The Effects of Recent Technological Change on Skill Demand: An Analysis Using Direct Intra-Industry Measures

Ann Bartel
(Columbia University and NBER)

Casey Ichniowski
(Columbia University and NBER)

Kathryn Shaw
(Carnegie-Mellon University and NBER)

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Introduction

The last two decades have been a period of dramatic internal change and reorganization for U.S. businesses. A large fraction of U.S. businesses have experienced fundamental changes in terms of new investments in computerization and information technologies and in terms of the work practices used to organize and manage their workforces. With respect to computer technologies, the dramatic decline in the cost of computing power during the last twenty years,[1] has led many businesses to invest heavily in these computer or information technologies (IT). During the latter half of the 1990's alone, the rate of investment in computers and software grew at an extraordinary rate of 28% per year (Council of Economic Advisors, 2001). Over the same period, U.S businesses have also increasingly introduced new human resource management (HRM) practices including the use of problem solving teams, job rotation, careful screening of workers in the selection process, enhanced job security policies, and higher levels of skills training and information sharing. Entering the 1980's, these HRM practices were the exception. Today, most American businesses have several of these HRM innovations in place.[2]

Taken together, these two trends reveal a picture of a fundamental overhaul of the internal operations of most U.S. businesses since 1980. Many analysts argue that these IT and organizational changes may also be responsible for the dramatic increase in inequality in the U.S. wage distribution over this period. According to these arguments, technological and organizational change over this period caused changes in labor demand that favored more skilled workers (Krueger, 1993; Berman, Bound, Griliches, 1994; Autor, Katz, and Krueger, 1998; Bartel and Sicherman, 1999; Acemoglu, 2000). Moreover, this skill-biased technological change appears to have a large "intra-industry" component -- it is not simply the case that wages in "high tech" industries rose relative to those in "low tech" industries. The direct tests of the proposition that new technologies

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[1] Since 1980, the cost of a computer performing one million instructions per second fell from $100 to less than 20 cents today.

[2] Several surveys document dramatic growth in these HRM practices since 1980 (Ichniowski, Delaney and Lewin, 1989; Black and Lynch, 1996, 2000; Gittleman and Joyce, 1998). Osterman's surveys (1994, 2000) cover a large representative sample of U.S. work establishments and show that the percent of businesses with multiple innovative work practices increased from 38% in 1992 to 71% in 1997, and the percent with at least one such practice increased from 65% to 85% over the same five year period.

and new work practices have increased demand for more skilled workers have either been case study in nature, applying to a few firms (Autor, Levy, and Murnane, 2002, Hamilton, Nickerson, and Owan, forthcoming), or have been very broad, applying to establishments across all industries (Autor, Levy, and Murnane (2001), Bresnahan, Brynjolfsson, and Hitt (2002), and Dunne, Foster, Halitwanger and Troske (2000)).[3] These studies leave a gap in the literature – there is a need for direct and convincing measures of technologies and organizational practices that vary across plants within a narrowly defined industry, so that it is possible to capture convincing changes in the production function over time and to measure the impact of those changes on HRM practices and skill demand.

In this study, we use a personally-collected data set from plants in one narrowly defined industry, valve manufacturing, to examine four related questions. First, what does the term "new computer and information technology" really mean? By focusing on plants in a narrowly defined industry, can we avoid the use of vague survey questions such as "do your workers use computers" and instead identify and measure specific computer technologies that have changed a very specific production process. Second, why do some plants adopt new IT and others do not – what factors contribute to IT adoption within a narrowly defined industry? Third, does the adoption of new computer-based technologies change the demand for worker skills? Fourth, if some plants in the industry have adopted new technologies that require higher levels of certain skills, do these changes also imply that these plants need to adopt new HRM practices for organizing and managing their workforce?

