CHAPTER 5

"New Technology" and Its Impact on the Jobs of High School Educated Workers: A Look Deep Inside Three Manufacturing Industries

Ann P. Bartel, Casey Ichniowski, and Kathryn Shaw

The deterioration of the economic position of less-educated men is part of a well-documented increase in income inequality in the U.S. labor market between the late 1970s and early 1990s. During this time period the income gap between high school educated and college-educated men rose substantially (see Autor, Levy, and Murnane, this volume). Many analysts have advanced the idea of "skill-biased technical change" to help explain the declining position of high school educated workers (see, for example, Autor, Katz, and Krueger 1998; Bartel and Sicherman 1999; Berman, Bound, and Griliches 1994; Caroli and Van Reenen 2001; Greenan and Mairesse 1996; Katz and Murphy 1992; Krueger 1993). Researchers suggest that rapid advances in computerization spawned new production technologies during this time and businesses adopting these new computer-based technologies may well have increased the demand for more-skilled employees to work with these new technologies. Unfortunately, when researchers use the existing data sets of individual data or plant-level data, the measures of computer technologies are often very incomplete or imprecise. Existing research therefore provides very little direct evidence on the extent to which new computer-based technologies affect the demand for high school educated workers.

In this chapter, we turn to information gathered from plant visits to examine the impact of technology on the demand for high school educated workers. We use information collected from on-site investigations of plants within three narrowly defined industries—medical equipment manufacturers, steel, and valve manufacturers—to address the following three questions:

1. What new computer-based technologies have businesses adopted within these industries?
2. How, if at all, have these new technologies affected the jobs of production workers and the skills required in those jobs?
3. When businesses do require new skills of their production workers, do they adopt new human resource management (HRM) practices, such as recruiting, training, or compensation practices, to help ensure that workers have the desired skills?

We then combine the answers to these questions to address the overall question: How has the demand for high school educated workers changed owing to technological changes?

INDUSTRY SETTINGS AND SITE VISITS

We investigated these three questions about new technology and the jobs of production workers through plant visits in the medical equipment manufacturing, steelmaking, and industrial valve manufacturing industries.[1] We focus on these industries because they employ a large number of high school educated workers; because they cover a spectrum of growth patterns, from declining industry employment (in steel) to stable employment (in valves) to rapidly growing employment (in medical instruments); and because our access to practitioners in these industries allowed us to study several plants in each industry.

THE THREE INDUSTRIES AS LARGE EMPLOYERS OF HIGH SCHOOL EDUCATED WORKERS

In this study, we focus on the jobs of production workers in these 3 industries. Production workers in these industries need considerable amounts of skill, knowledge, and experience to operate million-dollar technologies in a steel mill, assemble a delicate surgical instrument in the medical industry, or produce a valve to exacting customer standards in the valve industry. Thus, these industries tend to provide reasonable, highly skilled, well-paying jobs for high

Table 5.1 Demographic Characteristics of Workers in the Three Industries, 1986 and 1996

	1986			1996		
Industry[a]	Union Members	Female	Average Education (Years)	Union Members	Female	Average Education (Years)
Medical, dental and optical instruments	8.7%	49%	13.0	4.2%	47%	13.6
Miscellaneous fabricated metal products	30.0	23	11.8	19.6	22	12.2
Blast furnaces, steelworks, rolling and finishing mills	60.4	9	11.7	50.1	11	12.6

Source: Hirsch and Macpherson (1997).
[a] These are the CPS industry groupings and are broader than the four-digit SICs used in tables 5.2 through 5.4.

school educated workers. As shown in table 5.1, the average years of schooling for steel industry production workers was 11.7 years in 1986 and 12.6 in 1996, while production workers in valves averaged 11.8 years of schooling in 1986 and 12.2 years of schooling in 1996. Education levels for production workers in medical equipment–making industries are about 1 year higher on average than they are in steel or valves—13.0 years in 1986 and 13.6 in 1996.[2] In 1992 these 3 industries employed upward of 370,000 U.S. production workers—170,885 in medical equipment, 134,500 in steel, and 63,711 in valves.[3]

These 3 industries differ markedly in terms of employment growth. Medical equipment manufacturing has been one of the fastest-growing industries in U.S. manufacturing. Industry shipments have increased by 5 to 6 percent a year in real terms since 1989, while the industry spent 8 percent of sales on research and development (R&D) in 1996, or about double the overall U.S. industry average (Standard and Poor's 1998). Accordingly, industry employment has grown rapidly. The number of production workers in this industry in 1992 (170,885) was nearly double the employment in 1972 (86,025), and some 30 percent more than the 1982 employment level (130,948). In contrast, the steel industry has witnessed a dramatic contraction of employment. While the mini-mill sector is fairly robust, with significant growth since the 1970s, contraction among integrated steel mills, especially in the early 1980s, resulted in large reductions in overall steel industry employment. Production worker employment in the steel industry in 1992 (134,500) was markedly below the number of production workers in 1972 (375,116) or 1982 (215,924). Valve making shows more stable employment over this time period, with employment levels for production workers of 60,224 in 1972 and 74,089 in 1982 before returning to its 1992 level of 63,711 (for more details on employment and wages, see tables 5.A1 through 5.A3).[4]

Therefore, by studying these three industries, we are investigating industries that employ well over one-third of one million high school educated production workers. Investigating how the jobs of these production workers have and have not changed with the advent of new production technologies provides one window on the changes in the situation of U.S. workers with relatively low levels of formal education.

WORKER DEMOGRAPHICS AND WAGES IN THE THREE INDUSTRIES

Statistics on business establishments and worker characteristics paint very different pictures of the workers and work sites in these 3 industries. Steel industry employees work in larger establishments (558 employees per establishment in 1992) than do employees in either medical equipment plants (44 employees per establishment) or in valve-making plants (63 employees per establishment).[5] Once inside the doors of these establishments, one observes production workers with different demographic characteristics. As shown in table 5.1, the medical equipment–making industry employs a large number of females (47 percent of the industry workforce in 1996) who are predominantly non-union employees (4.2 percent of the workforce was organized in 1996). In contrast, the steel industry production worker is much more likely to be a male union member: the steelmaking workforce is 50.1 percent organized and 89 percent male. The corresponding figures for the valve industry workforce for 1996 are 19.6 percent unionized and 78 percent male.

Average production worker wages in these three industries show that steel industry production workers earn the highest wages of the three ($23.44 an hour in 1982, $19.06 in 1987, $18.99 in 1992), and medical equipment industry workers the lowest production worker wages of the three industries ($9.90 in 1982, $10.74 in 1987, and $10.71 in 1992). Average wages of production workers in the valve industry fall in between the wages in the other two industries ($11.73 in 1982, $12.19 in 1987, and $12.11 in 1992).[6]

PLANT VISITS

We made extensive visits to plants in the three industries to investigate firsthand how technology has changed inside the plants and to conduct interviews about the effect of new technologies on production workers' jobs. In steel, we drew on many years of experience from recent research projects: we have personally visited forty-five finishing lines in integrated steel mills and thirty-four production lines in steel mini-mills. We have thus visited a significant portion of the entire industry's work sites. The information we report for the medical equipment industry is based on our observations and interviews at eight plants. For the valve-making industry, we conducted five plant visits but also made multiple visits to several plants. Our purpose was to obtain insights into our three questions about the nature of new technologies and their impact on jobs. Because no publicly available data on these questions exist, our plant visits were designed to enable us to observe new production technologies in these three industries firsthand and to conduct interviews with frontline personnel about how jobs have changed as a result.

During these visits we conducted interviews with several managers at each plant. Typically, these managers included the top plant or mill manager, an engineering expert, an operations manager, and the top HR staff person for the plant. Since we did not want to limit our interviews to getting "management's version" of the effects of new technologies on work, we also conducted start-to-finish production-line tours at each plant and discussed issues with production workers on these tours as well as off-line. Many of our interviews with production workers were conducted without managers present, and managers encouraged us to get the opinions and perspectives of production workers and union representatives in organized plants. The information and patterns reported in this chapter reflect the evidence collected during these interviews, discussions, and plant tours.

