Skill-Biased Technological Change

Evidence from a Firm-Level Survey

Chapter 1 - Introduction

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THE IMPORTANCE OF THE PROBLEM

For centuries, economists have considered the effects of technological change on labor composition and wages. Malthus (1978), Marx (1967), and Ricardo (1995) all expressed concern about the effects of innovation, especially in the form of new machinery, on the displacement of labor. Joseph Schumpeter (1975) hypothesized that technological change is a force of “creative destruction,” which generates new jobs and industries as it destroys existing ones.

In recent years, concerns about the effects of technology on the labor force have been heightened by large-scale corporate downsizing programs and increases in wage inequality. Because these trends have coincided with a large increase in investment in computers, several authors have attributed them, at least in part, to skill-biased technological change; i.e., change that is “biased” by favoring workers with higher levels of education and skill over those with lower levels. This bias occurs because the introduction of a new technology will increase the demand for workers whose skills and knowledge complement that technology.

Many technical advances are labor-saving innovations, enabling companies to eliminate low-skilled positions. This should lead to a shift in labor composition in favor of more highly educated workers. Furthermore, technology may increase the wage premium associated with additional investment in education or skill acquisition. Indeed, as noted by Berman, Machin, and Bound (1998), numerous studies have attributed both the greater wage premium for skill and recent increases in unemployment in Organization for Economic Cooperation and Development (OECD) countries to skill-biased technological change.

Skill-biased technological change has important implications for workers, employers, and public policy. One important issue is whether the implementation of a new technology is accompanied by elements of employee “empowerment” and development strategies. These elements of empowerment could include such factors as additional company-sponsored training, changing job responsibilities, the creation of new jobs and career opportunities, and an increase in employee control, or “voice.” It is important to note that advanced manufacturing technologies (AMTs) all involve some transformation of the work environment, because they are integrative (across functional areas of the firm such as manufacturing, marketing, and R&D) and information-intensive, requiring the use of computers. An examination of changes in human resource management (HRM) practices could have important implications for assessing the overall impact of investments in new technology on economic performance, given that recent studies (Bartel 1995; Black and Lynch 1997; Helper 1999) have documented a positive relationship between proxies for worker empowerment (sometimes referred to as “employee involvement” or “voice” practices) and productivity. To the best of my knowledge, however, there is no direct empirical evidence connecting empowerment strategies with specific technological innovations.

Most existing studies of skill-biased technological change have implicitly been based on the concept that technological improvements are homogeneous. In contrast, I examine the labor market consequences associated with different classes of technologies. A dissaggregated analysis also provides a more realistic and accurate documentation of changes in HRM policies, such as downsizing and employee empowerment, which emerge after technological change. Specifically, I analyze whether the signs and magnitudes of the skill-bias and employee empowerment effects depend on the type of technology that is implemented. The evidence could be useful to managers, who formulate HRM policies and strategies, and to policymakers, to help target subsidies for training programs and retraining of displaced workers more effectively.

These findings could also have important implications for studies of returns on investment in human capital. Existing theories of human capital imply that under conditions of rapid technological change, creating an environment that fosters organizational learning can increase firm profitability. Such an environment may begin with more adept employees. To build this environment, it is critical for workers to upgrade their skills through training and education, in order to increase proficiency and familiarity with new methods of production. Firms usually fund training for workers who remain with the company in the aftermath of technological changes. Indeed, it appears that this is a rational strategy, given recent evidence indicating positive returns to private sector training (Bartel 1994, 1995; Ichniowski, Shaw, and Prennushi 1997).

Some private sector training is subsidized by the federal government through the Job Training Partnership Act (JTPA). JTPA was established to replace the Comprehensive Employment Training Act (CETA), which targeted job-training programs to the public and non-profit sectors. CETA was terminated in 1982, amid charges of corruption, patronage, and a general sense that the positions created through the program were “make work” jobs. JTPA has a much stronger private sector orientation. It engages unions and firms as partners in training and job-search programs and allocates its funds through state governments, which then distribute the money through local programs. For example, JTPA provided $200 million to the United Automobile Workers to help employees adjust to new “high-performance work organizations,” which often accompanied implementation of the new manufacturing technologies (Applebaum and Batt 1994).

Skill-upgrading and employee empowerment are not of much use to workers who lose their jobs. JTPA funds have also been used to assist workers who are displaced in the aftermath of technical change. For instance, in 1993, the Harriman School for Management and Policy at the State University of New York at Stony Brook received JTPA funds, through the Suffolk County Department of Labor, to establish a semester-long "Jobs Project," or Dislocated Worker Training Program, in technology management for 72 older engineers who had been terminated by firms in the local region (Wolf et al. 1995). Although some economists are skeptical about JTPA programs, claiming that they focus on quick solutions and subsidize the most favorable candidates for job placement, bipartisan support for JTPA remains fairly strong. It appears that government funding for formal training programs, administered through local agencies, will continue. The empirical evidence presented in this monograph should be useful to policymakers with such an agenda, by helping them target resources invested in these programs more effectively.

