DOCUMENT RESUME

ED 317 674 CE 054 090

AUTHOR	Flynn, Patricia M.
TITLE	Introducing New Technology into the Workplace: The Dynamics of Technological and Organizational Change. Background Paper No. 8a.
SPONS AGENCY	Department of Labor, Washington, DC. Commission on Workforce Quality and Labor Market Efficiency.
PUB DATE	Sep 89
CONTRACT	99-9-4780-75-035-04
NOTE	46p.; In "Investing in People: A Strategy to Address America's Workforce Crisis" (CE 054 080).
PUB TYPE	Information Analyses (070)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Adult Education; *Case Studies; *Corporate Education; Educational Needs; Education Work Relationship; *Employment Practices; Industrial Structure; *Job Skills; Labor Needs; *On the Job Training; *Organizational Change; Policy Formation; Public Policy; *Technological Advancement
IDENTIFIERS	Life Cycles

ABSTRACT

A human resource strategy to enable the effective integration of new technologies in the workplace must be comprehensive, flexible, and sensitive to the dynamics of technological and organizational change. However, information from macro-level studies provides little guidance for anticipating and planning for the adoption of new technologies, failing to forecast their effects on employment and being conducted at aggregation levels that are too high. Case studies, when systematically analyzed in a broader conceptual framework, can produce useful generalizations for decision making. A skill training life-cycle framework identifies patterns in training requirements across four phases (introduction, growth, maturity, and decline) in the nature of tasks, type of job skills, effects on job structure, and type of training provider. At the organizational level, management practices and labor-management agreements determine how and when technologies are used. One characteristic vital to successful adoption is the support of workers and managers for change. Although human resource adjustments and workplace restructuring occur primarily within firms, public policy can play a leadership role in (1) provision of skill development to prepare the work force; (2) programs to ease the adjustment of workers in transition; and (3) support for research and development of effective ways to integrate technological change. (108 references) (SK)

8a. INTRODUCING NEW TECHNOLOGY INTO THE WORKPLACE: THE DYNAMICS OF TECHNOLOGICAL AND ORGANIZATIONAL CHANGE

Patricia M. Flynn

Bentley College

This project was funded under Purchase Order No. 99-9-4780-75-035-04 from the U.S. Department of Labor, Commission on Workforce Quality and Labor Market Efficiency. Opinions stated in this document do not necessarily represent the official position or policy of the U.S. Department of Labor, Commission on Workforce Quality and Labor Market Efficiency.

8a. INTRODUCING NEW TECHNOLOGY INTO THE WORKPLACE: THE DYNAMICS OF TECHNOLOGICAL AND ORGANIZATIONAL CHANGE

Patricia M. Flynn
Bentley College

INTRODUCTION

There is growing evidence that the United States is losing ground in terms of technological competitiveness relative to several other industrialized nations (Cyert and Mowery, 1987; Mowery, 1988; Dertouzos, Lester and Solow, 1989). This result is attributed at least in part to the failure of U.S. firms to effectively integrate new technologies at the workplace.

A vast literature exists on the impacts of technological change on employment, skill requirements, jobs and workers. In addition, technological change has long been known to be a source of both positive and negative disruption in the labor market. Yet, for a variety of reasons, including inaccurate forecasts and a myriad of ambiguous and contradictory research findings, decision makers have not been given much guidance in anticipating and planning for the adoption of new technologies.

This paper summarizes the research evidence, from aggregate and micro-level studies, on the impacts of technological change on employment, skill requirements, jobs and workers. In addition to macroeconomic conditions, it identifies and discusses a variety of technical and organizational factors that influence the outcomes of technological change. The paper highlights common patterns in skill and training requirements, the mix of institutional providers or job-related skills, and in labor markets as technologies mature. It also discusses a range of organizational factors found to affect the ways in which tasks are allocated and distributed among workers. These data suggest that the impacts of technological changes are not random and that actions can be taken to facilitate the adoption of new technologies at the workplace. The paper concludes with implications for public sector policies in the areas of human resource development to promote the beneficial outcomes of technological change, and to mitigate its negative impacts.