NEW TECHNOLOGY AND ITS IMPACT ON JOBS IN THE MEDICAL EQUIPMENT INDUSTRY

The medical devices industry is composed of four separate four-digit industries—SIC3841: Surgical and Medical Instruments; SIC3842: Surgical Appliances and Supplies; SIC3844: X-ray Apparatus and Tubes; and SIC3845: Electromedical Equipment—that make a wide variety of medical products.[7] Our plant visits to eight establishments documented this wide variety of medical products and production processes. We visited plants that produced relatively "low-tech" items (such as syringes, sutures, catheters, and elastic bandages), those that made medium-tech devices (such as anesthesia apparatus or drug pump and IV equipment), and those that made "high-tech" items (such as electrosurgical equipment and respiratory monitoring devices).

As we conducted our field research into the three questions about new technology, production worker jobs, and HRM practices in this industry, a clear difference in production processes and jobs was evident between medical plants with continuous, high-volume production processes and those with small-lot batch production processes. Therefore, we organize our evidence on our three questions from our visits to eight plants in this industry into two parts: conclusions for high-volume medical equipment producers and conclusions for batch medical equipment producers.

CONTINUOUS, HIGH-VOLUME PRODUCERS: SEEING TECHNOLOGIES AND JOBS OF THE PAST AND PRESENT

The Production Process Among our many plant visits, one that offered some of the most dramatic and direct insights into the effects of new technologies on the jobs of production workers was a plant (in SIC 3841) that makes a low-tech medical product, such as biopsy needles or intravenous catheters.[8] To make a product such as a biopsy needle, a plastic plunger is inserted into a barrel, and then the needle is attached to the barrel. The specific steps in the production process are: molding the plastic into plungers and barrels; imprinting the barrel; assembling the barrel plunger and needle components; packaging and wrapping; and sterilizing packaged goods by radiation. The production process for catheters is similar, but in that case a needle is attached to a tube.

The high-volume plant we describe here provides especially direct answers to our three questions. Our evidence from this plant comes not only from interviews with managers and workers who have experience with new and old technologies, but also from direct observations of new and old production processes. In particular, this plant still operates a much older production line for specialty products that it produces in relatively small quantities. Our tours of this plant therefore took us from the technologies and jobs of the past to those of the present.

Examples of New Technology When the plant opened forty years ago, production was 10 million units per year. Today the plant makes 6 million units per day. In the last decade output rose substantially while employment fell some 20 percent. New technologies that the plant has adopted underlie these dramatic changes in output and employment. Several examples demonstrate the causes for these changes.

Several new technologies in this plant helped raise productivity. Ten years ago, continuous motion machines replaced incremental motion machines in the step of the production process that assembles the component pieces—the barrels, stoppers, and plungers. The difference between the new and old machines is that in the new there are dials that feed the component parts together in a smooth continuous motion, whereas the older technology assembles component parts in a much slower, stop-start motion. Continuous motion machines increase assembly speed substantially, thereby generating dramatic productivity improvements. In packaging, sophisticated robots fill units into blister packs, wrap the packs, move the correct number of packs into boxes, and send boxes on to sterilization and shipping.

The "computer guts" of all of these assembly and packaging machines are programmable logic controllers (PLCs). Programs inside PLCs determine the precise, three-dimensional movements of robotic arms. They track how many times a machine stops and starts and maintain the synchronized, split-second movements in continuous motion assembly machines, while also detecting line malfunctions. The sophistication and capabilities of PLCs have advanced dramatically in the last twenty years, and with these advances have come corresponding advances in the speed and accuracy of medical equipment production at high-volume plants.

PLCs and computer chips embedded inside the newest production machinery automatically identify problems and abnormalities in the production. Units in the production line can be rerouted automatically to other normally functioning lines while a computer display shows a map of the machines that highlight the problem areas.

Another set of new technologies at this plant improves the quality of these medical products. Around the same time the plant introduced continuous motion machines, it also began to use computer numerically controlled (CNC) lathes to improve the quality of the tip of the needle. As a result of this new technology, tips can meet higher-quality tolerance levels. Another example of a quality-improving technological change is the use of computerized laser cameras that inspect the products during the manufacturing process.

Jobs and Skill Requirements As the plant introduced these computer-controlled, high-speed, and high-volume technologies, the jobs of production workers changed dramatically. During our tours we often saw no employees at all in large areas of the plant. The new technologies are capable of operating on their own for long periods. At the old-technology packaging line of this plant, the picture was very different. Employees remained fixed at specific spots on the line. These workers fed the units into the blister packs, sorted the packs along the line, and stuffed the packs into boxes. On the high-volume lines, robots have automated all of these routine tasks.

If production workers on lines with older—and lower-output—technologies are tied to the lines performing routine tasks, and these tasks have been eliminated by PLC-controlled machinery, what do the jobs of production workers on new-technology lines now involve? Our plant tour of the lines with state-of-the-art technologies revealed a relatively small number of workers who were "dotted" around the plant rather than stationed at one spot next to a particular machine. These workers responded to flashing lights, buzzers, and computerized maps that indicated problems on the lines (signals that are set off by sensors tied into PLCs). Otherwise, these workers were conducting regular rounds, checking on equipment. Production employees now work with many more pieces of equipment and do diagnostic, resetting, and repair tasks. As another example, under old technologies, workers needed to inspect needles for quality imperfections based on predetermined sampling procedures, while employees on newer lines inspect and diagnose the operations of the laser cameras that automatically do the quality control and inspection work.

These changes in the nature of the jobs of workers operating the production lines have in turn changed skill requirements for workers significantly. Skill requirements have clearly increased. The skills required for today's line technologies at this plant are troubleshooting skills, diagnostic skills, and knowledge for equipment maintenance and repair. Because equipment repair and improvement often involve team problem-solving efforts, managers also look for employees who have the interpersonal skills to operate in teams.

New Human Resource Management Practices How does management work to ensure that production employees have the required skills for the plant's high-technology and high-volume production process? One avenue is through the hiring and selection process. The head of HR for the plant said they are looking for employees who have diagnostic and interpersonal skills and are computer-literate rather than employees with only a specific technical ability to operate a machine. However, the plant recruits in an often-tight, not heavily populated, local labor market, and applicants generally do not have these characteristics.

The plant therefore relies more heavily on a combination of training and compensation policies to develop the desired skills in employees. A centerpiece of these two HR practices is the plant's skills matrix, which is consistent with the new skills workers now need. Key elements in the matrix include the ability to operate a wide range of production machinery, the ability to diagnose equipment failures and errors, and skills in production coordination and planning and work group facilitation. Training initiatives are aimed at enhancing these skills. Training comes in the form of ever-evolving classroom computer training (on- and off-site), off-site classroom training at local area colleges that work in partnership with the plant, and apprenticeship periods in different areas of the production process. Trained "skill assessors" certify each employee's standing on the different dimensions of skill in the matrix. An employee's position in the matrix then determines a significant portion of his or her pay in the pay-for-skill pay component of compensation.

In addition to these HRM practices in the areas of training and compensation that are aimed at developing the requisite skills among production workers, other HRM practices have also changed. Most obvious is the change to broader, more flexible job definitions now that workers are required to work in many more areas of the plant with a broader array of equipment. Historically the plant has had as many as 150 job titles; it now operates with 30 titles. Problem-solving teams have also been introduced within the last 10 years. Workers are now organized into product-focused teams that operate as businesses. The teams visit their customers, monitor product quality, and are responsible for hiring, firing, and performance management. These teams also engage in problem-solving activity to address problems with the sophisticated technologies.

We are not able to document the dynamics of wage changes for production workers as technologies changed for this plant (or for the others we discuss here). New technologies were introduced unevenly throughout the plant over many years, and wage data over long periods were not available. However, the plant's HR manager does believe that wages for production workers at this highly automated medical equipment plant (whose jobs have become more broadly defined and now require broader sets of skills) are much higher than they are in other medical equipment plants where jobs remain narrow in scope and more limited skills are needed for specific tasks. This manager cited the example of another medical equipment plant in the company that makes a low-tech product and hires production workers to perform basic production and assembly tasks with pay at or near the minimum wage. A production worker who has made it to the top of the skills matrix at the continuous, high-volume medical equipment manufacturer would earn about three times the minimum wage. Recall that, as shown in table 5.A1, the typical wage in the medical equipment industry is $10 to $12 an hour.

