Is Technology Raising Demand for Skills, or Are Skills Raising Demand for Technology?

BY ETHAN LEWIS

A common view is that recent technological advances, such as the introduction of computers, have rendered obsolete some occupations that require less skill and have increased businesses' desire to hire skilled workers. However, some economists have challenged this view: What if the rising skills of U.S. workers are inducing businesses to adopt — and maybe even develop — new technologies that require workers who are more skilled? In this article, Ethan Lewis assesses this alternative view. To do so, he examines the evidence that increasing skills are driving technological change.

Since the late 1990s, incomes of the highest earning Americans have risen faster than the income of other Americans, a trend that has not gone unnoticed by the press.[1] The recent rise follows a decade of relative stability in income distribution, but it resumes a pattern of growing inequality that began in earnest in the 1970s. Until recently, a standard explanation for rising inequality was that a steady flow of technological advances, such as the increasing power and falling price of computers, has raised the desire of businesses to hire skilled workers and has made obsolete some occupations that require less skill. Economists call this phenomenon "skill-biased technological change" because new technologies are "biased" toward raising the productivity (and, hence, wages) of the most skilled workers. The primary direct evidence for this explanation is that the use of advanced technologies is more common among more-skilled, highly paid workers and in plants and industries with more-skilled workers.[2]

Some economists, however, have challenged this standard view, arguing the reverse: Rising skills of U.S. workers — as evidenced by the rising proportion of people who complete college — are driving businesses to adopt and possibly even to *develop* new technologies that require more-skilled workers. Paul Beaudry and David Green argue that the decision to use new technology is not automatic but depends critically on the availability of skilled labor and capital. Daron Acemoglu goes further, arguing that as the proportion of workers who are skilled rises, inventors will direct more effort toward technological advances that skilled workers can use.[3] The distinction is subtle. Technology is still involved in rising inequality, but it is the increase in the proportion of workers who are skilled, rather than technology per se, that is the cause of rising inequality.

This article assesses the alternative views that recent technological advances may have driven up inequality or that rising skills may be driving technological advances. It begins by examining the recent changes in the income distribution. How exactly has the distribution been changing, and why might technological forces

[1] Both the *Wall Street Journal* and the *New York Times* have recently published series on rising inequality. See, for example, the article by David Johnston and the one by David Wessel.

[2] Wage and skill are closely related. In a perfectly competitive labor market, a worker's wage exactly reflects how productive the worker is, which, in turn, depends on her skill level. In practice, that is not always true (wages might also reflect a worker's bargaining power, for example), but highly paid workers do tend to have higher values of observable characteristics that are valued in the labor market, such as education and work experience. Skill-biased technological change, it is argued, has raised the value, or "price," of skills in the market and, hence, the wages of skilled workers compared to those of less skilled workers.

[3] Keith Sill's article describes Acemoglu's theory of directed technical change in more detail.

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be responsible? Is there any direct evidence that new technologies favor skilled workers? Is the association large enough to explain rising inequality? Are rising skills driving technological change?

RECENT CHANGES IN THE WAGE STRUCTURE

The basic facts about rising inequality were presented in an article by Keith Sill, but they bear repeating here. The most basic fact is that the gap between the wages of the most highly paid workers and others has been rising in recent decades in the U.S., especially in the 1980s and in the late 1990s (Figure 1). The figure shows an index of hourly wages (adjusted for changes in the cost of living) in different parts of the wage distribution from 1979 to 2003. For our purposes here, I exclude women; only men's wages have been used in the calculations. (Inequality growth is smaller if women are included: Women's wages are rising over this period compared to men's. For more on this, see *Women's Wages and Increasing Inequality*.) The 90th percentile line represents the wage for high-skill men: Only 10 percent of men earn more than this wage. The 10th percentile line represents the wage for low-skill men: only 10 percent of workers earn less than this wage. The median, or 50th percentile, represents the middle of the distribution. The top line in Figure 1 shows the gap between the 90th percentile and median wages, a measure of inequality. The figure reveals that the growth in inequality has been driven not only by the rising wages of high earners but also by the falling wages of low and median earners.

