused on whether work was upskilled or downskilled and to what extent technology was used to control labor.[10] Numerous case studies of the impact of new technology on skill led to the conclusion that there was nothing inherent in technology that increased or decreased labor skills.[11] Many researchers were optimistic that the new automated technologies would require higher-order mental and teamwork skills (Hirshhorn, 1984) and that technology coupled with demand for diversified products would allow the return of the new technical craftsman (Piore and Sabel, 1984). Studies often found that the impact of technology on work depended upon the HR system in which it was imbedded (Hunter and Kafkas, 1998; Bresnahan et al,1998). Case studies analyzing how technological change affects skills, job tasks, and pay have raised serious questions about how to interpret the relationship between skill and technology variables and wages in studies using national data sets (Moss, 1997).

At the establishment level, most researchers agreed that the impact of new technology depends upon the nature of the technology, and so they identify and study a specific technology. Being able to study a specific technological change is one of the strengths of case studies as opposed to national studies, where technology is often only vaguely defined (e.g., computers). Here we refer to three studies that focus on the importance of shifts in technology that have changed the nature of work, increased skill requirements, and opened new output possibilities for companies.

[9] Examples of this include studies of how technology affects the intrinsic nature of work, firm strategic decisions, and communication systems within and across companies. See Liker, et al (forthcoming 1999) for a review of the sociological literature of the impact of technology on the nature of work and organization. Thomas (1994) studies the dynamic-interactive relation between the choice and implementation of technology and organization process.

[10] See Adler (1992), Cappelli (1993, 1996), and Vallas (1990) for concise reviews of this literature.

[11] See Flynn (1988) for a survey of case studies of technological change that show considerable variance in the effects on employment and skill levels. How to define and measure skill remains an issue for researchers (Spenner, 1990; Vallas 1990).

Zuboff (1988) shows how digital technology has dramatically changed work by automating routine tasks and allowing some workers to perform new kinds of work in both manufacturing and service companies. She argues that although technology automates routine tasks, its true potential lies in its ability to “informate” work and organizations by making key information more widely and easily accessible, by generating new information, and by revealing previously hidden relationships. The use of this information transforms the experience of work, requires developing workers’ potential for learning, and opens new possibilities for the organization. Application of the technology dramatically changes the way work is done and organizations function, and the transition is often traumatic for both the workers and organization.

Levy and Murnane (1996) and Murnane, Levy, and Autor (1999) reach a similar conclusion about the way new computer technology has changed work. They argue that job tasks include routine or rule-based problem-solving operations, which can easily be done by a computer, and exceptions or model-based problem-solving , which cannot be done economically by a computer. The use of computers results in the exceptions shaping the demand for labor both in terms of quantity and skills. In their case study of accountants at a large urban bank (Levy and Murnane, 19965), computerization eliminated the routine parts of the job (e.g., data entry and transfer, computation) and left the more difficult exceptions (e.g., data rework, valuation, and analysis). Although computerization increased the demand for skilled labor in the redesigned job, the bank chose to provide in-house training rather than increase the wages and skill requirements for new hires. Computerization also required upgrading the skills of the first-line managers and allowed the development of increasingly complex products. Murnane, Levy and Autor (1999) also studied the how the lower-skilled jobs in check processing were redesigned with the introduction of image processing technology. The outcomes for these jobs were more complex, in that instances of both increases and decreases in skill and pay occurred. The transformation required a structured training program and worker buy-in to be successful.

Barley and Orr (1997) study technicians and the “technization of work”, or the emergence of work that is comparatively complex, analytic, and abstract, because it makes use of tools that generate symbolic representations of physical phenomena. Sometimes technization of work does not change what an occupation is called, and technicians may appear to be doing what they have always done, even though the work is done in dramatically different ways. Managers often do not understand and may undervalue the work of technicians.

In our own field work in a telecommunications company (Brown et al, 1997), we also witnessed a job that was transformed without recognition that new skills were being used in a dramatically different job. Telephone line assignors, who traced telephone lines by hand in a book of city telephone lines, were largely replaced by computers that automatically assigned lines except for the non-routine cases, which were done by a group of retrained workers.

When we asked how much more they were paid as computer operators, the surprised workers replied that they were paid the same wage since they were doing the same job.