TECHNOLOGICAL CHANGE AND EMPLOYMENT

Macro-level studies indicate that technological change in the United States has traditionally been associated with employment growth (National Commission on Technology, Automation and Economic Progress, 1966; Office of Technology Assessment [OTA], 1985; Cyert and Mowery, 1987; OTA, 1988). Analyses of aggregate data demonstrate that technological changes have <u>not</u> historically generated widespread unemployment, resulted in significant changes in skill requirements, nor contributed significantly to job loss. Instead, while often labor-saving in its immediate impact, technological change has generated productivity gains and indirect employment effects that in the long-run more than compensated for initial job losses.

It has long been known that a strong national economy eases the integration of technological change at the workplace. High labor demand provides alternative employment opportunities, it also fosters voluntary quits and reduces the amount of adjustment required within adopting firms. Economic growth has been credited with easing the integration of technological change during the unfounded "automation scare" of the 1950s (National Commission on Technology, Automation and Economic Progress, 1966). More recently, relatively strong growth in the non-manufacturing sectors has facilitated the integration of office automation (OTA, 1985; Hartman, Kraut, and Tilly, 1986).

With respect to skill levels, aggregate studies suggest that the effects of technological change have been largely neutral (Spenner, 1985, 1988).[1] In other words, empirical evidence supports neither claims of significant upgrading nor claims of significant downgrading in overall skill requirements as a result of technological change.

Macro-level studies also suggest that adoptions of new technologies play a relatively minor role in permanent job loss in the United States. On the contrary, there is growing evidence that the failure of U.S. firms to remain technologically competitive contributes more to worker displacement and job loss than does the adoption of new technologies (Flamm, 1988; Mowery, 1986; Cyert and Mowery, 1987). A 1986 U.S. General Accounting Office (GAO) survey of approximately 400 establishments, for example, cites the most significant cause of plant closings and mass permanent layoffs to be reduced product demand, followed by increased competition, high labor costs, and the high value of the dollar (U.S. GAO, 1986). Facility obsolescence and production automation, factors more directly associated with technological adoptions, were cited by relatively few respondents as key causes for workers being displaced from the firm.

In addition, despite anecdotal information suggesting the contrary, aggregate indicators show that, on average, the rates of technological innovation and diffusion have not risen considerably during the past two decades (Mansfield, 1968; Rosenberg, 1976; Hunt and Hunt, 1983; Cyert and Mowery, 1987). Studies on technological diffusion also indicate that the United States lags several of its international competitors in terms of rates of adoption and levels of utilization of new technologies, such as advanced machine tools and robotics (Nasbeth and Ray, 1974; Ray, 1984; Technology Management Center, 1985; Mowery, 1988).

Limitations of Aggregate Studies

While extensive in scope, aggregate-level studies provide little guidance for anticipating and planning for the adoption of new technologies. Macro-level studies have, for instance, failed in their ability to forecast the effects of technological change on employment. In addition, these studies are conducted at such high levels of aggregation that they mask the actual effects of technological changes at the workplace.

Employment Forecasts. Forecasts of the impact of new technologies on employment have traditionally been incorrect (Cyert and Mowery, 1987; OTA, 1985). The disruptive impacts of technological adoptions have been both underestimated and overestimated. It appears, however, that actual outcomes generally fall short of oft-cited dire predictions regarding technology-induced unemployment and job loss (Buchanan and Boddy, 1983; OTA, 1985; Cyert and Mowery, 1988).