The Valve Manufacturing Industry

Before addressing these questions, we first provide a background on the valve manufacturing industry, its production process, and any changes in computerized technologies that have occurred in this industry in recent years. Valve manufacturing is a

[3] Several empirical studies have attempted to measure the impact of technological change or organizational change on the nature of labor demand over this time period. To investigate this question, Dunne, Foster, Haltiwanger and Troske (2000) use LRD data; Autor, Levy and Murnane (2000) combine CPS and Dictionary of Occupational Titles data; and Bresnahan, Brynjolfson and Hitt (2002) use data from a survey of large companies. Data limitations restrict definitions of technology to survey questions on "computer use" or levels of investment, and data on organizational practices are even more limited in these sources and in some cases non-existent.

more narrowly defined industry classification than a three-digit SIC classification. Valve making occurs in three different 4-digit SIC categories – SIC 3491, 3492 and 3494. To understand this particular industry context, we first visited five valve making plants in the United States. During these visits, we conducted tours of the production process and conducted interviews to identify new computer-aided technologies that have become part of this industry's production operations, to discuss the use of innovative work practices in the industry, and to solicit the views of experienced managers and workers about how skill requirements of jobs may have changed when new technologies were put in place.

The Production Process. Valves control the flow of liquid or gases through pipes. For example, in a bottling plant, a valve would control the amount of liquids passing through the pipes that then combine the liquids as they feed into bottles. A simple valve would be made by taking a steel pipe and etching grooves at each end (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 use a drill to bore a hole down the middle of the block; use a turning process to etch grooves at both ends (for screwing in); 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 is organized into the stages of machining, welding, assembly, testing, and packaging.

Examples of New Technology. There has been a real IT revolution within the traditional manufacturing process of valve production. And the revolution has occurred in all phases of manufacturing – in production, inspection, and product design.

In the past, the reshaping of the steel block would be done on a work bench with manual tools to chip or drill or bore holes—it was a very labor intensive work 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 numeric control (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 numeric control

(CNC) metal working machines which spread gradually throughout the industry since that time and have improved dramatically. In the overall machine tool industry that 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. However, by 1997, 69 percent of machine tool plants used some form of these machines (AMT, 2000).

The CNC machine embodies a highly computerized technology, and thus CNC machines have improved dramatically in the last five to ten years with improvements in all computer technologies. The IT revolution of the last ten years is noted for much faster microprocessors and much greater amounts of information storage. As the new CNC machines have incorporated the faster processors and greater storage, the software running the machines is much more sophisticated, and as a result the CNC machines can perform a much wider range of tasks on one machine, and do so automatically with much less programming by the operator. The vastly improved software that controls the machine is also combined with technological improvements in metalworking. Thus, 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.

Computer-controlled devices have also automated the quality control process and reduced the time it takes to inspect the products. Each dimension of a complicated valve often must be produced to an accuracy rate of 1/1000 of an inch, so inspection is a critical part of the production process. For many years, inspection was done with hand-measuring devices, which was very time-consuming. In the last few years, inspection machines have been introduced which use a laser probe technology, so that the operator touches each surface (interior, exterior, holes, etc.) of the valve with a probe that develops a 3-D picture and measures all dimensions.

In addition to computerization embedded within the CNC machine itself, and the computerization found in automated inspection sensors, computer software and high-speed PC's have improved the product design phase. Valve production is very specialized and new valves are often designed for each customer. In the 1990s, valve-producing firms began switching from 2-dimensional CAD/CAM software programs to 3-

dimensional CAD/CAM software that shows the valve as a solid model rather than a 2-dimensional representation—thus facilitating rapid design of new products substantially. 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 re-work after a valve is in production.

Field Observations on 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. The machinist at each station sets up the machinery to do the particular operation. A machinist must therefore understand the blueprints, set the metal cutting speed at feed, determine how much metal to take off, how much to chip, then use inserts and holders to do the milling, drilling, tapping or turning. Different machinists are skilled at different jobs. Thus, some might specialize in the drill press, while others might specialize in the lathe.