Evidence from our plant tours and interviews at this plant clearly document that, even within the narrowly defined medical equipment industry, production processes vary considerably in the extent to which new computer technologies are used. Furthermore, new computer-based technologies lead to changes in the jobs and skill requirements of production workers. Finally, indirect evidence from interviews also suggests that wages in plants with new technologies and more skilled production workers can be well above the wages of other (less-skilled) production workers in the same industry who work in technologically simpler production processes.

BATCH PRODUCERS IN MEDICAL EQUIPMENT: THE TECHNOLOGY IS IN THE PRODUCT

The Production Process Several medical equipment manufacturers that we visited make products such as oxygen pumps, ventilators, automated IV drug pumps, or surgical instruments. These SIC 3845 plants make their products in batch production processes, and these share several characteristics. First, the production lines are themselves a series of tables typically arranged in a U shape with component parts nearby. Products go from one end of the U to the other, passing through a series of assembly steps along the way. The U-shape layout promotes communication among workers, and with modular tables, electrical outlets throughout the ceiling, and everything on wheels, the plant's architecture is easily reorganized. Second, the assembly work is generally performed by low-skill labor. A worker at one of the tables may be performing a task like attaching or inserting some component piece of the overall product. At each stage, these assemblers also typically check the quality of their own work and the work that precedes theirs, and they may also be aided in their assembly tasks by small pieces of automated equipment. Fourth, the products are made in batches to fill specific customer orders. For example, as certain features of a drug pump change, certain elements of the pump change as well and require different parts or setups. Fifth, labor costs account for about 10 percent of production costs.

Examples of New Technology The central point described in our tours of these plants was that "new technology" for these plants is the technology imbedded in the products. Although production workers do make use of some automated equipment, such as mechanized tools for attaching equipment or computer programs to check tolerances on features of equipment, the products themselves often contain sophisticated computer technology. More specifically, ongoing improvements in computer chip miniaturization have allowed the plants to develop and produce new products. For example, the number of products made in one product area of a maker of advanced surgical devices increased from one to sixteen in less than a year—the most rapid rate of product innovation in that group ever. Surgical equipment evolves rapidly as surgeons request product modifications that will better meet their needs in the operating room. At another plant, managers indicated that over half of all sales are from products that are less than two years old.

At the same time, some examples of "new technology" are similar to those in the high-volume medical equipment plants. The clearest example here is that both the high-volume producers and these batch producers typically use sophisticated computerized irradiating equipment to sterilize their packaged products. The packaging technology of batch producers has also undergone technological improvements that have led to reductions in production costs, but these changes are not as extensive as the high-speed robotic processes used in the high-volume plants. Overall, the central observation about "new technology" in these medical equipment plants that make higher-tech products in smaller batch sizes is that new computer-based technologies are imbedded in the products themselves. These technologies are not focused on increasing the number of units produced per worker. Productivity gains are measured primarily in terms of improved product sophistication, and the success of the plants rests critically on how fast they can develop new product varieties.

Jobs and Skill Requirements The impact of new technology on skill requirements in this segment of the medical devices industry is therefore quite different from the effect of technology on jobs in the continuous, high-volume plant. Unlike the latter type of plant, where new technology has eliminated routine tasks and now requires employees to apply diagnostic and problem-solving skills on a broader range of equipment, the production worker jobs in the batch manufacturers are still assembly jobs. As one manager pointed out, "Don't let the clean, bright appearance of the assembly plant fool you. These are basically low-skill jobs." Assemblers in these plants do not necessarily require a rich understanding of the equipment they are using. One manager commented that many of the assemblers would not know how to restart a testing program on the computer if it stopped.

Some subtler changes in skill requirements were noted in our interviews. The sophisticated nature of the products has made the assembly process more complex and checking for product quality is now an important component of the workers' jobs. Managers commented on the need for reliable workers who pay attention to detail. In addition, because products now change more rapidly than in the past, managers indicated that they need employees who are flexible and can adapt to frequent line changes. The plant managers also felt that communication and interaction skills were important because the assemblers were required to interact with engineers, design people, and quality supervisors.[9]

Notice that managers have used the word *flexibility* to describe the changes in jobs and skills of workers after new PLC-controlled equipment came on-line in the high-volume plant as well as the changes that took place in the batch manufacturer as product design changes occurred more rapidly. Our direct observations on these different production processes, however, reveal that the word *flexibility* refers to very different ideas. In the high-volume plant, workers are now more "flexible" because they work on many more pieces of equipment, in a wider range of tasks throughout the plant, and with higher skill requirements, including the ability to complete diagnostic and repair tasks. In the batch plant, workers are more "flexible" because the assembly routines change more frequently as the products change, but the workers are still performing a limited range of assembly tasks that are relatively easy to pick up.

New Human Resource Management Practices All of the plants require a high school diploma for the assembler jobs, and many of them hire employees through temporary agencies in order to have time to observe whether a new employee is a good fit for the company. Because basic assembly skills are much the same as they have always been, this screening process involves identifying workers with fundamental literacy skills, problem-solving skills, adaptability, and willingness to learn.

Nevertheless, some plants are taking novel approaches to help workers develop other desired skills and traits. Because quality control on medical equipment is of paramount importance, workers need to pay attention to detail. Training to ensure the highest standard of quality control is a central HR focus. One plant has instituted a training program in which workers watch private broadcasts of surgeries using the plants' products. This practice has led to a greater appreciation on the part of employees of the need for equipment that performs perfectly. Note that these plants hire primarily women for this detailed assembly work. (As shown in table 5.1, 47 percent of all medical instruments employees are women, and for production workers the percentage is even higher.)

Outside of the area of selection and training for skill acquisition and development, these batch medical plants employ many innovative HR practices. Workers still do low-skill assembly work, but managers have attempted to create a team environment for them. The plants also employ job rotation. However, the main rationales for these practices are that workers need to know how to perform the job on the station before and after their own and that workers are more attentive if their assembly tasks change periodically. Although managers indicated that these practices are better for managing a workforce than more traditional practices, the technology-related story that characterizes the continuous, high-volume plants is much less applicable here.

NEW TECHNOLOGY AND ITS IMPACT ON JOBS IN THE STEEL INDUSTRY

We also visited a large number of mills in the steel industry (SIC 3312)—both integrated steel mills and steel mini-mills. The production processes in these mills, particularly the integrated mills, cover a very large geographic territory. Accordingly, our integrated steel mill visits focused on a specific finishing line technology; we visited a total of forty-five finishing lines. In the mini-mill sector, we visited thirty-four mills with an emphasis on rolling and shaping operations.

The Production Processes The production processes in the two sectors of the industry are fundamentally different. To produce molten steel from material inputs, mini-mills use electric arc furnace technology, while integrated mills use the basic oxygen furnace technology. Because of the vast differences in production technologies, we describe the two production processes in turn.

Mini-mill production begins with scrap metal as the basic input into the electric arc furnace. Each "charge" from the electric arc furnace pot produces molten steel. Molten steel is then poured directly into the continuous casters, which take the stream of liquid steel and separate it into one or more strands of steel that cool and harden into steel billets (or long, thick rails of steels) after exiting the caster. Billets are then reheated, thinned in narrower and narrower bars, rods, or wires, and then shaped into a series of sequential "stands" through which the reheated steel passes.

In integrated steel mills, the raw materials are iron ore, limestone, and coal. Before reaching the steelmaking furnace, these raw materials are first transformed into molten iron by blast furnaces. The basic oxygen furnace transforms iron and additional inputs into molten steel, and then the molten steel proceeds to the continuous caster, as in mini-mill steel production. Our visits to integrated steel mills focused on finishing line operations. Once the molten steel has been processed into long sheets of very thin steel rolled into coils, many different finishing processes can be used. For example, "pickling" is the process that cleans the steel by removing iron oxides from intermediate steel products, such as steel coils. Cleaner steel permits higher quality and more reliable finishing-end treatments. The temperature of the acid bath used to pickle steel is critical to its effectiveness. We focused on one particular kind of finishing operation, but all finishing processes clean, treat, or coat the steel to give it the dimensions and properties required by the customer.