The indirect and longer-term effects of technological changes on labor markets have proven difficult to model. Even input-output analyses which incorporate interactions among industries, have been shown deficient in reliably estimating how technological changes will influence employment (Leontief and Duchin, 1986; Cyert and Mowery, 1987). Among the complicating factors has been an inability to forecast rates of diffusion of particular technologies, a key variable in determining the employment impacts of such change (Mansfield, 1968; Rosenberg, 1976; OTA, 1985; Cyert and Mowery, 1987). In addition, technological innovations are difficult to accurately foresee, as are the size and nature of new markets (NSF, 1983; Rosenberg, 1982).

These restrictions have severely limited the use of employment forecasts for signalling skill and occupational needs associated with new technologies. In fact, a recent evaluation by the Office of Technology Assessment (OTA) of the reliability of macro-level forecasts for identifying future changes in employment due to technological change concludes that their chief value is to "force attention to the many complex and uncertain ties" between these variables (OTA, 1985, p. 45).

Micro-level phenomena. The problem with using industry or national data to study the impacts of technological change has two dimensions. First, the skill and job impacts of technological change are fundamentally plant-level phenomena, the scope and diversity of which are hidden in aggregate data (van Auken, 1959; Doeringer and Piore, 1985). Second, data which combine technologies and products at different stages of their development, fail to accurately portray the fundamental processes of change (Nelson and Winter, 1974; Krumme and

Hayter, 1975; Nelson and Norman, 1977; Ford and Ryan, 1981; Malecki, 1983).

The most relevant and comprehensive data on the impacts of technological change are found in detailed case studies. Enterprise-level studies indicate how and which skills, jobs and workers are affected when technologies are adopted. In addition, as the mix of employers and production activities in an area influences the extent to which technological change results in layoffs and unemployment, micro-level analyses of firms and labor markets are the key to unraveling how technological change will affect local economies (Malecki, 1986; Browne, 1983; Flynn, 1984; Rosenfeld, Malizia, and Dugan, 1988).

Case study data show considerably more volatility in employment and skill requirements due to technological change than suggested by aggregate studies. In some instances technological change has been found to increase skill requirements (Attewell and Rule, 1984; Adler, 1983; Kelley and Brooks, 1988). In contrast, technological change has been shown to simplify or eliminate the need for various skills (Bright, 1958; Braverman, 1974; Kraft, 1977; Greenbaum, 1979; Levin and Rumberger, 1983).

The average level of skill has been shown to increase after the introduction of technological change in some firms, but remains constant or decreases in others. Similarly, net employment at the firm has been shown, alternatively, to increase, decrease or remain stable after technological change.

With respect to workers, technological change has been found beneficial by generating new jobs and advancement opportunities.

However, other workers have suffered from skill obsolescence, truncated job ladders or layoffs. Technological change has resulted in significantly diverse impacts on local communities as well, resulting in new jobs and rapid economic growth in some areas, but plant closings and unemployment in others.

The conventional wisdom is to interpret this diversity as a sign that anything can and will happen -- that "uncertainty prevails" (Spenner, 1985, 1988). This view offers little hope of unraveling the complexities of technological change at the workplace, or of developing policies to minimize the negative aspects of such change.

However, while case studies are often seen as "special cases" whose findings cannot be generalized, recent work suggests that when systematically analyzed in a broader conceptual framework, case materials can lead to generalizations useful to anticipating and planning for technological change (Flynn, 1988). In addition, while the use of micro-level studies limits quantitative assessments and forecasts of the effects of technological change, such as the overall extent of upgrading, layoffs, and the like, this level of disaggregation permits an in-depth view and understanding of the processes of technological change not otherwise possible.

Case studies confirm the importance, noted earlier, of an expanding economy in easing adjustments to technological change. They also show, however, that a booming economy does not ensure against layoffs, unemployment and the downgrading of employees when technologies are adopted. More importantly, micro-level analyses highlight a series of technical and organizational factors that play key roles in determining the impacts of technological change.

TECHNICAL CONSIDERATIONS[2]

The characteristics and complexity of a technology affect the skills required to perform various tasks. These, in turn, influence training needs, occupational labor markets, and hiring and staffing patterns of employers.