According to interviews, today's CNC operator must be a skilled machinist as in the past, but must also add problem-solving skills and some computer skills. Nowadays, 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, calculations which in the past would have been done by hand by the operator with blueprints. Thus, it would seem that the operator could be less skilled than in the past. Yet, employers state that they still wish to hire highly skilled machinists for these jobs, for several reasons. First, because CNC machines cover a broader range of machining activities (drilling, tapping, turning, etc.), today's operators need to be skilled in all these activities. Previously, operators tended to be more specialized. Second, the newer technologies require employees to undertake more problem-solving activity, 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.[4]

Thus, overall, there is likely to have been greater skill demand within the metalworking part of production. Due to this computerization of machines, valve manufacturers today are likely to hire skilled machinists with problem-solving skills, but also are not hiring the less-skilled operators whom they used previously. In the past, when the production of valves would require the use of six to ten machines, some machines would be set up by skilled machinists, but then would be operated by much less-skilled operators. Now, CNC machines do far more tasks automatically on one machine, and thus very low-skilled operating jobs are gone. This is not surprising—overall labor demand has declined per unit of output due to automation.

According to interviews during our visits, 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. There is no need for draftsmen as 3D CAD/CAM machinery produces the blueprints automatically, and the 3D nature of the program eliminates the need for the multiple drawings that would have previously been required. There has also been a decline in the demand for engineers due to the use of the new machines.

Observations on New HRM 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. Overall, 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 and steel. There is greater participation of machinists in problem-solving activities. Very little of this problem-solving 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 will recognize the problem instantly and won't continue. Employees do not need to solve this sort of problem via team activity. Instead, there is

[4] Note however, that when CNC machines were more difficult to program, the manufacturers would have a small staff of programmers who would help program the machines for the operators. These programmers are no longer needed.

likely to be more problem solving away from the machine for two reasons. First, in designing new products, a team will get together to clarify a drawing, perhaps making changes (in space or tolerance) and suggesting equipment or methods of production. Second, the machinist is involved is in improving the approach to production. For example, to improve performance, a certain area of operations might be videotaped. Machinists and others would then brainstorm to improve the process.

Managers during our site visits also focused on expanded skills training as an extremely important practice for their machine operators. When hired, these operators would have a high-school education and then have acquired the additional machining skills at a community college or technical institute. Thus, these jobs are held by individuals with high-school educations with some additional training. After they are hired, the firm will train the worker on how to run the specific CNC machines, and this training will take place on the job, or if new machines are purchased, the training would be done by the seller of the machine. Finally, they also train workers for the use of the inspection machines. Thus, overall the firm undertakes extensive training on these machines.

Sample and Data

The data collection strategy for this study followed several steps. First, plant visits and interviews allowed us to observe directly the industry's production process, the extent of any new computer technologies, and the nature of jobs and skill requirements. Second, based on these insights, we developed an industry-specific survey to collect data on the technologies, work practices, jobs, and skill requirements of plants in this industry.[5] Third, we purchased contact information for 523 businesses in valve making industries (in SIC's 3491, 3492 and 3494) from Survey Sampling, Inc. that had 50 or more employees, and pilot tested the survey with four plants in the sample. Fifth, after revising the survey based on the pilot tests, the Office for Survey Research at the Institute for Public Policy and Social Research at Michigan State University conducted the survey by telephone from July 31, 2002 through October 22, 2002.

[5] A sample of the complete survey is available from the authors.

Of the 523 plants identified by Survey Sampling Inc., 109 were determined to be ineligible due to no production at that location or were duplicates, 27 were determined to have fewer than 50 employees upon contacting the business, 56 were no longer in business (determined by reaching a non-working number then verifying by directory and web searches). Of the eligible 331 plants contacted, 139 completed the interview for a response rate of 42%. Interviews with these 139 respondents lasted an average of 19.85 minutes with an average 7.6 phone contacts needed to complete the survey. Empirical results in the study are based on the responses from these 139 valve making plants.