In an analysis of the impact of technological change in the early twentieth century, Goldin and Katz (1998) argue that historically shifts in technology have been more important than changes in relative factor prices in altering capital-output and capital-labor ratios. They present a framework in which capital and skilled labor are used to create "workable capital" (e.g., equipment), which is used by unskilled labor to create output. They provide evidence of technology-skill and capital-skill complementarities in manufacturing from 1909 to 1929 in the U.S. They suggest that these complementarities were associated with the introduction of continuous and batch process technologies and with the adoption of electric motors and that the decline in the price of electricity reinforced the adoption of these technologies. They argue that skill-biased technological change in the first part of the century did not lead to increased wage inequality because the simultaneous spread of public schooling increased the supply of skilled labor.

In both the industrial and microelectronics revolutions, these studies indicate that technological change increased skill levels without increasing wages either because the supply of skilled workers increased (Goldin and Katz, Levy and Murnane) or because the new skills were not acknowledged and rewarded (Barley and Orr, Brown et al). These studies indicate that the exact relationship among technological change, skill, and wages requires more research. We must not dismiss the possibility that in a non-clearing market where good jobs are rationed or in a situation where skilled workers can be developed fairly quickly, technological change can increase skills and productivity without increasing wages. Either situation indicates that some form of non-clearing markets probably existed prior to the introduction of new technology, since the potential skills of workers were not being developed or jobs were being rationed other than by wages.

Although the macroeconomic and institutional environment mediates how firm strategies and practices play out, few researchers have attempted the ambitious task of relating micro (firm) policy and macro environments. One example is the sustainable prosperity approach, which focuses on the interrelationship between the investment and competitive strategies of major companies and the political economic forces that have changed company profitability and the bargaining power of workers and management over profits (Lazonick and O'Sullivan, 1996; Moss, 1997).

B. The Relationship Between New Technology and Human Resource Practices

As skill-biased technological change became the prime candidate for the cause of increased wage inequality in the United States, researchers put renewed energy into understanding how technological change has affected skill demands. New national surveys directed at this issue as well as creative use of existing data sets have increased our understanding of the relationship while at the same time undermining the reliance on skill-biased technological change as the culprit for rising wage inequality. First we look at national studies that explore the relationship between technology and components of the HR system, and then at studies that directly include wages. The components of the HR system include hiring, training, promotion, work organization, job assignments, monitoring and evaluation, compensation and incentives, and discipline. So-called high performance HR systems include a decentralization of decision making that increases worker voice, involvement, and autonomy.

In a study of training and technological change, Bartel and Sicherman (1998~~c~~) find that the training associated with higher use of technology cannot be driving the increase in earnings inequality. Instead the training gap by education narrows and the proportion of workers receiving training increases at higher rates of technological change. They use the National Longitudinal Survey of Youth (NLSY, 1987-1992) for men, and six proxies for industry rates of technological change in manufacturing to study the relationship between training and technological change. Workers (especially production workers) in industries with higher rates of technological change are more likely to receive formal company training than workers in industries with less technological change (controlling for worker, job, and industry characteristics). The effect of technological change on non-company training is insignificant. More educated workers are more likely to receive company training, but the training gap by education narrows as the rate of technological change increases. The likelihood of training, but not the hours of training per participant, increases with the rate of technological change.

Bresnahan, et al. (1998), using original firm-level data, find IT use is correlated with both skills and decentralized work organization. They argue that as IT prices have fallen steadily, the demand for IT capital has risen along with the invention of new organizational forms and new services or higher quality, and together these changes have increased the demand for high-skilled workers. IT use is measured by value of computer equipment and processing power (MIPS). Skill measurement includes information for production/clerical worker on educational requirements, percent receiving training, skill level of jobs, and degree of computerization of work for production/clerical worker as well as information on the overall education and occupation distribution of all employees. Work organization measurement includes degree of autonomy and decision-making by line workers, use of self-managed or employee-involvement teams, impact of computerization on job activities, and degree of cross-training. Empirically the combination of IT and work organization is a better predictor of the demand for human capital than is IT alone[12], and workplace organization and human capital are good predictors of IT use. Increased IT investment is associated with higher output increases in firms with decentralized work organization or high levels of human capital, or both. Caroli and Van Reenen (1998) also found evidence in Britain and France of skill-biased organizational change, prompted by technology change and a more educated workforce.