Examples of New Technology in Mini-Mills Our mini-mill tours concentrated on the rolling and shaping stands near the end of the production process, but managers pointed out new technologies in earlier stages of production as well. In scrap metal processing, magnetic sensors and related computer programs analyze the content of the scrap metal and allow producers to select scrap that more closely resembles the desired chemical composition of the finished steel. This screening improves both steel quality and productivity by eliminating the need to alter the composition of steel by burning out impurities or by adding metal alloys to achieve the desired chemical properties.

The production process from the reheat furnace through the rolling and shaping operations has also changed. Formerly, based on personal observations, line workers were required to use manual controls to adjust the reheat furnace, which takes billets (the intermediate product) and heats them to the point where they are malleable enough for subsequent machines. Automation has also removed the need to have workers "walking the line" and setting controls for every motor and pump to desired settings. Rather, computerized sensors and controls now monitor the line, synchronize some pieces of equipment automatically, and relay information back to a central operator who issues computer commands to make additional adjustments from a central location. Finally, computer-aided automation has also allowed for coordination among the production steps in mini-mills. It is now possible to send a hot billet or steel bar emerging from the caster stage directly to the shaping and finishing stage. This coordination is only possible with computer-aided analysis of whether the hot output from the caster is suitable input for the reheat furnace.

An important distinction we observed was that the degree of this technological sophistication varies across mini-mills. More complex products require more technologically complex production processes. Some mills make simpler steel products with much less exacting specifications. Producing thick I-bar and reinforcement bars (used to strengthen concrete in large construction projects) is a relatively straightforward process compared to the process of producing a very thin steel product with various kinds of angles and bends. The former is a simpler rolling process that involves relatively few stands after the reheat furnace to reshape and narrow the diameter of the billet. In the latter process, many more stands and more elaborate shaping machines are required to make a thin, angled product to exacting shape specifications. Predictably, the latter processes involve more computer monitoring of the rolling stands and steel throughput.

Examples of New Technology in Finishing Lines at Integrated Mills
In our tours of steel finishing lines at integrated mills, we saw many

technological improvements. New steelmaking technologies have significantly enhanced product quality because computer-automated equipment constantly checks and adjusts throughput and intermediate outputs according to programmed production specifications. Productivity is dramatically higher as a result of new technologies because materials move much more rapidly through the process from the warehouses of steel coils to the shipping dock, and because, for a number of reasons, the lines experience many fewer line stops. Finishing lines are highly automated and very dependent on elaborate computer hardware and software systems.

Cleaning and finishing operations often run steel coils through an acid bath as part of the production line. Previously, workers adjusted the acid bath based on their own observations of steel output and the "feel" for the process they had acquired from years of experience. Now sensors relay information through computerized systems back to a central computerized pulpit where an operator can control both the acid content of the bath and the speed of steel through it. In addition, computer controls make automatic adjustments to the finishing process.

Computer programs also automatically allow the steel to be processed through these finishing lines in a continuous process. Computer software and programs are used to keep track of all steel coils in a warehouse. The characteristics of coils coming off a finishing line need to be matched as closely as possible with the next incoming coil. Computer programs call automatically for the next coils in the schedule, and automated machinery delivers the coil with little or no manual handling to the entry end of the finishing line. Computerized gauges also ensure accurate alignment of the outgoing and incoming coils as the two coils are welded at the entry end of the finishing line. Because of the size and gauge of two successive coils is better matched, welds between coils are more reliable, and line stops due to weld breaks are thus reduced. We also observed sophisticated automation in delivery, shipping, and packaging operations at the end of these lines. In some lines, steel coils are transported from the end of the line to the appropriate delivery and shipping area by computer-driven vehicles that wind their way unmanned through the plant.

Jobs and Skill Requirements Several patterns emerge when we look at the effects of new computer-aided technologies on production worker jobs. First, because materials handling by operators has been reduced to a very low level, a number of the most demanding physical tasks have been eliminated. Machines move raw materials and finished product, often in accordance with computerized inventory and shipping programs. Prior to these changes, employees were responsible for the tasks now performed by the machinery and computer-aided sensors.

Second, employees are now less likely to be stationed at specific locations along a line performing very specific tasks. In some ways, employees previously acted as the computerized monitors of today's lines, making judgments based on experience about the way steel should look as it moves through the process. Employees were more likely to perform narrowly defined jobs, whether operating specific pieces of equipment or developing a rich knowledge about specific characteristics of the look of steel at particular stages of production.

A third pattern lies in how employees talk about their work. Employees in steel operations do not describe themselves as "machine operators" but rather speak of themselves as "monitoring" the equipment. One example from a finishing line illustrates this distinction. With the adoption of a larger number of sensors and gauges with automatic computer-generated information on the quality of the finishing operation, one employee now works from a central pulpit where all of this information is displayed. Previously, these aspects of this finishing process required two employees at both the entry and exit ends of the process.

The skills required of employees also change as jobs become broader, as employees work at more areas of a production line, and as computer-generated information increases substantially. Employees now need to be able to trouble-shoot problems on a wider array of equipment. They are no longer controlling routine actions but fixing disruptions and breakdowns when computerized machinery is no longer conducting the routine operations correctly.

Paramount in the changes in skills is the increased demand for group problem-solving skills. Statistical process control (SPC) technologies generate large amounts of information on operations. Not only does the SPC technology increase the demand for data analysis skills, but the computer-generated SPC data helps identify areas of the production process that are out of normal operating ranges. These data become the input into team problem-solving efforts. The problem-solving process requires a new set of analytical and interpersonal skills, and the ideas generated from these continuous-improvement activities are now a critical employee contribution to line performance.

As perhaps expected, the jobs at the mini-mills that make more basic I-bar or rebar products were the exception to this pattern of changing skill requirements. Managers there did not indicate a pressing need for problem-solving skills from their employees. In these lines, it is not hard to identify a production problem. Because there are fewer steps and the product has less exacting specifications, rectifying production problems does not require elaborate analyses of SPC data by problem-solving teams uncovering hard-to-identify sources of problems and devising elaborate measures for improving output. Again, product complexity is intricately related in this industry to production process complexity. In the mini-mills where the complexity of the production process and product is relatively low, the demand for these worker activities and skills was correspondingly low as well.

In sum, changes in jobs and skill requirements in many steel mills show close parallels to several of the changes observed in continuous, high-volume medical equipment makers. Computerization has freed employees from specific stations and broadened job descriptions. Workers monitor the line and the information on the line generated by computer technologies. Diagnostic skills are increasingly in demand, as are analytical and problem-solving skills. These changes were less noticeable in certain mini-mills that make less complex steel products.

New Human Resource Management Practices Over the past twenty year all mini-mills and integrated steel finishing lines have become much more automated and rely much more heavily on computer hardware and software systems, but the extent of this automation varies from mill to mill. The capital equipment at the newest lines (those opened between the early 1980s and early 1990s) is the most highly automated and computerized. We therefore use examples from these more modern facilities in this section to illustrate the HRM practices that the mills are using to obtain workers with the skills to operate these technologically advanced lines.

Overall, these firms are looking for employees who have not only a high school education but a range of key skills and personal traits that only high-quality high school graduates would have. For example, one mill identifies the following specific skill dimensions: "Analysis (identifying problems, securing relevant information, relating data from different sources, identifying possible causes of problems); judgment (developing alternative courses of action and making decisions which are based on logical assumptions and which reflect factual information); interpersonal cooperation (working effectively with others on the team or outside the line of formal authority to accomplish organizational goals); and ability to learn (assimilating and applying new, job related information, taking into consideration information complexity)." This mill's list of skill dimensions includes ten additional personal skills. The mill also identifies a set of technical computer skills in the area of machinery operations, instrumentation services, mechanic services, and electrician services.

At this mill, applicants go through eight steps in the selection process, which includes tests, exercises, and interviews. Managers provided us with a detailed checklist showing the match between each of the eight screening devices and different subsets of the skills being sought. Such selection processes are important mechanisms at many such lines for identifying employees with the right skills.