Table 1 reports a series of statistics that indicate that the valve-making industry provides a good setting to study the effects of new computer-based production technologies and new HRM practices. Panel A reports results from questions that ask for the year that the plant installed: its first CNC machine (column 1); software assisted product inspection sensors (column 2); and 3-D CAD/CAM valve designing. Panel B reports the time trend of adoption for: problem solving teams (column 1); skills training programs (column 2); and any one of several possible incentive pay plans including pay-for-output plans or special bonuses (column 3).

Panel A shows that the basic valve making machine has changed between 1980 and today. In 1980, less than one-fourth of all plants had a CNC machine, but by 2002, 87% report having at least one CNC machine on line. 3D CAD/CAM technologies for designing valves were very rare in the 1980's and by 1990, only one in ten had this technology. Over the last ten years, the use of 3D CAD/CAM technology has spread to nearly four-fifths of all plants. Automated product inspection sensors are the least common among these computerized valve-making technologies. Like 3D CAD/CAM technology, roughly one in ten plants had the technology in 1990, but its growth has been slower than 3D CAD/CAM's. Today, one in three plants have automated sensors. Still, these computer technologies were the exception rather than the rule in 1980. The valve making machineries of today are embedded with many high technology, computer-aided features.

Panel B shows dramatic growth in the use of innovative HRM practices over the same time period. Problem solving teams show the largest growth – from 4% of all plants in 1980 to 69% today. Formal skills training programs are the most common of the three practices reported in Table 1, growing from 19% to 83% of all plants. The use of some kind of incentive pay has also become more common, growing by some 5.5 times its 1980 level over this period, though the extent of incentive pay among valve-making plants is well below the extent of the other two practices.

The Adoption of CNC Technology By Specialty and Commodity Producers

The heart of the valve making process occurs at the NC and CNC machines where blocks of raw material are made into valves. In this section, we focus on the adoption of CNC machines as perhaps the most central example of increased computerization in valve making plants. One puzzle in the research on changing nature of job skills and wages due to new computer-aided production technologies is the idea that the effects of new technologies on jobs and wages have a large intra-industry component. Within narrowly defined industries, what factors can explain why some establishments would adopt new technologies while others would not.

During our field visits, a consistent theme we heard about the benefits of CNC technology was that a primary benefit of CNC machines was their ability to produce custom-made features on valves. Accordingly, in our survey, we asked what percent of their annual production was attributable to customer orders directly from their product catalogue versus customer orders with special features not in the catalogue.

Based on the survey results, we define two types of valve producers: the "*commodity producers*," where 90% of their output goes to filling orders from the catalogue; and the "*specialty producers*," where less than 90% of their output goes to filling catalogue orders. For these two groups, 96% of the average output for the commodity producers goes to filling catalogue orders, and 43% of the average output for the specialty producers goes to filling catalogue orders. Just under one half of the plants (n=55) are commodity producers and over one half (n=71) are specialty producers. [6]

[6] We add three plants to the "commodity" group that do not have any catalogue use. These plants produce in batch sizes of 10,000 to 50,000 (or 4 to 20 times the average batch size of firms with high values of percent from catalogue). Product characteristics in these plants are those of commodity producers, and we suspect that "percent from catalogue" = 0 for these plants because the plants produce such a narrow range of products that a catalogue is not needed or available.

Production in the commodity-speciality subsamples is very different in a number of respects. Compared to the specialty producers, the commodity plants produce almost twice as many units annually (3.8 million vs. 2.1 million), have a substantially lower price for their most important product ($226.59 vs. $366.17) and produce valves in batch sizes more than twice as big (4961 vs. 2306).