[12] IT variable is identified by instrumenting with a four period lag of the log of the variable.

Now let us turn to studies that directly include wages. These studies do not find a consistent direct relationship between the use of new technology and wages, largely because of the role played by the HR system. In a study of customer service representatives in retail banks, Hunter and Kafkas (1998) argue that the relationship between technology and wages is driven by the interaction between the form of the technology and the firms' work practices. They find the coupling of automation with new forms of work organization, which allow individual autonomy and team decision making are associated with higher wages, but coupling the technology with traditional work practices is associated with a negative impact on wages. Automation in itself may increase or decrease wages; the effects of automation and work practices on wages depend on their joint impact.

Cappelli (1996) finds that increased use of computers in a firm may often occur with HR practices that include organizational restructuring to decentralize decision making. When HR system variables are included in the statistical analysis, the influence of computer use on wages is greatly reduced. He finds that the use of new work practices like TQM may be raising wage inequality between establishments, with higher wages being paid by those establishments that use the new practices, but the use of new work practices may be lowering inequality within establishments.

Levine, O'Shaughnessy, and Cappelli (1999~~8~~) argue that firm specific skills or bargaining power are increasing in importance and these, rather than general skills, are driving the increase in wage inequality. Although this study does not explicitly include technological change in the analysis of the relationship between wages and job characteristics, the finding that increased between-firm inequality is not associated with higher job skills and responsibility indicates that increased inequality is not being driven by SBTC. They used Hay Associates job points, which are calculated using specific criteria to measure skill, effort and responsibility, for five broad managerial jobs in 39 companies in 1986 and 1992. The study finds that increases in mean wages within broad occupational classifications contribute most of the increase in the sample mean wage, which was offset only slightly by shifts in jobs from the higher-paying to the lower-paying classifications as organizational hierarchy flattens. Between-firm inequality increases somewhat faster than within-firm inequality. Rising returns to Hay points accounts for most of the rise in within-firm inequality, but Hay points explain none of the rise in inequality between firms. They find that workers in similar jobs are paid quite differently across companies, but none of the differences in mean wages between high- and low-wage firms results from differences in skills and responsibilities.

These studies reinforce earlier research that showed the impact of a given technology depended upon how it was implemented (i.e., the HR system) as well as on other firm-specific characteristics, such as market power and global competitive strategy. These studies also indicate that at the firm level, the use of new technology does not necessarily lead to higher wages. Within firms, the introduction of new technology seems to lead to more equal training. The use of high performance work practices, especially those that increase employee voice and involvement, seems to be a necessary condition for wages to rise with the use of new technology. Although the use of both new technology and high performance work practices is associated with higher wages across firms, rising inequality seems to reflect firm-specific characteristics rather than the use of higher-skilled labor. The possibility that technology variables are acting as proxies for firm-specific characteristics is reinforced in a national firm-level study of IT on firm productivity, which found that firm effects account for as much as half of the productivity benefits imputed to IT (Brynjolfsson and Hitt, 1995). The cause of the firm-specific wage premiums remains unknown.

C. The Impact of Technology on Labor Productivity and Firm Performance

NextNext we turn to studies that explore the relationship between new technology and productivity growth. David's historical work (1990) on the slow diffusion of the electric dynamo in the early part of the 20th century analyzes another period when a productivity paradox was also in evidence. David's work sheds light on the difficulties of commercialization of a major technological innovation and its slow impact on productivity growth, although he points out differences in the characteristics of the dynamo and computers.

. Brynjolfsson and Yang (1996) review the literature on economy-wide, industry-level, and firm-level studies on information technology (IT) and worker productivity in order to explore the productivity paradox in which the use of IT has had little impact on productivity growth at the national level and has had significant impact on productivity improvements at the firm level. In order for measurement error to bias downward the estimated impact of technological change on productivity growth, the measurement error associated with measuring output must be increasing. Researchers therefore have looked at how the error in measuring output has been changing with computerization. Brynjolfsson and Yang argue that the main use of computers is in areas like improved quality, variety, timeliness, customization, customer service, flexibility, and product innovation, which are not well-measured in the official productivity statistics but can be included at the case study level. Since IT helps us to do new things in new ways rather than only produce more of the same things, they argue that we need to measure these new forms of value of output or welfare (see also Berndt and Malone (, 1995) and David (1990)). Also, in line with the studies reviewed in this section, they mention the need to reengineer work when introducing major IT investments. (xx Daniel Sichel?)