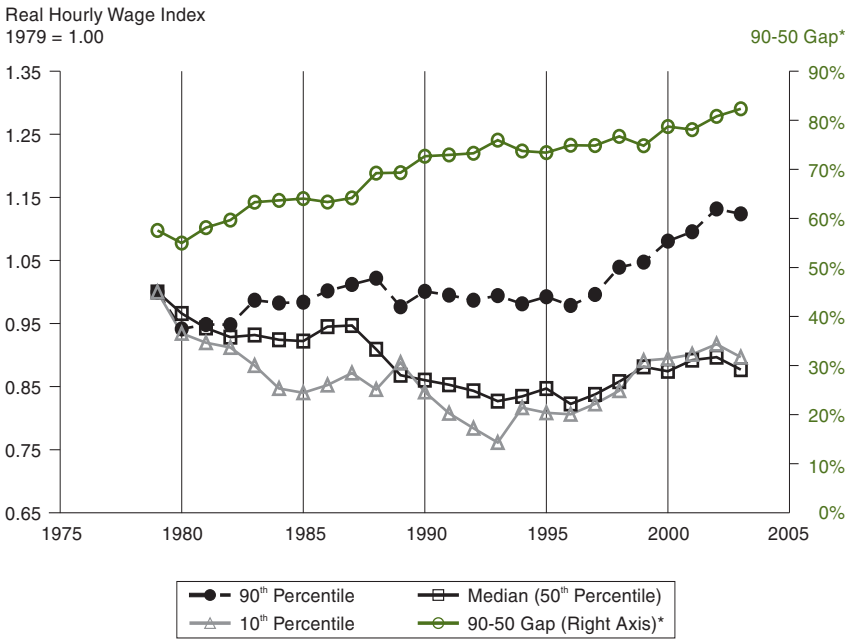
At least some of the increase in wage inequality, and some argue most of it, seems to be due to rising "return" to skill, that is, an increasing wage premium paid to workers with more skills.[4] One place this shows up is in the rising gap between the wages of more and less educated workers. Figure 2 shows wage indexes at different education levels, again for male workers only. These indexes are adjusted for changes in the cost of living, and in this case, they are also adjusted to represent workers who have similar amounts of work experience (15 years). The upper line shows that the return to a college degree — the percentage difference in earnings between a college degree and a high school diploma — has risen dramatically in the past few decades: from 30 percent to 50 percent. Earnings gaps between the other levels of education have also risen, as seen in the spreading out of lines in the lower part of Figure 2. Adjusted for inflation, the earnings of less educated workers, especially high-school dropouts, have fallen.

At the same time that the relative wages of more educated workers have been rising, the proportion of

[4] Interestingly, wage inequality has increased even among workers with very similar characteristics (for example, the same education, work experience, and occupation), which suggests not all of the increase in inequality should be attributed to an increased skill premium. However, Chinhui Juhn, Kevin Murphy, and Brooks Pierce argue that increases in inequality among similar workers could reflect increasing returns to skills that are not easily measured.

FIGURE 1

Real Hourly Wages (Males), 1979-2003



Data Source: Current Population Survey merged outgoing rotation groups, 1979-2003. Calculations include working males age 16-65 old enough to be out of school. Wages are adjusted for changes in the cost of living.

* 90-50 gap is the percentage difference between the hourly wage of the median male worker and the hourly wage of the male worker earning the 90th percentile wage.

workers who complete more education — the supply of skilled workers — has also been rising (Figure 3). The figure reports the fraction of workers with different levels of education. The fraction of workers who are high-school dropouts trends down, while the fraction with at least some college education trends up. If demand for different types of workers remains the same, a simple model of supply and demand would suggest that as the educational level of the work force rises, the gap between the wages of more and less educated workers should narrow. That the gap actually widened suggests that the availability of skilled workers may not have kept up with the pace at which businesses wanted to hire them, causing wages for skilled workers to rise. Another way to say this is that demand for skilled workers rose faster than supply.

There are competing explanations for the simultaneous rise in the supply of skilled workers and their relative wages. A standard view is that skill-biased technological change is responsible. This view originates from the observation that rising inequality coincides with the spread of computers: The PC was introduced in 1981, for example, and the late 1990s "tech boom" was a period of rapid investment in and diffusion of new information technologies (for example, the Internet and e-mail). This view posits that skilled workers are needed to operate and maintain computer technology, so demand for skilled labor rose after its introduction.