Another reason selection processes tend to be very careful is that wage levels are quite high (about $20 per hour plus benefits) for jobs requiring only limited education. At a second steel production line, the selection process includes the following steps: a job fit survey to identify cooperative attitudes compatible with a team-based work environment; an attitude survey to identify ability to learn; a work history survey to identify past supervisory experience; a safety index test to identify more accident-prone employees; process and mechanics skills tests to identify diagnostic skills; electronics and maintenance skills tests to identify technical skills; and interviews by two current employees. Management at this production line also used academic specialists to validate any formal survey and test instruments.

Training opportunities to develop operation skills, diagnostic skills, maintenance skills, and interpersonal skills take many forms. On-site skill development exercises, off-site classroom training, tailor-made programs using outside consultants, and educational benefits are part of the array of programs used. Another interesting form of training for workers at many lines is the practice of regularly scheduled visits to customers. Managers and workers agree that this direct dialogue about customer problems is a critical source of employee knowledge.

These modern lines also tie incentive pay to skill acquisition through a pay-for-skills compensation plan. Employees advance to higher levels in the pay plan by taking tests that measure the degree to which they have mastered the use of different machinery and more general skills as well.

In addition to these skill-enhancing HRM practices, the most modern lines use other new work practices. Almost by definition, jobs are defined broadly with a very small number of job classifications. Active problem-solving teams are common to all of the newest production lines. These teams address recurring problems with an eye to making long-term improvements in line operations part of a regular continuous-improvement process.

Older steel production lines have fewer "innovative" HRM practices, but the trend in these plants has been to adopt more of the practices that are commonplace among the most modern lines. Problem-solving teams and skills training are now found in almost all of the production lines we visited, new or old. Skill requirements are met more often through training initiatives than through employee selection at these older lines, owing to the limited number of new hires. Again, the main exception we observed to the pattern of widespread use of teams and skills training is the mini-mill that makes low-complexity products. Elaborate problem-solving efforts are simply not needed to identify the source of problems in line operations when the product is simpler to make and equipment is technologically less advanced.

Thus, in almost all steel production lines we visited in the mini-mill and integrated sectors—save for mini-mills that make less complex products—we observed many examples of new computer-based technologies that have changed the jobs and skill requirements of production workers. These work environments relied heavily on innovative HRM practices to help ensure that workers had the new skills needed in these technologically sophisticated production processes. These conclusions for the continuous, high-volume steelmaking processes therefore mirror very closely the conclusions for the continuous, high-volume medical equipment makers.

NEW TECHNOLOGY AND ITS IMPACT ON JOBS IN THE VALVE MANUFACTURING INDUSTRY

The Production Process Valves control the flow of liquid or gases through pipes. For example, in a bottling plant a valve controls the amount of the liquids passing through the pipes, which then combine the liquids as they feed into bottles. A simple valve is made by etching grooves at each end of a steel pipe (for screwing to pipes), boring holes at different spots to attach control devices, and then making and attaching the various devices that control the flow. Thus, the production process involves milling, grading, drilling and tapping, boring, and turning. Workers bore a hole down the middle of the block, etch grooves at both ends, bore numerous holes in different spots in the block for bolts or attachments, and produce protrusions that permit controls to be attached. Overall, manufacturing in valves or machine tools is organized into the stages of machining, welding, assembly, testing, and packaging. Valves are often produced in small lot sizes for specific customers. Thus, the valve-making industry (SIC 3491, 3492, and 3494) provides another example of a batch production process.

Examples of New Technology In the past the steel block would be reshaped on a work bench with manual tools to chip or drill or bore holes. This very labor-intensive work was done by a skilled machinist who understood the use of the tools and the properties of the steel block that would enable it to be shaped to precise specifications. This process is still used in some areas of valve plants for complicated products or large products. In the 1950s this process was modestly automated with numerically controlled (NC) machines that used computer tapes to code instructions for the machines. In the 1970s production technology for making valves improved radically with the advent of the computer numerically controlled (CNC) metal working machines, which have spread gradually throughout the industry since that time and improved dramatically. In the overall machine tool industry, which is similar to the valve industry, NC and CNC machines were only 5 percent of the total machining base of equipment in 1983, 15 percent in 1987, and 32 percent in 1998. By 1997, 69 percent of machine tool plants used some form of these machines (Association for Manufacturing Technology 2000).

Between the 1970s and today the number of machines required to produce a valve has declined dramatically. In addition, the time required to produce a commodity valve product has declined from several days to one. It is computerization that has produced these productivity gains, by improving performance in three areas:

1. CNC machines have dramatically improved the metalworking phase of production. The CNC machines developed in the last ten years can perform a wider range of tasks on one machine and do so automatically with less programming by the operator. The extensive software that now controls the machine has been combined with technological improvements in metalworking. The newest software allows operators to run CNC machines through a simple graphical user interface, and the computer-generated instructions automatically move gauges and drills to precise spots for very accurate drilling and forming operations. Thus, these machines can not only produce a much greater range of products but produce them much faster. The setup time (the time required to program the machine for each type of valve produced) has been falling over time as CNC machines have become more technologically advanced. Because the setup time has declined, companies can switch products much more frequently and produce a wider range of products to suit their customers' needs.

2. Computer-controlled devices have now reduced the time it takes to inspect products. Each dimension of a complicated valve often must be produced to an accuracy rate of one-thousandth of an inch, so inspection is a critical part of the production process. For many years inspection was done with very time-consuming hand-measuring devices. In the last few years inspection machines have been introduced that use a laser probe technology: the operator touches each surface of the valve (interior, exterior, holes, and so forth) with a probe that develops a three-dimensional picture and measures all dimensions.

3. Computer software and high-speed personal computers have improved the product design phase. New product design is an important element of production—valve production is very specialized, and new valves are often designed for each customer. In the 1990s valve-producing firms began switching from two-dimensional CAD/CAM software programs to three-dimensional CAD/CAM software that shows the valve

> as a solid model rather than a two-dimensional representation, thus substantially facilitating the rapid design of new products. Three-dimensional design software eliminates the need to produce a demonstration model and significantly improves the quality of the design by reducing production errors and the amount of rework after a valve is in production.

Jobs and Skill Requirements Even before the introduction of the CNC machines, a machine tool operator was a skilled machinist, and that is still true today. Because the machinist at each station sets up the machinery to do the particular operation, he or she must understand the blueprints, set the metal cutting speed at feed, determine how much metal to take off and how much to chip, then use inserts and holders to do the milling, drilling, tapping, or turning. Machinists specialize in different tasks—some are skilled at the drill press, for instance, and others at the lathe.

Today the CNC operator must have not only machinist skills but problem-solving and computer skills. The CNC machine performs the operations much more automatically: the operator programs in the dimensions of the valve, and the computer software calculates the correct method of machining the valve. In the past these calculations were done by hand by the operator with blueprints. Thus, it would seem that the operator could be less skilled today, but employers have several reasons for continuing to hire highly skilled machinists for these jobs. First, because CNC machines cover a broader range of machining activities (drilling, tapping, turning, and so forth), today's operators need to be skilled in all these activities rather than specialize, as they did in the past. Second, the newer technologies require that employees be problem-solvers; thus, machinists must understand the machining technology even though the CNC does the calculations for them. Third, more computer skills are required, though these programming skills take a relatively short time to learn compared to machining skills because the graphical interface with the computer simplifies the programming tasks.[10]

Thus, skill demands within the metalworking part of production have probably increased overall. Owing to the computerization of machines, not only are valve manufacturers likely to hire skilled machinists with problem-solving skills, but they also are not hiring the less-skilled operators they used previously. In the past, when the production of valves required the use of six to ten machines, some of them were set up by skilled machinists but operated by much-less-skilled operators. Now CNC machines do far more tasks automatically on one machine, and thus very low-skill operating jobs are gone. This is not surprising: automation has caused overall labor demand to decline per unit of output.

Skill demand has also risen in the product design stage because draftsmen have been eliminated by the new software and only engineers are needed for design. With three-dimensional CAD/CAM machinery producing blueprints automatically, there is no need for draftsmen, and the three-dimensional nature of the program eliminates the need for the multiple drawings that used to be necessary. The use of the new machines has also resulted in a decline in the demand for engineers.