Researchers have found computer investment is positively correlated with product quality and labor quality in manufacturing (Siegel,19945); labor and multifactor productivity improvements of IT capital and other types of capital are similar in twenty industries (Berndt and Morrison, 1995); and estimated production functions find a marginal rate of substitution between IT and non-IT workers in the business sector of one to six (at sample mean for 1988-91) (Lichtenberg,1995). (Xx manf?)

_______.—However these national-level studies do not incorporate the impact of the human resource practices as an intervening variable, which has been found to be important in case studies. Kelley (1994) finds that using programmable automation (PA) technology provides a significant efficiency advantage over conventional machining. She uses a survey of 584 establishments in 21 industries engaged in precision metal cutting. Two work practices (dependence on operators rather than specialists for programming and the presence of a union) and firm-specific characteristics (large volume, frequent product changes, time since the technology was introduced, and more machines per worker) are correlated with greater productivity. In the semiconductor industry, Brown et al (1999) shows that both the HR system and technology used are associated with a plant's quality and output performance.[13] Their study of twenty-three semiconductor manufacturing plants shows that when plants use mew IT and automation systems, the impact on firm performance varies with the HR system. In general, manufacturing success is related to the involvement of the trained workers in problem-solving teams under the direction of engineers, who play a key role in successfully implementing new technology in this high-tech industry.

A recent national study finds a relationship between investments in new technology and, productivity, and HR practices. Black and Lynch (1997) in their study using a special survey of manufacturing establishments find that investments in new technology are associated with significantly higher establishment productivity. Productivity is also higher when the proportion of non-managerial workers who use computers is higher, while the proportion of managers using computers is not significantly related to productivity. (xx cf Brynjolfsson?) Training is not significantly related to productivity. High productivity is associated with how work practices are implemented within the establishment rather than if the employer adopts a particular practice, such as TQM. In particular, employee voice or involvement seems to be a necessary condition to making the practices effective. In general these findings are consistent with Bresnahan et al (19908), who find that productivity is not significantly associated with worker skill or with the interactive term of IT and percent professional workers and is associated with decentralized work organization (including employee voice) and its interaction with IT capital . Black and Lynch also find that uUnionized establishments with joint decision making and incentive pay have higher productivity than similar nonunion plants; otherwise unionized establishments with traditional labor management relations have lower productivity.

These studies document the complex interrelationship of new technology, HR systems and firm performance. They also indicate that the productivity paradox may eventually be resolved both at the real level--

[13] Other studies, such as Ichniowski et al (1997) have shown the importance of complementarities among work practices in their impact on productivity when technology is held constant.

companies are able to implement effective uses of their new technologies through organizational changes, including high performance HR systems--and at the estimation level--researchers find better ways to measure technological change and its impact on output at the national level.

V. Conclusions

Recent studies of the impact of technology on work and wages have increased our knowledge of this important topic. Here we summarize our review of the literature in terms of what we know, including findings that are still controversial. Then we briefly discuss the areas where we believe future research efforts should be directed.

A. What We Know and Don't Know

At the national level, researchers consistently have found an increase in wage inequality in the U.S. in the 1980s that is consistent with skill-biased technological change. Other phenomena have been proposed to explain the change in the wage structures, but these phenomena have not been able to account for a very large proportion of the overall increase in earnings dispersion. Studies that have combined measures of technological change with individual characteristics and firm or industry characteristics have found conflicting results. Depending on the methodology and data base used, researchers have found both that technology can explain most of the increase in wage inequality and that technology can explain very little of the increase in wage inequality. Some inconsistencies may actually reflect the simple fact that findings are not comparable because of they are measuring different variables or comparing different time periods. We also see that measurement of technology at any level of aggregation is problematic and must be dealt with very carefully.