Table 2 reports results from models that compare the adoption and use of CNC machines between specialty and commodity producers. The first two columns show results from a cox proportional hazard model where a "years until adoption of first CNC machine" is the dependent variable and the independent variable is a dummy for "specialty plants." The dependent variable is equal to "year of adoption – 1980" for plants opened before 1980, and to "year of adoption – year plant opened" for younger plants. The column 2 specification is identical to that of column 1, but includes a control for the year the plant opened, since younger plants will be more likely to adopt CNC machines quickly. Plants that have no CNC machines are censored observations. The results in the hazard models indicate that specialty plants are significantly more likely to be earlier adopters of CNC technology. The annual hazard rate for specialty plants is some 1.55 to 1.75 times greater for specialty plants than it is for commodity plants.

In columns 3 and 4, we examine the difference in the use of CNC machines between the two types of plants by comparing the "percent of all valve making machines that are CNC machines" as of 2002. In the column 3 OLS regression, the specialty dummy is the lone regressor, while in column 4 we include a set of additional plant characteristics as controls.[7] According to the results of these OLS equations, the proportion of valve making machines that are CNC's is some 13 percentage points higher in specialty plants.

Taken together, the Table 2 results provide systematic confirmation of the interview evidence from our plant visits. Specialty plants were earlier adopters of CNC technology and a higher percent of the machines in specialty plants are CNC machines. At the same time, it is important to note that, by 2002, CNC technology is widespread in the industry, across both specialty and commodity plants. We have classified

[7] In a study of establishments in SICs 34-39, Astebro (2002) found that plant size predicted adoption of CNC technology. Based on data collected in his survey, he concluded that the plant size effect was due to opportunities for spreading the fixed costs of adopting the new technology.

approximately 55% of this sample of plants as specialty producers, yet 89% of all plants now have some CNC machines. CNC technology continues to become less costly and more capable, providing benefits to many valve makers. These benefits however appear to be greater and to have occurred sooner for specialty valve makers.

The Importance of Worker Skills Under New Technologies and Specialty Production

Unlike previous studies of the effects of new production technologies on workers' jobs, this study collects direct industry-specific measures of new computer-aided production technologies that became increasingly prevalent in the 1980's and 1990's.[8] Furthermore, the previous section identifies a plant-specific characteristic (specialty product focus) that can help account for differential rates of technology adoption. To address the question of whether these new technologies increased the importance of certain skills, we asked respondents to indicate whether any of six different skills (math skills, general computer skills, computer programming skills, problem solving skills, cutting skills, and skills to operate multiple machines) were: not important, somewhat important, or very important.

Managers find that some of these skills are more likely than others to be very important. The sample mean for the proportion of plants that indicates a given skill is "very important" varies considerably for the different skills:

Is The Skill "Very Important?"

	Programming Skills	General Computer Skills	Problem-Solving Skills	Math Skills	Operate Multiple Machines	Cutting Skills
Mean Response	43.3%	30.4%	73.2%	71.7%	59.0%	40.6%

Problem-solving skills and math skills are the most important skills – viewed as very important by 73.2% and 71.7% of the sample respectively. The skills to operate multiple valve making machines are also viewed as very important (59.0%). Computer skills to

[8] Using data from the 1975, 1981 and 1983 Industry Wage Surveys for SIC 35 and information on the skill content of various job titles from the Dictionary of Occupational Titles, Keefe (1991) studied the impact of numerically controlled machine tools on worker skills. He found that this technology, whose use doubled between 1978 and 1983, did not have a significant impact on machine shop skill levels.

program machines and more important than general computer skills, and cutting skills are least likely to be seen as very important.

Most important, skill demand rises with IT use: as CNC use rises, several skills become more important. In Table 3, we estimate probit models that express a dummy variable that equals one when a respondent says the given skill is "very important" as a function of the specialty dummy variable and a variable measuring the percent of all machines that are CNC's. The high-IT plants prefer workers who have strong programming skills, are able do multi-tasking by operating several machines, and are able to problem-solve. And note that while specialty plants tend to use CNC machines more (recall Table 2 results), specialty production has no effect on skill demand. Thus, it is IT use that raises skill demand, whether the CNC's are used by commodity or specialty producers.