But the timing of the spread of computers is a weak argument for its effect on the returns to skill. The rise in inequality in the 1980s was largely due to a decline in the wages of less-skilled workers. As many researchers have pointed out, this may have been caused by other contemporaneous forces, including an influx of less-skilled immigrants, declining union participation, and increasing trade with the developing world.[5] Other forces that may have increased inequality and skill premiums in the 1980s include an increase in the proportion of women working (see *Women's Wages and Increasing Inequality*) and the substantial erosion in the real value of the minimum wage (Figure 4). A careful analysis by David Lee shows that the decline in the minimum wage may have been largely responsible for the increase in inequality during the 1980s.[6]

Still, economists disagree about the degree of influence of these other forces on inequality. Proponents of skill-biased technological change have pointed out that alternative forces like the minimum wage have little to say about why the wages of skilled workers would rise.[7] Also, the late 1990s

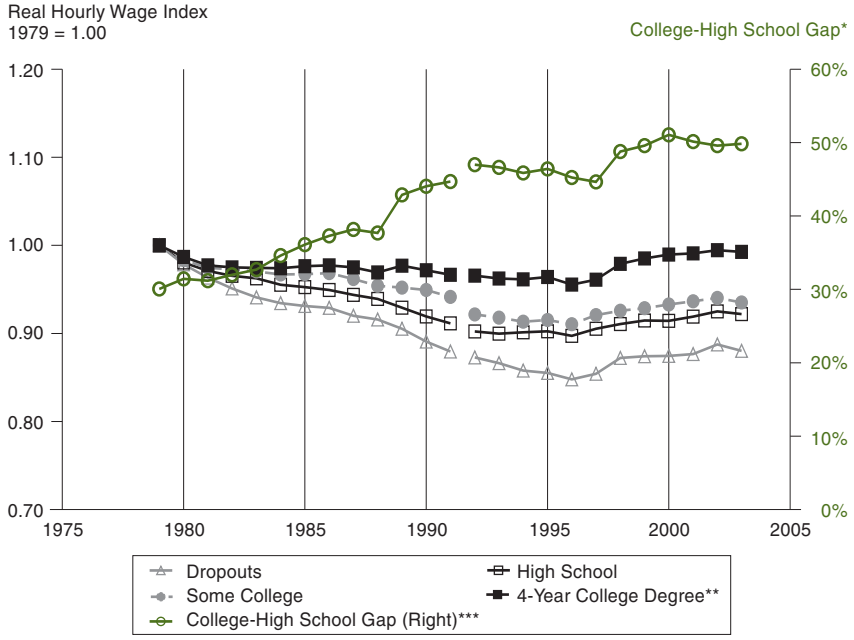
[5] For more on these factors, see Sill's article.

[6] Lee supports this view by showing that inequality rose in poorer states where many workers were earning the federal minimum wage and rose hardly at all in richer states where few earned the minimum wage.

[7] See the article by David Autor, Lawrence Katz, and Melissa Kearney.

FIGURE 2

Experience-Adjusted* Average Hourly Wage by Education Level (Males, 1979-2003)



Data Source: Current Population Survey, merged outgoing rotation groups.

*Wages are adjusted to reflect the mean for males with 15 years of work experience and for changes in the cost of living.

** Exactly 4-year degree. The series is broken between 1991 and 1992 because of a change in how the education question was asked beginning in 1992.

*** Percentage difference between the average male worker with 15 years of experience with exactly a 4-year college education and one with exactly a high-school diploma.

Women's Wages and Increasing Inequality

Most researchers who study the recent increases in wage inequality exclude women from their analysis. This is an important omission. If women are included in the calculations, recent increases in inequality are substantially smaller. This is shown in Figure 1a, which is identical to Figure 1 in the text except that both men and women are included in the calculations. Compared to Figure 1, the 90-50 wage gap measure of inequality increased by only half as much over the last 25 years and has changed little since the mid-1990s.

The reason inequality growth is smaller when women are included is that women's wages compared to men's rose rapidly over the same 25-year period. Figure 1b shows that women's mean hourly wages rose from only 67 percent to nearly 85 percent of male mean wages in the past 25 years. One force that may have made women's wages increase is women's increasing participation in the work force. Figure 1b also shows that during this same period, the proportion of women who work rose from 60 to 70 percent.[a] Another force is the rising skills of women. Women have increased their presence in professional occupations, especially since the late 1960s, a change research has linked to women's increased ability to delay child-bearing after the birth-control pill became widely available.[b] Changing social norms may have also played a role in raising women's ability to advance in professional careers.