Computerization is a ubiquitous example of technological change, and studies analyzing the impact of computerization on labor market outcomes have had ambiguous results. These studies show that computerization leads to an increase in demand for skilled workers and also to a change in wage structures. Researchers consistently estimate the wage differential associated with computer use (a rare skill) at 10 to 15%; yet using similar methodology, the wage differential associated with using a pencil (a common skill) is shown to be of similar magnitude. This demonstrates that wages are not determined only on the basis of skills;~~, but~~ some rationing of jobs is also at work~~a factor~~.

Another problem is that studies can only explain changes in between-group wage inequality. No inferences can be drawn on the significant growth of wage inequality that is occurring within groups, especially within industry and across firms. Better control variables, especially for firm and industry characteristics and for market rents, are needed.

~~We still know little about the impact of technology on the national structure of employment. We see that in many industries technological change leads to an increase in the ratio of high-skill workers to low-skill workers. However we do not know how technology is affecting labor demand across all industries.~~ (xx leave in?)

The actual mechanism by which new technology affects skills, job tasks, productivity, and labor demand remains a mystery in studies of national data sets. Case studies that analyze application of specific technologies at the workplace have been able to shed light on this process. However, case studies have found different relationships than national studies, and case studies have consistently found that technology alone can have a wide array of outcomes in its impact on work and productivity, since its impact depends on the HR system within which it is imbedded. Furthermore a company chooses and implements ~~makes its choice and implementation of~~ new technology along with other investment and strategic decisions, and these decisions are affected by the macro and institutional environment of the firm. At the plant level, most studies have found that when new technology is introduced with high performance HR systems, most workers' skills are increased. However studies have not found a consistent relationship between use of new technology and wages. At the firm level, the use of high performance work practices seems to be a necessary but not sufficient condition for wages to rise with the use of new technology. To what extent wage increases reflect payment for the use of higher skills or reflect firm-specific characteristics remains unclear, since researchers do not agree on why wage dispersion has increased more across firms than within firms and why returns to skill vary across firms. Some workers have shared in the productivity increase while others have not. We are left with the wage inequality paradox that use of new technology seems to increase skills and wages at the national level but not necessarily at the firm level.

Case studies have also documented that new technology changes the way work is done and organizations function. In particular, the introduction of microelectronics technology has involved new ways of producing services and products that change their nature (e.g., quality, variety, and customization as well as new products and services) and improve delivery (e.g., timeliness, flexibility, and customer service) rather than simply producing more of the same things more efficiently. We do not have measures for all these improvements even for specific industries, and national output measures still have difficulty incorporating quality improvements. Although which improvements to incorporate and how to do so is controversial, most researchers agree that current measures of national output do not adequately address the changes brought about by the new technology. However even relatively crude measures of technology and productivity at the firm level have found a positive relationship that is higher than the relationship found in national studies. In order to reconcile the firm-level and national-level data, and in order to know the overall impact of new technology, we must know the employment shifts that are occurring as relative prices change and as new products and services are introduced, both of which are affected by the technology. To what extent the productivity paradox reflects national employment shifts, the need for companies to restructure their HR systems before they can take advantage of new technology, or problems with measuring technology and productivity remains unclear.

B. Future Research

We suggest that future research on work and technology focus on the following three issues:

~~*The impact of technology on wages*. We need to study the relationships among use of new technology, impact on work activities and skill use, and compensation. Since wage dispersion has grown more across firms than within firms, we need to study what is causing firm-specific returns to technological change and what role firm-specific rents are playing in the process. If wage premiums are not directly related to skills or other observable productivity-enhancing characteristics, then we must ask how the institutions governing the rationing of jobs into higher-paying firms (i.e., which workers get them) are affected by technological change as well as other phenomena. This will allow us to understand how technological change is affecting wage structures as it reshapes skill requirements, market rents, firm competitive strategies, and bargaining power. Empirical work needs to be done with longitudinal data by establishments and across industries and with comparative data across countries.~~

Measurement of technology and productivity. O~~As suggested by many researchers, o~~ur current measures of technology usage and costs are woefully inadequate and our measures of output, and hence productivity, do not reflect many of the improvements provided by the new technology. Until we have better measures, we cannot place much confidence in the results. T~~s.~~

~~However, with t~~he increased availability of matched employer-employee databases ~~it is becoming~~will make it easier to address technology and productivity measurement issues. A combination of the analytical approaches of Autor, Katz, and Krueger, and Mishel and Bernstein using matched databases~~ would be very powerful. Combining Autor, Katz and Krueger with Mishel and Bernstein~~ would allow an analysis of the impact of technical change on employment outcomes of workers across the entire wage distribution while controlling for shifts in supply~~, and the use of matched employer-employee databases would facilitate the measurement of technology.~~ and for specific types of new technology.~~ –~~ A study of this type would illuminate the interactions of technology, supply and demand shifts, and wage outcomes that confound much of the analysis of this issue.