A common question in the skill-biased technical change literature is, does greater IT prevalence on the job require higher levels of computer skills by typical workers? In the case where the IT is embedded in CNC machines, the answer is yes: operators of these machines clearly require more programming skills for these particular machines. However, "general computer skills" are not required. Our plant-visit information confirmed however that the programming skills required can be learned on the job, and that this training (for particular machines) is offered on the job.

Also in keeping with the literature, we find that both IT use and more complex production processes raise the demand for problem-solving skills. As shown in studies using more general data bases (Autor, Levy, Murnane, 2001), IT use raises the demand for problem-solving skills (which IT is measured by CNC use herein). However, note that if a plant focuses on producing specialty products, the production of these products is likely to be more complex and variable and thus requires more problem-solving skills (see columns 10-12 of Table 3) (see also Boning, Ichniowski, and Shaw, 2001)

New Technology, Specialty Production, New Skills and the Adoption of New HRM Practices

We have shown that IT use increases skill demand, and that the adoption of more IT-intensive technology on the production line varies across producers. Thus, the experience of the valve-making industry provides support for the idea that the adoption of new computerized production technology can vary in systematic ways within narrowly defined industries—customized producers use more computer-aided production technology. Furthermore, once adopted, these new technologies make certain worker skills – such as programming skills, problem-solving skills, flexibility or the ability to operate multiple machines, and math skills – more important.

Some analysts have argued that skill demand also rises with the use of innovative HRM practices, such as flexibility and employee involvement, particularly when workers are operating more technologically sophisticated equipment (see especially, Bresnahan, Brynjolfson, and Hitt, 2002). The two panels of Table 1 show the kind of evidence that promotes this kind of hypothesis. New computer technologies became dramatically more common since 1980, and over the same period, plants in this industry adopted many new HRM innovations.

In this section, we examine the hypothesis that new computer-aided production technologies that require more worker skills also make new HRM practices better choices for managing the plant workforce. In short, are the same plants that are introducing new technologies also adopting the new work practices?

Two approaches are used to test the hypothesis that IT use requires the adoption of innovative HRM practices. First, we simply look at the cross-sectional data, asking whether HRM practices arise more in plants with more CNC machines. Second, we estimate a difference-in-differences model to examine whether the adoption of new CNC machines tends to result in the use of new HRM practices.

In the first cross-sectional test, we find that plants with new CNC machines are those that are more likely to utilize problem-solving teams. Table 4 presents results of probit models where the dependent variable measures the presence or absence of a given HRM practice in 2002. Only in the case of problem-solving teams does greater use of CNC machines favor adoption of innovative HRM practices. And, not surprisingly, when plants have problem-solving teams, the managers are more likely to report that problem-solving skills and training are very important (column 2) Note finally that even though specialty plants are more likely to have high levels of CNC machines, by 2002 CNC machines were also important technologies for all producers – specialty and commodity—and the prevalence of CNC machines, rather than specialty production, is the better predictor of the use of teams in valve making plants.

Our valve industry survey also asked for data on the vintage of CNC machines. Not only did we collect data on the year that the first CNC machine came on line, we also asked for the age distribution of the current CNC machines – specifically, the percent of machines that are less than five years old, five to ten years old, and more than ten years old. Therefore, we can also examine the timing of the adoption of the problem solving teams (and other HRM practices) more closely to see whether more recent investments in CNC machines also imply more recent adoption of teams.