Because researchers want to ignore these compositional changes in the work force when studying skill-biased technological change, they have typically excluded women from the analysis. Put another way, proponents of skill-biased technical change argue the wage paid to a skilled worker is higher today than a similarly skilled worker in the past; they argue that including women would risk clouding the analysis because it would mix the rising "price" of skill with an increase in the proportion of workers who are skilled (owing to women's increased presence in highly skilled occupations).[c]

While this is a widely held view, other research that examines women's wages more closely tends to reject the idea that changes in women's and men's wage distributions can be treated separately. For example, Nicole Fortin and Thomas Lemieux

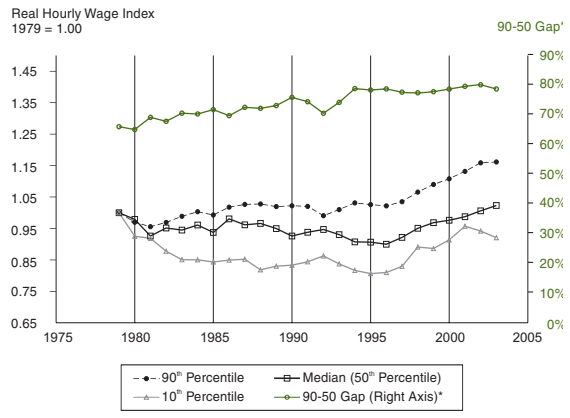
[a] Beyond this most recent period, since World War II there has been a dramatic increase in how much women — especially married women — work. Aubhik Khan's *Business Review* article describes some of the possible causes of this.

[b] See the article by Claudia Goldin and Lawrence Katz.

[c] A more subtle issue that worries economists is that women are "self-selected": that is, not all women work, and those who do may have very different earnings capacity from those who do not. If the amount of selection has changed over time — and the fact that the proportion of women who work has increased suggests that it has — it would confound measures of inequality growth. In fact, Casey Mulligan and Yona Rubinstein argue that women's wages have increased entirely because highly skilled women used to not work, and now they do. This "problem" can be overstated. The proportion of men working is also not 100 percent (in 2003, 83 percent of men age 16-65 worked) and has also been changing over time (it has been falling). However, most economists believe selection problems are smaller for men than they are for women.

FIGURE 1a

Real Hourly Wages Including Women

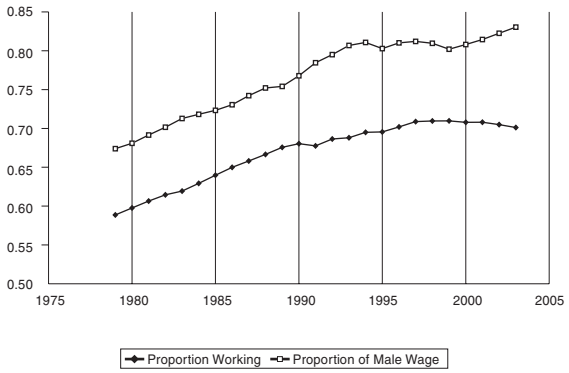


Data Source: CPS, merged outgoing rotation groups, 1979-2003. Calculations include working men and women age 16-65 old enough to be out of school. Wages are adjusted for changes in the cost of living.

* 90-50 gap is the percentage difference between the hourly wage of the median worker and the hourly wage of the worker earning the 90th percentile wage.

FIGURE 1b

Women: Proportion Working and Hourly Wage as a Proportion of Men's



Data Source: Current Population Survey, merged outgoing rotation groups, 1979-2003.

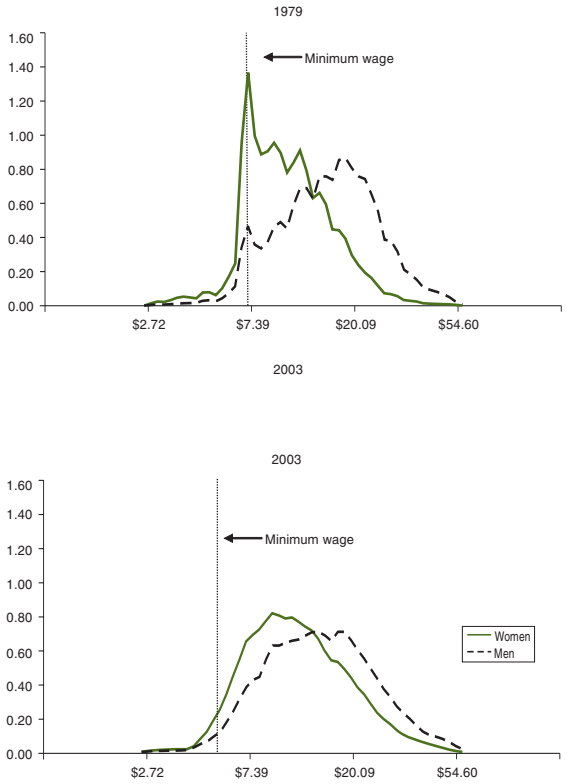
Women's Wages and Increasing Inequality (continued)