Technologies, like products and production processes, exhibit patterns of growth and development, characterized by sequential "life-cycle" phases of introduction, rapid growth, diminished growth, and stability or decline (Ford and Ryan, 1981; Foster, 1982; Shanklin and Ryans, 1984). Introduced slowly at first, technologies, such as a numerical control technology, a micro-electronics technology, or a data-processing technology, become more widely adopted as intensive R&D efforts lead to improved performance; eventually reach a peak; and are often replaced by a new, superior technology.

Technological evolution can signal impending changes in products and production processes (Abernathy and Utterback, 1978; Hayes and Wheelwright, 1979a, 1979b). As a technology matures, for instance, uncertainty about its capabilities and limitations declines, and products and processes can become more standardized. Rapid product innovation accompanies the earliest phases of a technology's development, whereas process innovation peaks later in the technology's cycle as product design stabilizes. Innovations in the later stages of development of a technology, when they occur at all, are primarily minor improvements in equipment rather than major fundamental changes in either product or production process.

Extension of the life-cycle framework to human resource issues highlights a skill-training life cycle (STLC) which identifies common patterns in skill and training requirements, in the mix of institutional providers of job-related skills, and in occupations as technologies evolve (Flynn, 1988). [See Chart 1.]

Skill and Training Requirements

Empirical evidence demonstrates that skill requirements and training needs change over the development of a technology. The early stages of a technology's development are relatively skill- and labor-intensive (Hoover, 1948; Utterback and Abernathy, 1975; Nelson and Norman, 1977; Markusen, 1984; Bartel and Lichtenberg, 1987). Engineers and scientists are needed for product development, the construction of pilot models, and the implementation of design changes. Equipment used in relatively early stages of a technology's development tends to be general-purpose in nature, requiring skilled operatives able to adjust to frequent changes and to adapt the equipment to the individual company's needs.

As technologies mature, standardization and the expanded use and complexity of equipment foster a greater division of labor and the subdivision of multifaceted tasks into more narrowly defined assignments (Bright, 1958; Enos, 1962; Utterback and Abernathy, 1975; Nelson and Phelps, 1966; Nelson and Norman, 1977). Tasks that have been simplified, i.e., "deskilled," can be performed with less skill,

Chart 1

The Skill-Training Life Cycle [STLC]

	I Introduction: New and Emerging Skills	II Growth: Increased Demand for Skills	III Maturity: Tapering off of Growth for Skills	IV Decline: Skill Obsolescence
Nature of Tasks	Complex	Increasingly routinized	Increasingly routinized	Narrowly defined
Type of Job Skills	Firm-specific	Increasingly general	General; transferable	General; transferable
Effects on Job Structure	Job enlargement; New positions created when a significant change in skill needs occurs	Emergence of new occupations	Relatively rigid job hierarchy; occupations associated with formal education and related work experience requirements	Elimination of occupations
Skill Training Provider	Employer or equipment manufacturer	Market-sensitive schools and colleges	Schools and colleges, more generally	Declining number of schools and colleges; some skills provided by employer

Adapted from: Patricia M. Flynn, Facilitating Technological Change: The Human Resource Challenge, (New York: Ballinger Publishing, 1988): 19.

experience and independent decision-making on the part of workers (Bright, 1958; Braverman, 1974; Kraft, 1977; Greenbaum, 1979). The tasks of semiskilled operatives, for example, often shift to monitoring and control of the equipment. In addition, product assembly can be done by low-skilled and unskilled workers who concentrate on a limited number of narrowly-defined tasks. Once embodied in the workforce, skills are transferred to the production equipment.