New Human Resource Management Practices In the valve industry most plants are quite small. The work environment in many plants has long been characterized by a family feel. Still, HRM practices have changed considerably over time. In small shops everyone is part of the team and called upon when needed. New technology has changed the nature of the production worker's job in ways similar to what we observed in the continuous, high-volume plants in medical equipment and steel. Valve industry machinists participate more in problem-solving activities, very little of which occurs while operating the machinery. For example, if the machinery is worn down (as when the ball screw in the machine is too worn to turn the pallet properly or the hydraulics are clogged), the computer recognizes the problem instantly and will not continue the process. Employees do not need to solve this sort of problem through team activity. There are two reasons they are more likely instead to solve problems away from the machine. First, in designing new products, a team gets together to clarify a drawing, perhaps making changes (in space or tolerance) and suggesting equipment or production methods. Second, the machinist is involved in improving the approach to production. For example, to improve performance a certain area of operations might be videotaped. Machinists and others then brainstorm to improve the process. Machinists at these kinds of firms tend not to rely on incentive pay. Most are paid a flat hourly rate, with some bonuses to meet special targets.

Training is extremely important for machine operators. When hired, they not only have graduated from high school but have acquired additional machining skills at a community college or technical institute. Thus, these jobs are held by individuals with a high school degree with some additional training. After they are hired, the firm trains them in running the specific CNC machines—either on the job or, if new machines are purchased, through the seller of the machine. Finally, firms also train workers to use the inspection machines. Overall, firms provide extensive training on these machines.

THE FUTURE OF WORK IN THE THREE INDUSTRIES

The rising income inequality of the last twenty-five years suggests that many workers have been "left behind"—that is, the real incomes of better-educated workers rose while the incomes of the less-educated declined in relative terms, possibly because of new technologies. In the three industries studied here, plants have adopted sophisticated new production technologies made possible by advances in computer hardware and software. These new technologies often led to fundamental changes in the jobs of production workers and the skills they need. In steel, valves, and high-volume medical instrument production, workers began to run the production process through computerized monitoring systems rather than through "hands-on" manual control of production. Only in low-volume medical instruments have jobs been relatively unchanged.

The key question is: Why have we retained these high-paying jobs in the United States? Will these jobs continue to be available to high school educated workers in the future? Our interviews with plant managers provided us with the opportunity to gather information about the types of jobs and plants in the three industries that are likely to remain in the United States or likely to be moved offshore. In this section, we discuss the factors that create comparative advantages for U.S. plants and thus increase the likelihood that these plants and their production worker jobs will remain in the United States.

Several factors affect labor demand. Technological changes can reduce the demand for labor as capital substitutes for labor—in other words, the substitution effect reduces labor demand. In addition, higher wages in the United States relative to other countries can reduce the demand for labor. However, if firms are able to either increase quality or reduce prices as a result of technological changes, these improvements will increase product demand and thus increase labor demand and retain jobs in the United States. This scale effect increases labor demand.

Jobs are retained because some firms value the high skill levels of U.S. workers, but this factor alone cannot account for the overall job retention. As summarized in table 5.2, several factors have combined to retain jobs in the United States. For the most part, jobs are retained because workers are skilled, the customers are close by, and firms are producing sophisticated products that are more efficiently designed and built in the United States. However, manufacturing plants may be staying in the United States but they are also producing with fewer workers per unit of output. Managers told us that the high costs of labor are inducing them to introduce labor-saving technological improvements. In all three industries new technologies are reducing labor demand per unit of output as capital substitutes for labor. However, it is the rising and higher-quality output that then increases the overall demand for these skilled workers, and proximity to customers and R&D that keeps jobs in the United States.

Finally, the jobs that remain in the United States are going to individuals who are relatively more able among the high school educated: they are literate, often use basic math skills, have good interpersonal and communications skills, often are good problem-solvers, and, in the case of manufacturing, often have strong mechanical skills. In other words, these workers may not be typical high school graduates. Our work tells us that this should change: high schools should educate students with the objective of teaching these "soft skills."

THE HIGH SKILL LEVEL OF THE LOCAL LABOR FORCE

In two industries, we heard evidence that production worker jobs will remain in the United States because of the high skill level of the American worker. The plant manager at the medical equipment plant with the continuous, high-volume production process felt that one of the reasons the plant would remain open was the good local labor pool, which had the skills (computer literacy, problem-

Table 5.2 Why Production Jobs Are Retained in the United States

	Medical Devices			
	Continuous, High-Volume	Batch Production	Valves	Steel
The skill level of local labor force is high	✓	—	✓	✓
Plant is close to R&D and/or engineering group	✓	✓	✓	—
Plant is close to customer	—	✓	✓	✓
Labor cost is small share of total cost	✓	✓	—	✓
Existing fixed capital stock is hard to move	✓	—	—	✓

Source: Authors' compilation.
Note: A check indicates that we judge this to be an important reason jobs are retained in the United States.

solving skills, diagnostic skills, and communication skills) required by the production process. Although this company operates a similar plant in Mexico, it is unlikely to close the U.S. plant and consolidate operations in Mexico because the requisite skill set is not available there.

In looking at why production worker jobs in the valve industry are likely to stay in the United States, it is important to recognize that many valve makers are specialty design firms. Working with engineers, they design for specific applications. The production of commodity valves in large batches is declining. As long as there is an adequate supply of skilled machinists in the United States, the specialty design segment of the industry will probably remain. This part of the valve industry would be hurt if developing countries were eventually able to supply these same skills in a lower-wage workforce.

PROXIMITY TO ENGINEERING AND R&D GROUPS

When new products are being developed, it is best to have the manufacturing process close to the R&D group so that the two groups can experiment with alternative production approaches and fine-tune the production process. Managers in virtually all of the plants echoed this idea. The low-tech medical product plant has an engineering group on-site that designs new products and designs and builds the production machines. The on-site location facilitates the design and testing of the new machinery. Similarly, R&D shops are located on-site at the plants that produce high-tech medical products as well. For many plants, the on-site engineering group interacts frequently with R&D personnel at U.S. headquarters. The fact that plants are fairly close to U.S. headquarters facilitates this interaction between production and R&D.

Thus, as long as the United States remains preeminent in the R&D phase of medical device manufacturing, some production worker jobs in this industry will remain in the United States. We can reach similar conclusions for the valve and steel industries. In valves, most producers in the United States are making customized valves to the specifications of individual customers. Thus, new valves are designed on the premises and then the process moves directly to production. The steel industry is constantly developing—usually on-site—new products with different specifications, shapes, and metallurgical compositions. In sum, it is in part the preeminence of the engineering and design workforce in the United States that contributes to maintaining high-quality production jobs in the United States. Thus, a high-quality engineering workforce is indirectly helping to keep high-wage production jobs in the United States.

PROXIMITY TO THE CUSTOMER

Proximity to the customer has been a key reason the small-batch medical equipment plants have remained in the United States. For example, in a plant that manufactures complicated surgical equipment we learned that ideas for new products and product modifications come from the customers (doctors, hospitals) and that there is significant interaction between the customer and the manufacturer during the design and manufacturing phases.

Proximity to the customer also influences location decisions in some parts of the steel industry. Finished steel products from integrated steel mills that are shipped to automotive assembly plants often come from steel mills that have close working relationships with those auto plants. Steel finishing processes are likely to remain close to auto plants. In fact, some Japanese steelmakers opened steel finishing facilities in the United States to serve the needs of auto plants opened here by Japanese car companies.

The location of steel mini-mills is also geographically constrained by the nature of the markets for their products. For example, mini-mills that produce rebar steel supply their products to metropolitan and regional construction markets. These mini-mills are also likely to remain in close proximity to their product markets because of the high transportation costs of their product and the wide availability of scrap steel. In most of the plants we visited in the three industries, being located in the United States confers a greater advantage than moving abroad because here plants interact closely with customers.