find that as women have entered into high-wage jobs, they have displaced some men, leading both male inequality and women's wages to rise at the same time. A version of their analysis is shown in Figure 1c, which gives the distribution of men's and women's wages in 1979 and 2003 (on a natural log scale). In 1979, many women were concentrated in jobs earning near the minimum wage, while men were disproportionately high earners. By 2003 men's and women's wage distributions converged and became more symmetric, as women rose to the part of the wage distribution where men formerly dominated, and men fell to the part of the wage distribution where women formerly dominated. Fortin and Lemieux argue that the increased competition from women in high-wage jobs may have increased male wage inequality, a circumstance that is missed by focusing on changes in male wages alone.[d]

However, recent research by Marigee Bacolod and Bernardo Blum argues skill-biased technological change might also partly explain the increase in women's wages. They show that women are concentrated in occupations that require "cognitive" skills (for example, doctors) whose wages have risen (arguably because of skill-biased technological change), while more men than women are in occupations that require "motor" skills (for example, mechanics) whose wages have been falling. They find that the changes in the prices of different skills account for at least 80 percent of the observed increase in women's wages compared to men's, which may mean that skill-biased technological change has helped raise women's wages compared to men's.[e]

FIGURE 1c

Distribution of Men's and Women's Real Hourly Wages (natural log scale)



Data Source: Current Population Surveys. Wages are in 2000 dollars.

[d] The figure also nicely shows the role that the fall in the minimum wage may have played in increasing inequality. In 1979, when minimum wages were high, the figure shows that wages are compressed in a spike near the minimum wage. After the real value of the minimum wage fell in the 1980s (see Figure 4 in the text), this spike in the wage distribution disappears.

[e] On the other hand, the fall in the price of motor skills might reflect other forces such as de-unionization and a fall in the real value of the minimum wage, rather than technological change.

appear to be different from the 1980s: The increase in inequality in the late 1990s was driven largely by the rapid increase in the wages of skilled workers.

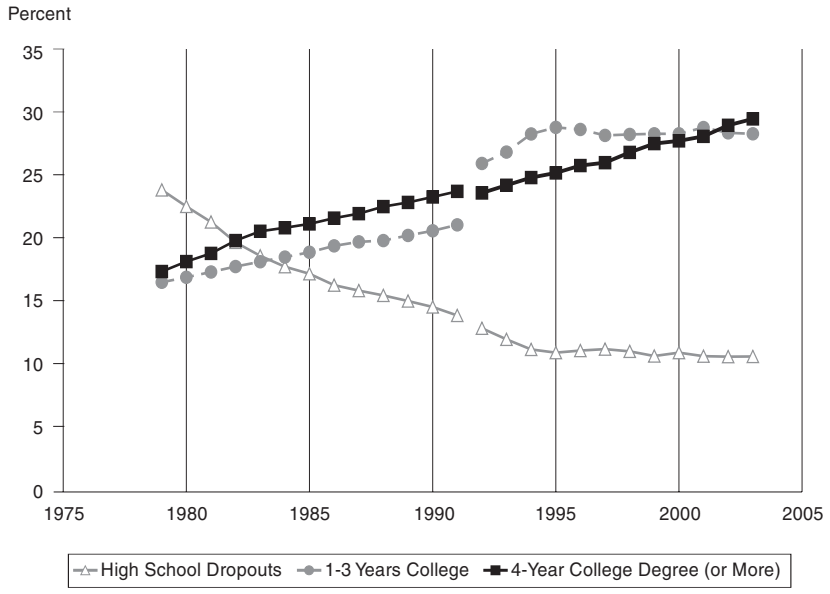
To bolster their case, proponents of skill-biased technological change have attempted to find more direct evidence of the link between technology and wages using data on individual workers, industries, and plants.