The impact of new technology on wages. We need to study the relationships among use of new technology, impact on work activities and skill use, and compensation. Since wage dispersion has grown more across firms than within firms, we need to study what is causing firm-specific returns to technological change and what role firm-specific rents are playing in the process. If wage premiums are not directly related to skills or other observable productivity-enhancing characteristics, then we must ask how the institutions governing the rationing of jobs into higher-paying firms (i.e., which workers get them) are affected by technological change as well as other phenomena. This will allow us to understand how technological change is affecting wage structures as it reshapes skill requirements, market rents, firm competitive strategies, and bargaining power. Empirical work needs to be done with longitudinal data for establishments and across industries, and eventually with comparative data across countries.

Impact of new technology on employment systems. In order to understand the growing dispersion within groups of similar workers and across firms within an industry, we must continue the case study analyses of the relationship among wages, use of technology, and HR systems. These case studies complement the national level studies, and together their goal is to understand what creates firm-specific effects and what determines the differences in returns to skills across firms. In particular, we need to study what creates market rents for a firm, how these rents are divided among the owners and the workers, and how new technology changes these relationships.

When we can confidently answer the questions raised in this research agenda, then we will know to what extent freely-chosen human capital investments are driving the wage distribution and to what extent workers are being rationed into a structure of job-wage slots, and how technological change is affecting these outcomes. Until we know to what extent the observed outcomes are supply- and demand-driven, as a society we cannot evaluate the wage distribution or devise appropriate policies for dealing with the forces of technological change.

~~(xx Impact of technical change that is embedded in different institutional arrangements)~~

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Key Data Sources

Current Population Survey

The Current Population Survey (CPS) is a monthly survey of about 50,000 households conducted by the Bureau of the Census for the Bureau of Labor Statistics. The CPS is the primary source of information on the labor force characteristics of the U.S. population. The sample is scientifically selected to represent the civilian non-institutional population. Respondents are interviewed to obtain information about the employment status of each member of the household 15 years of age and older. The CPS contains variables covering a variety of characteristics including age, sex, race, marital status, educational attainment, occupation, industry, and class of worker. There are also supplemental questions covering a variety of topics including school enrollment, income, previous work experience, health, employee benefits, work schedules.

Annual Survey of Manufactures

The Annual Survey of Manufactures contains historical Census of Manufactures' data and the Annual Survey of Manufactures' data covering intercensal years are available out to the 4-digit level of the Standard Industrial Classification. It contains establishment level data on total number of employees, payroll, number, man-hours, and wages of production workers, value added by manufacturer, cost of materials, value of shipments, capital expenditures, inventories, investments, and costs and quantities of fuels purchased.

Survey of Manufacturing Technology

The Survey of Manufacturing Technology (SMT) is an establishment-based survey of advanced manufacturing technology use and plans for use. The Census Bureau has carried out three individual SMTs: 1988 SMT, 1991, SMT, and the 1993 SMT. The survey asks respondents about their use and plans for use of 17 manufacturing technologies including computer aided design, pick and place robots, automated storage and retrieval systems, automated guided vehicle systems, computers used for control on the factory floor.

Longitudinal Research Database

The Longitudinal Research Database (LRD), which consists of annual cost and output data on manufacturing establishments (plants) from the Census of Manufactures (1963, 67, 72, 77, 82, 87 and 1992) and from the Annual Survey of Manufactures (since 1972), linked to form an unbalanced longitudinal panel.