THE LOW LABOR CONTENT OF THE PRODUCTS

Products that have low labor content and need strong technical infrastructure support will continue to be produced in the United States. One company that makes drug infusion pumps is keeping these jobs in the United States but manufacturing abroad the disposable plastic tubes that are used in very high volume with the pumps. Similarly, another company that makes pumps keeps these jobs in the United States but the plastic injection-molded equipment that goes with the pumps comes from other countries. Steelmaking is also very capital-intensive. Even if steelmakers in other countries could employ lower-wage workers, most managers believe that this cost disadvantage for U.S. firms is not significant as long as labor costs are a fairly small part of steel production and as long as workers here are highly skilled. However, integrated U.S. steel firms are suffering under the huge overhead costs of pensions and health care owed to retired workers.

FIXED CAPITAL STOCK

In all three industries, especially steel, many plant managers indicated that jobs will remain in the United States because the current capital stock exists here and it would be very costly to move abroad.

CONCLUSIONS

A set of in-depth plant visits inside three industries helped us document how new technologies have and have not changed the nature of production worker jobs. Several conclusions about the relationship between new production technologies and the nature of production worker jobs emerge from this look inside these three industries.

First, narrowly defined industries contain plants making very different products with very different technologies. All of the medical equipment plants share the same three-digit SIC classification and span only three different four-digit classifications. The steel mills are all part of the same four-digit classification, and valve manufacturers are part of only three different four-digit industry classifications. However, plants within these three industries use very different technologies, and the extent to which plants have adopted new computer-based technologies varies dramatically from plant to plant within an industry.

Second, in all three industries new computer-based technologies have produced significant improvements in productivity and product quality—and thus, in some cases, falling product prices. Productivity has clearly risen in the continuous, high-volume manufacturing plants—in all three industries—and in some cases prices have fallen or product quality has risen. Productivity gains are less evident in medical equipment plants that use assembly workers in batch production processes and in some valve plants, but in these cases a greater range of products, and thus higher-quality products, has evolved from the technological improvements in design and production in these industries.

Third, changes in job tasks due to increased computerization have often, though not always, resulted in "up-skilling" in these industries.[11] The full range of changes in skill demand are summarized by industry in table 5.3, which shows the growing importance of the "soft skills." As is emphasized in Autor, Levy, and Murnane (this volume), computers are now doing the symbolic processing. Retrieving data and acting on it in systematic ways to run the production lines, computers are doing the routine work of production. It is the nonroutine work, like addressing production-line failures or correcting small errors in line performance, that neither computers nor less-skilled operators can perform. Thus, computerization causes firms to demand workers with good problem-solving and communication skills, and sometimes the reading and math skills to undertake problem-solving. In the high-volume steel and medical equipment industries, workers are much more mobile throughout the plant and now must apply diagnostic and problem-

Table 5.3 Skill Requirements in Response to Technological Change

	Medical Devices			
	Continuous, High-Volume	Batch Production	Valves	Steel
High school diploma	Yes	Yes	No	No
Mechanical or machine skills	No	No	Yes	Yes
Problem-solving skills	Yes	No	Yes	Yes
Diagnostic or monitoring skills	Yes	No	Yes	Yes
Communication skills	Yes	Yes	Yes	Yes
Ability to learn basic computer skills	Yes	No	Yes	Yes
Flexibility in learning new jobs	Yes	Yes	Yes	Yes
Statistical skills or basic motor skills	No	No	Yes	Yes
Dexterity or high attention level	No	Yes	No	No

Source: Authors' compilation.

solving skills to highly automated machines that have eliminated routine work tasks.[12] In contrast, while valve manufacturing is now much more computerized, the up-skilling is more modest. These firms still require skilled machinists as before, and less-skilled operators are rarely hired. Finally, in some establishments, such as mini-mills and medical instrument assembly plants, skill demands have hardly changed because technological changes in production have been more modest. In plants with technology that is less complex, in particular mini-mills that produce less complicated products, skill demand has changed less.[13]

Even though up-skilling in these industries has increased the demand for soft skills, there has been only a modest increase in the demand for computer literacy. Nearly all of the jobs in these industries (except for a subset of those in medical assembly) require the workers to work at computer keyboards or monitors. In virtually all cases, however, the plant managers said that if job applicants have basic literacy, math, and people skills, and some technical skills such as machining (for valves), then computer skills can be readily taught on the job. For example, workers in valves no longer need to run lathes; those jobs have been automated with the use of new CNC machines. Yet these workers still need to have machining skills because they must understand how the CNC machine works; these machining skills are in fact more important than the computer skills that can be taught on the job. Thus, these firms do not require computer training in school. Although skill demand has risen, these firms continue to hire high school educated workers with mechanical or machining skills and do not seek to hire college graduates who do not have the required technical skills.[14]

Fourth, when jobs and skill requirements change, newly adopted HRM practices help address the plants' need for workers with new, more demanding skills. Table 5.4, which summarizes the full range of changes in HRM practices by industry, shows that the key change has been the introduction of greater degrees of worker flexibility—more job rotation, more training, and also more problem-solving. However, though technological changes have increased the need for worker flexibility, the capital-intensive technology dictates how these jobs should be combined for the most part. Plants have very limited options for redesigning jobs by task (unlike the results of Autor, Levy, and Murnane, this volume). The precise set of work practices that a plant uses to ensure that its workers have the necessary new skills varies from plant to plant. But selection, training, and pay-for-skills compensation plans all offer interesting and frequently used ways for plant management to elevate skill levels.

Thus, our research indicates that plants within narrowly defined industries adopt new computer-based production technologies at very different rates, and that when they do, skill requirements for production workers generally increase. To some extent, high school educated workers who want these jobs need to have some amount of computer literacy, since plants with these jobs prefer to hire such workers. At the same time, training programs and apprenticeships in different jobs appear to be especially important methods for workers to acquire the kind of plant- and equipment-specific computer knowledge they need. The primary skills that high school educated workers must bring to the job are the "soft skills," or the people skills—the ability to communicate, a willingness to learn on the job, and diagnostic and problem-solving skills.

Fifth, all three industries have witnessed increases in produc-

Table 5.4 New Human Resource Practices in Response to Technological Change

	Medical Devices			
	Continuous, High-Volume	Batch Production	Valves	Steel
Increased worker responsibility	Yes	No	No	Yes
Job rotation	Yes	Yes	Yes	Yes
Extensive training	Yes	No	Yes	Yes
Cross-training	Yes	Yes	Yes	Yes
Problem-solving teams	No	No	Yes	Yes
Pay-for-skills	Yes	No	No	Yes
Self-directed work teams	Yes	No	No	No

Source: Authors' compilation.

tivity, product quality, or product variety as a result of technological changes. Changes in labor demand, however, have varied across the industries. Innovations in product design and higher productivity in the medical equipment industry have increased product demand and thus doubled labor demand over time. For valve makers and steel mini-mills, labor demand has remained roughly constant; these industries have achieved higher productivity with approximately the same workforce. In the steel industry there has been dramatic downsizing and rising productivity over the last thirty years, but these changes did not arise from making technological improvements but instead from closing out-of-date, poor-performing plants and improving productivity in those that remained. In all three industries, however, new technologies appear to be the major reason we keep these jobs in the United States: they enable American manufacturers to improve products and serve nearby customers using a highly skilled, local workforce. The competitive advantage of the United States in the future in keeping these jobs lies in technology, the high skills of engineers and workers, and proximity to customers as firms design and produce the high-quality products they want.

For researchers, the patterns we observed in these plants suggest that new computer-based technologies vary across plants within narrowly defined, three-digit SIC industry groups and that these new technologies have changed jobs and skill requirements. Building upon the insights gained from this research, however, will prove challenging. The "new technologies" we uncovered are specific to individual work establishments and even vary across plants in a given company. Simple survey questions (like "Do you use a PC at your job?") do not capture the technologies we found in these plants. In some cases, the computer technologies were invisible to workers. With PLCs residing in enclosed metal boxes on the walls of a medical equipment plant, for instance, it was not obvious to the workers that they worked regularly with "computers." Future research that seeks to understand the impact of new technologies on the jobs, skills, and wages of high school educated workers could benefit by incorporating this kind of hands-on knowledge of specific industries. Field research that goes deep inside plants can identify in very concrete terms what "new technology" really is and what production workers really do.