EVIDENCE FROM WORKERS, INDUSTRIES, AND PLANTS

Workers. Alan Krueger was one of the first to attempt to show directly that computers may make workers, especially skilled workers, more productive. Using data on individual workers' wages and on-the-job computer use, he showed that workers who used a computer at work earned wages that were 15 to 20 percent higher than those who did not. This earnings premium remained when controlling for characteristics of workers, such as age, education, and occupation. In addition, Krueger found that the premium was especially large for more educated workers, suggesting that the technology favored more-skilled workers. On the basis of this finding, Krueger argued that the increased use of computers over time has led to an increase in in-

FIGURE 3

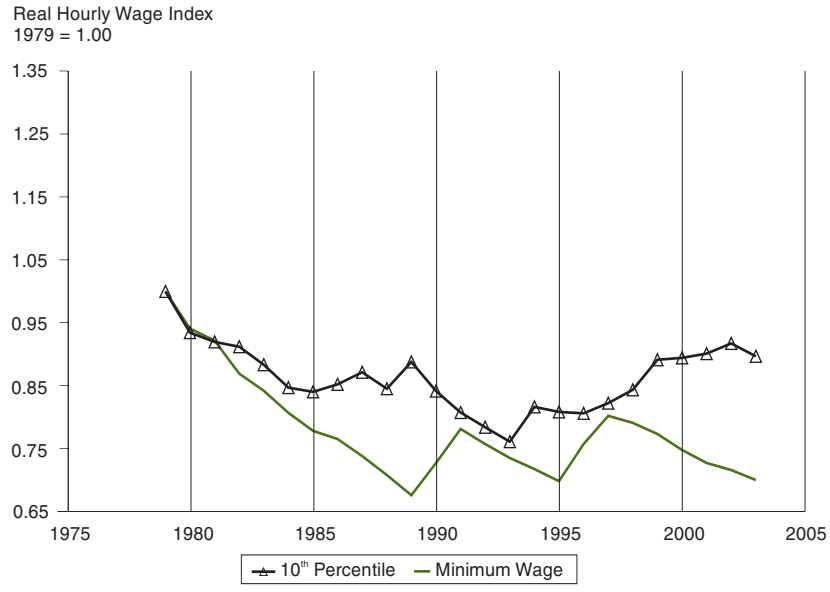
Rising Skills: Percent of Workers by Education



Data Source: Current Population Survey, merged outgoing rotation groups. The series is broken between 1991 and 1992 because of a change in how the education question was asked beginning in 1992.

FIGURE 4

Wages of Less-Skilled Males and the Federal Minimum Wage



Data Source: Current Population Survey, merged outgoing rotation groups, 1979-2003. See previous figures for further notes.

equality. He showed that, based on his estimates, as much as half of the rise in the college/high-school wage gap (see Figure 2) might be explained by computerization of the workplace.

In contrast to Krueger, Robert Valletta showed growing computer use at work is not likely to be responsible for growing inequality. Taking at face value the wage premium on computer use, his approach asks how much lower inequality would have been if different groups of workers (defined by work experience, education, gender, and race, among other things) had not increased their computer use between 1984 and 2003. During these 19 years Valetta estimates that on-the-job computer use rose substantially, from 25 percent to 57 percent of workers. Surprisingly, though, he finds that this led to virtually no increase in inequality. The basic idea behind this result is that the increase in computer use has been widespread, not limited to the most highly paid workers. As a result, although rising computer use may have made workers more productive and raised the general level of wages, it is unlikely to have increased the spread between high and low wages.

John DiNardo and Steffen Pischke provide further reason for skepticism about evidence based on association between computer use and skills. Using data on German workers, they showed that observationally similar workers who use a pencil at work earn a wage "premium" similar to that of those who use a computer at work. Since the use of a pencil does not require special skills, they conclude that one must be cautious about interpreting any wage premium on computer use. High-paying jobs may be more likely to involve a computer, they argue, but it is not necessarily the computer that makes the job high paying.