Tasks across the entire skill spectrum (e.g., professional, technical, craft, maintenance and repair, clerical, operative and laborer) have been found vulnerable to the deskilling process (Bright, 1958; Attewell and Rule, 1984; Flynn, 1988). In general, the skill level of the tasks being simplified is inversely related to the degree of standardization of the products and the production processes. When equipment is initially introduced into small-batch production, for example, high-skill handicraft work such as that of machinists and welders is simplified or eliminated. The evolution of machine languages, as well as the proliferation of software packages and user-friendly computer programs, contribute to the increasing standardization and simplification of relatively high-skill programming tasks. The automation of routinized assembly functions, in contrast, eliminates relatively unskilled tasks.

Shifting Institutional Responsibilities for Training

The nature of training needs and institutional responsibilities regarding the provision of job-related skills also change as a technology matures. When a technology newly emerges, the firm-specific nature of skills required and the lack of workers with these skills mean that employers must provide their own training or rely on the equipment manufacturer to do so.

After a technology becomes more widely adopted and equipment standardized, skills that were once "firm-specific" become "general" skills transferable among employers (Becker, 1964). As with products, increased demand and standardization of skills permit their "production" on a larger scale and at locations away from the R&D sites. Employers are less able to capture the return on investments in general, as opposed to firm-specific, skills, and generally prefer that such training be provided in the schools, where the government or individual students will pay for it. Moreover, as demand for such skills grows, it is easier to standardize the training and provide it in the schools. Together, these two forces, encourage the shift of skill development from the workplace to the formal educational system as technologies mature. Computer programming, keypunching, word processing training, and the set-up and operation of numerical control equipment are classic examples of this transfer.

There is ample evidence that the educational system responds to labor market changes as technologies evolve (Somers, 1968; Mangum, 1971; Freeman, 1971; Doeringer and Flynn, 1982; Taylor, Rosen and Pratzner, 1983; Grubb, 1984). Such responsiveness occurs, however, with various lag structures and differs significantly by occupation and by type of educational institution. As the provision of job skills shifts from the workplace to the educational system, the skills are initially offered by schools and colleges oriented toward meeting the needs of employers (Wilms, 1981; Flynn, .981; Taylor, Rosen and Pratzner, 1983). As demands for skills mature, training becomes more widely diffused among education and training institutions.

As old technologies become obsolete, training focuses on replacement needs and on the retraining of workers for other fields. A limited market for skills and declining student enrollments result in the termination of occupational training programs in these fields. The responsibility for training to fill relatively short-term, skilled replacement needs can revert back to the firm.

Technology, Occupations and Careers

Case study evidence also reflects shifting occupational demands as skills become standardized and transferable among firms. In contrast to their early-adopting counterparts, for example, later adopters of data processing and microelectronic technologies cite demands for relatively well-defined computer-related occupations, such as computer programmers, computer technicians and systems analysts. Similarly, case studies show that with adoptions of relatively mature technologies, technicians and operatives perform maintenance and repair work, which in earlier stages of the technology's development were the responsibility of engineers.

Empirical evidence also suggests that occupational changes over the development path of a technology can trigger a growing disparity between those who lose and those who gain from technological change at the workplace. More specifically, with the adoption of newly emerging technologies, job enlargement, the relatively high degree of uncertainty, and the lack of appropriately trained workers favors selection and retraining of current employees. As technologies mature, the emergence of occupations and the growing supply of appropriately skilled workers, allows employers to fill their technology-induced needs with workers who have acquired their skills (which are now transferable) at other firms or in schools and colleges. As occupations become more clearly delineated they often become associated with particular educational credentials and previous related-work experience -- a trend that further fosters discontinuous job ladders and barriers to advancement within firms as technologies mature (Collins, 1979; Menzies, 1981).

ORGANIZATIONAL FACTORS

While trends in skill requirements, training needs and occupations as technologies develop alter the larger environment in which firms operate, organizational factors, such as management practices and labor-management agreements, determine how and when technologies are used (Child, 1972, 1984; Wilkinson, 1983; Buchanan and Boddy, 1983; Clark _et al_., 1988). Recent studies confirm that similar technologies adopted by firms at the same point in time can generate dissimilar impacts on jobs and workers (Kelley, 1986; Jaikumar, 1986; Spenner, 1988; Kelley and Brooks, 1988).