We would like to acknowledge the superb support of the Russell Sage and Rockefeller Foundations. In addition, we thank the Alfred P. Sloan Foundation and the National Science Foundation for supporting our research on the steel industry and related work. Our coauthors on the overall steel project have contributed very significantly to the research, though they are in no way responsible for the views expressed in this chapter. We are indebted to Brent Boning, Richard Freeman, Jon Gant, Morris Kleiner, and Giovanna Prennushi. Finally, we thank the many industry participants who contributed their valuable time and insights to this study.

APPENDIX

Table 5.A1 Employment and Wages in the Medical Industry, 1972 to 1992

Industry	Year	Number of Plants	Total Employment	Production Workers	Average Hourly Production Wage[a]
Surgical and medical instruments (3841)	1972	357	34,018	71%	$9.85
	1977	456	42,630	67	10.04
	1982	708	56,393	68	10.02
	1987	975	72,163	62	11.25
	1992	1,121	97,183	59	10.93
Surgical appliances and supplies (3842)	1972	618	42,512	67	9.66
	1977	773	52,686	68	10.24
	1982	1,126	67,507	66	9.25
	1987	1,295	77,732	65	9.95
	1992	1,458	94,556	64	9.91
X-ray, electromedical, and electrotherapeutic apparatus (3693)[b]	1972	75	11,006	58	11.36
	1977	187	30,125	54	11.98
	1982	231	47,553	48	10.99
X-ray, apparatus, and tubes (3844)[b]	1987	67	8,711	63	12.50
	1992	112	14,239	49	12.83
Electromedical equipment (3845)[b]	1987	209	29,154	45	11.30
	1992	330	39,836	45	11.91

Source: Longitudinal Research Database.
[a] Deflated by CPI.
[b] In 1987 SIC 3693 was reclassified into two separate industry categories: 3844 and 3845.

Table 5.A2 Employment and Wages in the Steel Industry, 1972 to 1997

Year	Total Employment	Production Workers	Average Hourly Production Wage[a]
1972	469,100	81%	$17.23
1977	441,900	79	20.99
1982	295,800	73	23.44
1987	188,100	78	19.06
1992	170,600	77	18.99
1997	144,080	79	20.14

Source: Census of Manufacturers (1972, 1977, 1982, 1992, 1997).
[a] Deflated by CPI (1992 dollars).

Table 5.A3 Employment and Wages in the Valve Industry, 1972 to 1992

Industry	Year	Number of Plants	Total Employment	Production Workers	Average Hourly Production Wage[a]
Industrial valves (3491)[b]	87	369	45,808	64%	$ 12.42
	92	453	51,432	65	12.28
Fluid power valves (3492)[b]	87	346	27,352	65	12.45
	92	340	28,436	65	12.04
Valve and pipe fittings (3494)[b]	72	648	86,035	70	11.54
	77	764	107,892	70	12.03
	82	1,063	113,984	65	11.73
	87	372	24,774	70	11.76
	92	225	15,942	74	11.76

Source: Longitudinal Research Database.
[a] Deflated by CPI.
[b] Prior to 1987 all valve plants were categorized as SIC 3494. Beginning in 1987, three categories are used: 3491, 3492, and 3494.

NOTES

1. In the Longitudinal Research Database (LRD), medical equipment manufacturers cover industries 3841, 3842, 3844, and 3845 in the Standard Industrial Classification (SIC) system. Prior to 1987, the two SIC industries 3844 and 3845 did not exist but were a single classification, 3693. Steel manufacturing is industry 3312. Valve manufacturing plants were part of industry 3494 through 1982 and have been industry classifications 3494, 3491, and 3492 since then.
2. Education statistics are from Hirsch and Macpherson (1997). They define industries using CPS industry definitions that are somewhat broader than the four-digit SIC code definitions from the Longitudinal Research Database.
3. These figures may be conservative estimates of the size of the industries' production workforces, since these statistics come from the LRD, which uses narrower industry definitions than the Current Population Survey (CPS). The medical equipment manufacturers cover SIC industries 3841, 3842, 3844, and 3845. Prior to 1987, the two industries 3844 and 3845 did not exist but were a single classification, 3693. Steel manufacturing is industry 3312. Valve manufacturing was in industry 3494 through 1982, and the three industry classifications 3494, 3491, and 3492 since then.
4. Statistics on employment levels are from the LRD.
5. Data on number of employees and establishments are from LRD.
6. Wage data are reported in Hirsch and Macpherson (1997). Wages are deflated by the consumer price index (CPI) and are reported in 1992 dollars.
7. Prior to 1987, SIC codes 3844 and 3845 did not exist. Plants in those industries were classified as SIC 3693: X-ray, Electromedical, and Electrotherapeutic Apparatus.
8. To protect the confidentiality of this company and others that we visited, the products we describe are representative of the types of products we observed but not the exact products.
9. This pattern would be contrary to the predictions of the models of Kremer and Maskin (1996) and Acemoglu (2000).
10. When CNC machines were more difficult to program, manufacturers would have a small staff of programmers to help program the machines for the operators. These programmers are no longer needed.
11. For detailed empirical evidence on up-skilling across industries, see Autor, Levy, and Murnane (1998) and Bresnahan, Brynjolfsson, and Hitt (2002).
12. For additional evidence on the steel and medical equipment industries, see Applebaum et al. (2000).

13. For a similar conclusion, see Ballantine and Ferguson (this volume).
14. In contrast, technological change in some other industries, such as banking, has increased their use of college-level employees (Autor, Levy, and Murnane 2002).

REFERENCES

Acemoglu, Daron. 2000. "Technical Change, Inequality, and the Labor Market." Working Paper 7800. Cambridge, Mass.: National Bureau of Economic Research (July).

Applebaum, Eileen, Thomas Bailey, Peter Berg, and Arne L. Kalleberg. 2000. *Manufacturing Advantage*. Ithaca, N.Y.: Cornell University Press.

Association for Manufacturing Technology. 2000. *Producing Prosperity—Manufacturing Technology's Unmeasured Role in Economic Expansion*. McLean, Va.: AMT.

Autor, David, Lawrence Katz, and Alan Krueger. 1998. "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics* 113: 1169–1213.

Autor, David, Frank Levy, and Richard Murnane. 2002. "Upstairs Downstairs: Computers and Skills on Two Floors of a Large Bank." *Industrial and Labor Relations Review* 55: 432–47.

Bartel, Ann P., and Nachum Sicherman. 1999. "Technological Change and Wages: An Interindustry Analysis." *Journal of Political Economy* 107 (April): 285–325.

Berman, Eli, John Bound, and Zvi Griliches. 1994. "Changes in the Demand for Skilled Labor Within U.S. Manufacturing: Evidence from the Annual Survey of Manufacturers." *Quarterly Journal of Economics* 109 (May): 367–97.

Bresnahan, Timothy F., Erik Brynjolfsson, and Lorin M. Hitt. 2002. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *Quarterly Journal of Economics* 117: 339.

Caroli, Eve, and John Van Reenen. 2001. "Skills and Organizational Change: Evidence from British and French Establishments in the 1980s and 1990s." *Quarterly Journal of Economics* 116: 1449–92.

Greenan, Nathalie, and Jacques Mairesse. 1996. "Computers and Productivity in France: Some Evidence." Working Paper 5836. Cambridge, Mass.: National Bureau of Economic Research (November).

Hirsch, Barry T., and David A. Macpherson. 1997. *Union Membership and Earnings Data Book*. Washington, D.C.: Bureau of National Affairs.

Katz, Lawrence F., and Kevin M. Murphy. 1992. "Changes in Relative Wages, 1963–87: Supply and Demand Factors." *Quarterly Journal of Economics* 107(February): 35–78.

Kremer, Michael, and Eric Maskin. 1996. "Wage Inequality and Segregation by Skill." Working Paper 5718. Cambridge, Mass.: National Bureau of Economic Research.

Krueger, Alan B. 1993. "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989." *Quarterly Journal of Economics* 108(February): 33–60.

Standard and Poor's. 1998. *U.S. Industry and Trade Outlook*. New York: DRI and McGraw-Hill.