Industries. David Autor, Frank Levy, and Richard Murnane contribute to this debate by specifying the

mechanism by which computers affect the wage structure, and they provide empirical support for their view. They argue that computers replace routine cognitive tasks, that is, those tasks that involve thinking but that can be easily codified into a set of instructions for a computer. Recordkeeping is an example of a cognitive routine task. Creative writing is a nonroutine cognitive task: Computers cannot substitute for humans in this task. Autor and his co-authors also distinguish manual tasks from cognitive tasks and argue that computers replace only routine cognitive tasks (though factory automation, discussed below, may replace some routine manual tasks as well). As the price of computers falls, workers who perform routine cognitive tasks will likely be replaced by computers (or take a cut in wages), while skilled workers will be more productive because they can spend more time on nonroutine tasks.

To evaluate this view, the authors examined the relationship between the tasks performed in different occupations and increases in computer use over a long period. They use Labor Department surveys to measure how much routine cognitive, nonroutine cognitive, routine manual, and nonroutine manual tasks were required in each occupation. They found that the more an industry increased its use of computers between 1984 and 1997, the more it decreased its employment of workers in routine cognitive occupations and increased employment of workers in nonroutine cognitive occupations in recent decades. In the 1960s, before the widespread introduction of computers, the authors find little shift in occupation mix in the same industries. Though the evidence is supportive of their view, the authors are careful to acknowledge that the association between occupation shifts and computer use does not necessarily imply that the shift was caused by computerization.

Plants. Computers are not the only technology that may have contributed to rising inequality. Over the past few decades, manufacturing plants have become more automated as technologies such as robotics have become increasingly powerful and prevalent. Some research has focused on the impact of factory automation.

Mark Doms, Timothy Dunne, and Kenneth Troske obtained detailed data on the use of a variety of new automation technologies at a sample of manufacturing plants, as well as the characteristics of the workers at those same plants. They found that more-automated plants paid higher wages and had a higher proportion of workers who were college graduates, engineers, and nonproduction workers. However, they also found that the same plants had more skilled workers long before the technologies were introduced. Like DiNardo and Pischke's result for pencils, this finding suggests that automation was not necessarily the cause of the increased employment of skilled workers, even if it is associated with it.

GEOGRAPHIC DIFFERENCES IN TECHNOLOGY USE

Another way to explain the relationship between technology and income inequality is to treat different parts of the U.S. as different "markets." This approach takes advantage of the fact that there are wide differences in technology use and the availability of skilled workers in different regions of the U.S. To assess the causal relationship between technology and skills, I examined, in a previous article, how the relative availability of skilled and unskilled workers in a plant's local geographic market (metropolitan area) affected automation.[8] Aiding this approach is the fact that some differences in skill mix across local markets occur for idiosyncratic reasons that probably have little to do with technology. For example, some markets have a lot of less-skilled workers because they contain enclaves of less-skilled immigrants, whose numbers have increased rapidly in recent decades. Los Angeles, for example, has twice as many high-school dropouts per capita as other cities, largely because it is a major destination for Mexican immigrants, many of whom arrive in the U.S. without a high school diploma.

On the other end, some markets have a lot of highly educated workers because they were lucky enough to receive federal funds to build land-grant universities in the 19th century. These idiosyncratic differences provide natural "experiments" to evaluate the causal relationship between skills and technology.

In this earlier work, I found that in places with abundant unskilled labor, plants are less automated, and in places where skilled labor is abundant, plants are more automated. In addition, increases over time in the availability of skilled labor lead plants to increase their use of automation. This suggests that plants adopted these technologies to fill shortages of unskilled labor. Put another way, the use of technology responds to the amount of skilled labor available to operate it.

Looking across geographic markets also reveals a similar relationship for computers. In another article, I used another "natural experiment" — the aftermath of the Mariel boatlift, the 1980 exodus of Cubans that dramatically increased the availability of unskilled labor in Miami — to evaluate the impact of skills on technology.[9] I found that businesses in Miami were much slower to adopt computers at

[8] See my 2005 *Business Review* article.

[9] See my 2004 working paper.

work after the boatlift than businesses in other, similar cities.