Turning to the difference-in-differences estimation, we find that plants that adopted problem-solving teams and that plants that adopted incentive pay in the last five years were those that also increased their CNC use in the last five years. In Table 5, we estimate probit models that have as a dependent variable a dummy for whether these plants adopted new HRM practices between 1997 and 2002, as a function of an increase in the percent of all CNC machines that were brought on line since 1997.[9] While we show that the adoption of teams and of incentive pay in the last five years rises with the greater CNC use, we cannot show causality – within the five-year interval, we do not know whether CNC preceded HRM adoption or whether HRM adopted preceded CNC use. Note also that training does not seem to rise with increased CNC use, but by 1997, well over half of all plants had required training, thus perhaps its prevalence explains it's independence from new CNC adoption.

Conclusion

The extensive literature on increasing earnings inequality in the U.S. since the 1980's has led many analysts to conclude that "skill-biased technological change" is an important cause for the increased inequality documented over this time. Others have elaborated on this theme by arguing that it is a combination of new technologies and new work practices that has increased demand for more skilled workers. While some

[9] Despite the difference in the samples between Tables 4 and 5 (all plants in Table 4 versus plants that had not adopted the given practice as of 1996 in Table 5) and the difference in the measure of technology (percent of all machines that are CNC's in Table 4 versus percent of all machines that are CNC's that are less than five years old in Table 5), the substance of the findings in the two tables is very consistent.

exceptions exist, the studies that draw these conclusions typically use data on production technology, information technology, human resource practices and skills that are of a very general nature—applying across industries. While these studies have the advantage of generalizability, they tend to lack the ability to truly isolate specific changes in the production process, thereby diminishing confidence in their conclusions regarding skill and technology demand.

In this paper, we provide the first intra-industry study with concrete measures of all three of these factors – computerized technology, HRM practices, and skill demand – that are critical to the explanation of skill-biased technological change. Our analysis of personally collected data from 119 plants in the U.S. valve making industry provides very specific evidence regarding skill-biased change. We find that:

(1) The use of new computer-aided information technologies (IT) grew dramatically over the 1980-2002 time period, and these information technologies were more likely to be adopted by plants that make specialty products. Measuring IT adoption by the use of new CNC machines, we find evidence of the differential use of IT within a very narrowly defined industry – consistent with the conclusion in the literature that there are differences within narrow industries in technology use. However, by 2002, as the IT content of CNC technology continued to improve dramatically, most producers (commodity and specialty producers) used CNC technology—87% had CNC machines.

(2) Where IT machinery is in greater use, managers are significantly more likely to elevate the overall skill demand and demand a wider range of skills. The more-IT intensive plants demand more computer programming skills and more math skills to run the machines. But in addition, they also demand a broader range of problem-solving skills and skills for multi-tasking or worker flexibility (e.g., and ability to run multiple valve making machines). This effect of CNC technology on higher skill demand appears to exist among both commodity and specialty producers.

(3) New information technology is correlated with the use of new HRM practices – those plants that adopt new IT-intensive CNC machines in the last five years were also more likely to adopt the HR practices of problem-solving teams and incentive pay.

Note finally that the methodology and data collection procedures that we follow in this study underscore the importance of collecting concrete, high-quality measures of the constructs being investigated. This study collects direct measures of technology, skills and HRM practices from each small plant, and these measures are tailored to the context of a specific industry setting. The field research involving visits to plants and interviews with experienced industry experts was essential for developing a data collection instrument that could measure IT, HRM, and skill variables in a meaningful way.

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TABLE 1

The Diffusion of New Technologies and New HRM Practices in the U.S. Valve Industry

Panel A: Percent of Plants with Computer-Aided Production Technologies

Year	First CNC Machine	Computerized Product Inspection	3-D CAD/CAM Design
1980	.23	.01	.01
1985	.46	.04	.02
1990	.61	.11	.10
1995	.77	.15	.24
2000	.86	.30	.66
2002	.87	.34	.79

Panel B: Percent of Plants with New HRM Practices

Year	Teams	Training	Any Incentive Pay
1980	.04	.19	.08
1985	.07	.23	.12
1990	.14	.31	.18
1995	.36	.55	.24
2000	.63	.81	.39
2002	.69	.83	.45