BENEFITS OF EXAMINING THE LONG ISLAND SURVEY

Numerous empirical studies have been conducted on skill-biased technological change. Many of these studies suffered from important limitations. First, most have been based on industry-level data. Firm-level data may be more appropriate because there could be substantial heterogeneity in technology usage and compositional effects within industries. A second limitation is the use of proxies (such as expenditures on R& D and computers) for measuring technological change. One problem with the use of such proxies is that they constitute R&D inputs, rather than outputs (such as patents or the actual implementation of a new production process). Thus, the use of "indicators" limits the accuracy of technology measurement and precludes a precise analysis of timing effects.[1] A third problem is a lack of detailed information on labor force composition. Most datasets identify only two types of laborers: production and nonproduction workers.[2] The underlying problem is that firms are reluctant to provide detailed information on technology usage and workforce characteristics.

The purpose of this monograph is to address the effects of technological change using a new, rich source of firm-level data on technology usage and labor force composition. The empirical investigation is based on a comprehensive, firm-level survey of computer-integrated manufacturing systems (CIMS) usage among Long Island manufacturers. The survey was conducted by a group of professors at the State University of New York at Stony Brook under the direction of Professor Matthew Sobel, with financial support from the New York State Urban Development Corporation.[3]

The primary purpose of the survey was to document the extent of investment in CIMS, which are technologies that use computers to coordinate workers and machines across functional activities, such as production scheduling, procurement, product design, marketing, and distribution, and to identify any obstacles to additional investment. In this monograph, I call these technologies *advanced manufacturing technologies* (AMTs), which is the more commonly used term. This survey provides an ideal data set for exploring the antecedents and consequences of technology adoption, because it contains information on specific types of technologies, the year of implementation, detailed information on labor force composition before and after implementation, and relevant characteristics such as the age of the firm and its R&D expenditures.

It is important to note that technology is not a vague term in this study. In contrast to most existing studies of skill-biased technological change, I directly examine the labor market outcomes associated with the implementation of new manufacturing technologies. Specifically, I examine a well-defined set of 12 AMTs that firms have actually implemented on the factory floor. The companies reported the year of implementation, so I can construct pre- and post-adoption measures of labor composition and relative compensation. AMTs include a wide range of labor saving and quality-enhancing innovations, such as computer-aided design/computer-aided manufacturing (CAD/CAM) systems, computer numerically controlled (CNC) machines, just-in-time (JIT) inventory systems, flexible manufacturing systems (FMS), and robotics (ROB), which allow firms to design, produce, and market new products more effectively and improve manufacturing efficiency. We also have comprehensive information on human resource management strategies that accompany AMT adoption. These data constitute a rich source of information for examining the managerial and policy implications of skill-biased technological change. Based on the survey data, I construct a complete historical profile of each firm’s AMT usage and examine the resulting changes in labor force composition and relative compensation over a four-year period. These data allow me to include controls in the econometric model for the endogeneity of technology adoptions, whereas previous studies have generally assumed that technological change is exogenous. I view the implementation of a new technology as a two-stage process. In the first stage, the firm makes a decision to adopt a new advanced manufacturing technology. This leads to an adjustment of the labor force in the second stage.

I also explore whether changes in human resource management policies that enhance employee empowerment arise in the aftermath of technological change. This is crucial because these technologies not only affect labor composition, but also change the work environment for employees in all areas of the firm (i.e., manufacturing, engineering, product development, marketing, R&D, and administrative units). In part, this is because the technological changes promote integration of these functional activities.

Although the survey is quite comprehensive, it cannot completely capture the organization-wide impact of workplace changes that result from the implementation of new technologies. Thus, I also present four case studies of firms that completed the survey, based on 20 plant visits and interview with company officials and workers. These firms reflect a diverse set of industries and varied experiences with AMT implementation. The case studies highlight some barriers to additional investment in AMT, which suggest some policy responses that might enable firms to surmount these barriers.

Finally, I conduct a dissaggregated analysis across two broad classes of AMTs, linked and integrated. This is important because existing studies of skill-biased technological change do not explicitly consider the economic implications of heterogeneous technologies.[4] Specifically, I hypothesize that it is important to distinguish between linked AMTs and integrated AMTs. Linked technologies generally constitute the first generation (or phase) of AMT. Typically, they involve the informational linking of the design and manufacturing functions and establishment of quality and production control practices. Computer-aided design (CAD) is a widely used AMT. CAD eliminates most of the drudgery associated with engineering design work, enabling engineers to devote more attention to the creative and evaluative aspects of design. CAD is often "linked" with computer-aided manufacturing (CAM) or with computer-aided engineering (CAE).