In another recent paper, Mark Doms and I examined businesses' adoption of personal computers in the 1990s. We found that the adoption of PCs by otherwise similar businesses depended on the availability of college-educated labor in the local market. For example, Figure 5 presents a version of a scatter plot from this paper. It plots the number of personal computers per employee in the average business, adjusted for the businesses' industry and employment, in different metropolitan areas against the share of the workers in that area who are college educated.[10] The college share is measured in 1980, before businesses used PCs, while computer use is measured in 2000, by which time PCs were the dominant computing technology (used by 50 percent of workers). The figure shows that high-skill cities, such as San Francisco, use personal computers intensively, while cities with fewer college-educated workers, such as Scranton, use computers less intensively. Philadelphia is near the middle of this skills-technology relationship. Once again, the data in the figure have been adjusted for industry and size. For example, the figure adjusts for factors such as San Francisco's large "tech" sector and New York's large financial sector (both are computer-intensive sectors). Another way to say this is that very similar businesses, for example, law firms of a certain size, appear to vary their use of personal computers depending on the local availability of college-educated labor.[11]

In one sense, these results support the notion of skill-biased technological change, since they imply that as technology gets cheaper, firms replace unskilled workers with cheaper technology and hire more skilled workers. But these results also provide a more complex view of the increased use of skilled labor and the adoption of new technologies. It is not only the availability of new technology that induces plants to hire skilled workers but also the availability of skilled workers that induces plants to adopt new technology. In this alternative view, recent technological change may result partly from the rising skills of U.S. workers (see Figure 3) rather than being a fully independent force affecting the labor market.

CONCLUSION

Wage inequality has risen over the past few decades. Many economists believe that this is related to steady advances in and the diffusion of information and automation technologies, which may favor the employment of skilled workers. Though this explanation is appealing because technology has rapidly become more prevalent and is more often used by skilled workers, recent research finds that it is not consistent with many of the facts.[12] Other

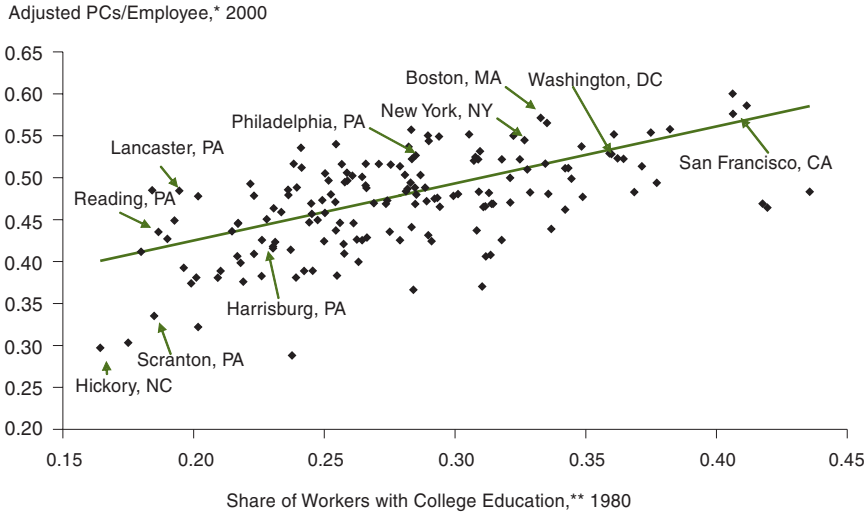
[10] The data for this figure come from two sources. College share comes from author's tabulations from the 1980 Census of Population, while personal computers per worker is tabulated from the "Harte-Hanks" data set, a proprietary establishment-level survey of technology use. Personal computers per employee figures are adjusted to control for the industry and size of the establishment. (Interestingly, this adjustment makes little difference!) College share includes all those with a four-year college degree plus one-half of those with one to three years of college education.

[11] In a similar result, Nicole Nestoriak found that plants in areas with an abundance of highly paid workers invested more in computing technology.

[12] See the article by David Card and John DiNardo.

FIGURE 5

Personal Computers/Employee vs. College Education by Metropolitan Area



*Data Source: Harte-Hanks, 2000-2002. Figures report number of personal computers per worker at the average business, adjusted for industry and establishment size (employment).

**Data Source: Census of Population, 1980. Figures report share of workers with at least a 4-year college degree + 1/2 of the share of workers with 1-3 years of college education.

forces, such as falling minimum wages, appear to have played a role in rising inequality. Researchers have also had difficulty establishing definitively that new technologies actually *cause* the number of jobs for skilled workers to increase. Some evidence even suggests the reverse: The spread of new technologies responds to the rising skills of the work force, rather than being an independent force affecting the demand for skills.

Economists are likely to continue to debate this issue. The latest increase in inequality, in the late 1990s, occurred during the period of rapid investment in information technology. This episode will be sure to inspire further research.

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