TABLE 2

Differences in the Adoption of CNC Technology for
Specialty vs. Commodity Valve Manufactures

Dependent Variable	Years Until First CNC Machine is Adopted		Percent of All Machines That Are CNCs	
Estimation Method	Cox Proportional Hazard		OLS	
	(1)	(2)	(3)	(4)
1. Specialty Plant	1.559* (.386)	1.748** (.444)	.137** (.053)	.128** (.057)
2. Other Controls	None	Year Plant Opened	None	- Age of plant - Union status - Shop Employment
Observations	92	92	117	111

* - Significant at .10 - level, two-tailed test
** - Significant at .05 - level, two-tailed test

TABLE 3

Probit Estimates of the Effect of CNC Technology
and Specialty Production on Importance of Worker Skills
(Dependent Variable: Dummy Variable for Skill is Very Important)

	Math Skills			General Computer Skills			Programming Skills			Problem Solving Skills			Cutting Skills			Skills to Operate Multiple Machines		
1. Specialty	.234	---	.204	.363	---	.333	-.021	---	-.080	.454*	---	.428	.091	---	.049	-.092	---	-.161
	(.25)	---	(.255)	(.252)	---	(.254)	(.239)	---	(.245)	(.266)	---	(.268)	(.246)	---	(.249)	(.245)	---	(.252)
2.Percent of All Machines That Are CNC	---	1.103*	.982*	---	.869	.815	---	1.671***	1.686***	---	1.131*	1.082*	---	1.067*	1.057*	---	1.582***	1.618***
	---	(.592)	(.595)	---	(.544)	(.550)	---	(.586)	(.588)	---	(.621)	(.629)	---	(.546)	(.548)	---	(.616)	(.618)
N	119	119	119	119	119	119	116	116	116	119	119	119	119	119	119	115	115	115

Other control variables in probit models are age of plant, number of shop employees and union status

*** - Significant at .01 – level, two-tailed test
** - Significant at .05 – level, two-tailed test
* - Significant at .10 – level, two-tailed test

TABLE 4

Determinants of Adopting New HRM Practices by 2002
(Probit Model Estimates: 2002 Cross-Sectional Data)

	Problem Solving Teams		Skills Training Program		Any Incentive or Bonus Pay	
1. Specialty	.193 (.267)	.124 (.277)	.140 (.309)	.040 (.326)	.100 (.241)	.149 (.245)
2. Percent of All Machines that are CNC	1.640*** (.632)	1.527** (.656)	.064 (.640)	-.156 (.667)	-.219 (.552)	-.155 (5.29)
3. Problem Solving Skills Are Very Important	--- ---	.735** (.303)	--- ---	.712** (.333)	--- ---	-.157 (.287)
N	119	118	119	118	117	116

Other control variables are age of plant, shop employment and union status.

*** - Significant at .01 – level, two-tailed test
** - Significant at .05 – level, two-tailed test
* - Significant at .10 – level, two-tailed test

TABLE 5

Changes in the Use of Information Technologies and HRM Practices:
Determinants of Adoption of New HRM Practice between 1997 and 2002
as a Function of Changes in CNC Use [(A)]
(Probit Model Estimates; Post-1997 Adoptees)

	Problem Solving Teams	Skills Training Program	Any Incentive or Bonus Pay
1.Specialty	.496 (.328)	.441 (.440)	.224 (.322)
2. Change in CNC Use: Percent Increase in CNC use as a percent of all machine use from 1997 to 2002	5.743*** (2.075)	1.232 (1.758)	2.279** (1.072)
N[(A)]	74	42	84

[(A)] - Samples include only those plants without the given practice as of 1996. Other controls are age of plant, number of shop employees and union status.

*** - Significant at .01 – level, two-tailed test
** - Significant at .05 – level, two-tailed test
* - Significant at .10 – level, two-tailed test