Integrated technologies can be thought of as the second generation (or phase) of AMT, involving the integration of other vital components of the manufacturing enterprise such as the material handling and control system. While most linked AMTs are designed to enhance product quality and reliability, the chief purpose of integrated AMTs is to streamline efficiency. Specifically, integrated technologies remove obstacles between physical and organizational entities, reduce costs, and improve flexibility and responsiveness to customers and suppliers. A flexible manufacturing system (FMS) is an example of an integrated AMT that allows the user to respond rapidly to changes in product design and production needs, improves the utilization of machinery and floor space, and reduces work-in-process inventories.

A recent review article (Fine 1993) in the operations management literature theorizes that shifts in the workforce and relative compensation in favor of highly educated workers will be more pronounced for integrated than for linked AMTs. Also, human resource management studies suggest that the effects on certain aspects of employee empowerment will be different for linked and integrated technologies (Applebaum and Batt 1994; Batt and Applebaum 1995). To verify these hypotheses and thus, the importance of this distinction, I separately examine the employment and empowerment effects of technology adoption for these two groups of AMTs.

OVERVIEW AND MAJOR CONCLUSIONS

The remainder of this monograph is organized as follows. Chapter 2 presents a comprehensive review of the recent literature on the employment and wage effects of technological change. Both labor and productivity economists have addressed this subject using different methodological approaches and a wide range of datasets.

Chapter 3 contains an extensive description of the database and the survey methodology. First, the survey design and some relevant aspects of the business environment on Long Island are discussed. I present summary statistics for the Long Island sample and a discussion of the representativeness of the sample. Although the study focuses on one particular region, the findings have important implications for national technology policy. The chapter also discusses the two main hypotheses of the monograph. The first is the “non-neutrality” of technological change with respect to the composition of the labor force, and the second is the importance of organizational learning in the process of adopting a new technology. I also discuss some econometric issues relating to assessing the impact of technological change on labor composition and show how I address these issues in the empirical estimation.

Chapter 4 provides an in-depth explanation of the salient characteristics of the advanced manufacturing technologies; examples are provided for each AMT. I postulate that it is important to distinguish between linked and integrated AMTs because linked and integrated AMTs could have differential impacts on labor composition and other aspects of the work environment. One characteristic of the work environment that could change in the aftermath of technological change is the level of employee empowerment. In the final section of this chapter, I provide an operational definition of empowerment and hypothesize that AMT investment, especially linked AMTs, will lead to greater employee empowerment.

Chapter 5 begins with a summary of the set of hypotheses I have outlined in previous chapters and wish to test empirically. The chapter continues with the empirical results regarding the determinants and labor market outcomes of technology adoption, including its impact on employment, labor composition, and proxies for employee empowerment, and how these effects differ for linked and integrated AMTs.

In Chapter 6, I present the case studies of four Long Island manufacturers and evidence from our visits to 16 additional firms in the sample. This qualitative evidence elaborates on certain points that could not be addressed in the survey and the subsequent statistical analysis.

Conclusions and policy implications are discussed in Chapter 7. The following is a summary of the key findings:

1. Technological change is associated with downsizing and a shift in labor composition in favor of workers with higher levels of education.
2. The probability of technology adoption is uncorrelated with the age of the firm but is positively associated with firm size, R&D intensity, and previous technology adoptions.
3. A factor analysis confirms the validity of the distinction between linked and integrated AMTs
4. Recomposition in favor of more highly educated workers appears to be

most strongly associated with integrated AMTs. It is important to be mindful of these differential impacts when formulating technology policies.

5. New technologies lead to greater empowerment for workers, where empowerment is defined as training of existing personnel, changing job responsibilities, creating new jobs and career opportunities, and increasing the extent of employee control. I find that empowerment is more closely associated with linked, rather than integrated, AMTs.
6. The field interviews appear to confirm the statistical findings. In the firms I examined, AMTs (especially, integrated AMTs) were indeed associated with personnel reductions and skill upgrading.
7. The field interviews also revealed two major obstacles to additional investment in new technology: difficulties in quantifying the benefits from technological investments and the high cost of customizing software to fit company needs.

NOTES

1. An exception is a paper by Doms, Dunne, and Troske (1997), which explores timing issues based on confidential, plant-level, U.S. Census data with direct measures of technological change.
2. A notable exception is Lynch and Osterman (1989), who examined compositional effects of technological change for 10 occupational classes of workers.
3. The CIMS project was sponsored by the New York State Urban Development Corporation under the auspices of the Long Island Office of the New York State Department of Economic Development. I am deeply indebted to Professors Gerrit Wolf and Manny London, and especially to Professor Matthew Sobel, for providing me with these data.
4. Contrast this to the literature on the impact of new technology on total factor productivity, where it is common to conduct such a dissaggregated analysis. As discussed in Lichtenberg and Siegel (1991), researchers have reported the “returns” on various types of R&D investments, such as product vs. process innovation, basic research vs. applied R&D, or privately funded vs. publicly funded R&D.