Table 1: National Individual Level-Data

Study	Data	Key Empirical Findings	Analysis
Bound and Johnson (1992)	CPS March demographic supplement 1973, 1979, 1988. 18-64 years of age, reported employment a major normal weekly activity.	Educational differentials increased and gender differentials decreased in the 1980s.	Changes in wage structures are not a result of a decline in manufacturing employment nor a result of a decline in the power of unions. Changes in wage structures are driven by shifts in the demand for skills.
Levy and Murnane (1992)	CPS March demographic supplement 1971, 1979, 1987. Year-round (>34 weeks), full-time workers.	Educational differentials and experience differentials increased in the 1980s	Changes in wage structures are driven by shifts in the demand for skills.
Katz and Murphy (1992)	CPS March demographic supplement 1964-1988. Year-round (>38 weeks), full-time workers.	Educational differentials and experience differentials increased in the 1980s. Wage structure shifts are observable within industries and within occupations.	Changes in wage structures are driven primarily by changes in the demand for skilled workers, observable at the industrial sector level.
Juhn, Murphy and Pierce (1993)	CPS March demographic supplement 1964-1990, and 1960 dicennial census. Full-time workers, working > 14 weeks, aged 18-65.	Educational differentials and within-group dispersion have increased in the 1970s and 1980s.	Changes in wage structures are driven by increases in demand for skilled workers.

Table 2: Findings of studies using industry-level technology variables.

Study	Data	Findings	Analysis
Berman, Bound and Griliches (1994)	Annual Survey of Manufactures 1958-1989. CPS outgoing rotation groups 1973, 1979, 1987.	The majority of skill upgrading occurred within white-collar occupations. The fraction of investment devoted to computers and to R&D expenditures both have a significant positive effect on wages. Within industry shifts in labor market outcomes are larger than between industry shifts.	Demand shifts for skilled workers occur within industries, and are correlated with technical change.
Allen (1997)	NSF R&D data. BEA industry level data 1979, 1989. CPS 1979, 1989, all workers between 18 and 64.	Wage differentials within industries are related to R&D intensity, amount of high-tech capital, age of technology and growth in total factor productivity.	Technology plays a key role in explaining between industry wage structures.
Sloan Industry Centers - HR Conference	CPS March Supplements augmented with industry-specific data	Changes in wage structures and dynamics vary greatly by industry.	Inter-industry differences play a key role in the evolution of wage structures.
Brown and Campbell (1999)	Plant-level data from the	Increases in technology are related to	The typical skill-biased technical

	semiconductor industry 1979-1994.	worsening career-ladders for high-skilled workers.	change hypotheses do not hold in this high-tech industry.

Table 3: Findings of studies using plant-level data.

Study	Data	Findings	Analysis
Davis and Haltiwanger (1991)	LRD 1963-1982. CPS 1963-1982.	Most wage dispersion can be attributed to observable plant characteristics; trade and changes in unionization have little effect on wage structures.	Skill-biased technical change can explain the growth in between plant wage dispersion.
Jensen and Troske (1997)	LRD 1979-1988	Most wage dispersion can be attributed to between plant differences. After accounting for the level of technology, most between plant wage differentials can be attributed to unobservable factors.	Even with a detailed data set unobservable factors play a key role in the evolution of wage structures.
Doms, Dunne, and Troske (1997)	SMT 1988, 1993. 1990 Census, LRD.	Plants that utilize new technologies hire more skilled labor and pay higher wages. Implementation of new technologies is not correlated with skill upgrading.	New technologies are more likely to be adopted at firms that have a more highly skilled workforce and pay higher wages.

Table 4: Findings of studies combining individual level data with industry-level technological variables

Study	Data	Findings	Analysis
Autor, Katz, and Krueger (1998)	CPS 1984, 1989, 1993, Census 1940-1990 NIPA and NSF industry-level data	Relative demand for college educated workers grew faster in 1970-1995 than in 1940-1970. Technology proxies explain most of the demand shift toward college graduates in the 1980s	The changes in skill-demand and wages for high-skilled workers in the 1980s are consistent with the hypothesis of skill-biased technical change.
Mishel and Bernstein (1998)	CPS 1973-1995, BEA industry-level data	Relative demand for college graduates in 1980s is similar to relative demand for college graduates in 1970s. Technical change favored workers at the bottom end of the wage distribution in 1980s relative to 1970s	Low-skill workers are relatively better off in the 1980s than in the 1970s, while high-skill workers are similar which dies not fit the skill-biased technical change hypothesis.