A variety of mechanisms, including retraining, the recruitment of new workers, transfers, liberalized retirement plans, hiring freezes, the use of temporary workers, and layoffs, have been used by employers to integrate technological change at the workplace (van Auken, 1959; Doeringer and Piore, 1985). To date, no unifying model or approach has been devised to systematically assess how conditions within the firm influence the impact of technological changes on jobs and workers. The development of such a model is beyond the scope of this paper. Instead, the sections that follow identify and briefly discuss several organizational factors found in micro-level studies to be instrumental in shaping the outcomes of technological change.

Management Practices and Business Decision Making

Management is usually responsible for the timing and selection of technologies to be incorporated at the workplace (Bright, 1958; Roberts, 1984; Katz, 1985). Case studies suggest that employers often plan technological changes to coincide with business expansions, when greater opportunities for internal promotions and transfers exist. Hiring freezes and the use of temporary workers in the period prior to the adoption have also been used to minimize the amount of disruption among regular employees. In addition, attractive voluntary retirement and severance pay packages have been used to reduce the pool of workers seeking reemployment. As a result of these and other internal adjustment measures, case study evidence suggests that most workers whose jobs have been eliminated by technological have been reassigned within the firm (Flynn, 1988).

Cases proving the exception to this conclusion -- that were characterized by massive layoffs and unemployment -- were those involving technological changes either (1) in firms in "declining industries," or (2) accompanied by a geographical relocation of production. In cases of firms in industries experiencing a long-term decline in output, such as in textiles, apparel and coal mining, transfer opportunities were few, if any. Thus, many of the workers whose jobs were eliminated by technological changes were often laid off. The second source of considerable layoffs involved intra-firm plant consolidations or the relocation of a plant geographically far from the initial work site. In these instances, lesser efficient plants were usually closed, in favor of technologically more sophisticated work sites. Workers displaced in the latter plant closings were generally offered jobs at the new work site, however, they often refused to accept a long commute or a residential move.

The timing of the adoption relative to the "age" of the technology also affects the nature of the adjustment at the workplace. As indicated above, the stage of development of the technology influences not only the nature of new skill needs but also the availability of appropriately trained workers. There are, however, a range of options available to managers in terms of ways in which new tasks can be integrated into the job structure. The deskilling of tasks need not result in deskilled jobs or downgraded workers. Tasks that have been simplified, or deskilled, can often be regrouped to generate jobs requiring similar or more advanced skills than prior to the change, rather than allowing jobs to become more narrow, easier and less satisfying. The use of job rotation and work teams, for instance, results in different skill needs of workers than does the decision to assign a smaller set of specific tasks to individual workers (Hirschhorn, 1984; Barley, 1986; Kelley, 1986; Jaikumar, 1986).

Organizational and managerial changes are often deemed necessary to fully exploit the potential productivity gains of new technologies (National Research Council (NRC), 1986; Cyert and Mowery, 1986). Managers have been criticized, however, for failure to: (1) effectively evaluate both the short-term and long-term costs and benefits of technological adoptions, (2) develop organizational structures that can fully exploit the productivity gains associated with new technologies, and (3) establish fruitful, cooperative relationships with workers (Cyert and Mowery, 1987). A variety of factors contribute to these results, including outdated cost accounting practices, antiquated organizational structures, and adversarial labor-management relationships (Hayes and Abernathy, 1980; Starr and Biloski, 1985; Brimson, 1986; Johnson and Kaplan, 1987; Drucker, 1988; Hayes and Jaikumar, 1988).

Labor Management Relations

Labor-management relations can significantly influence an organization's ability to adjust to technological changes. Changes in traditional job classifications and pay structures, for instance, often accompany the adoption of new technologies (NRC, 1986; OTA, 1985, 1988; Osterman, 1988). While collective bargaining agreements often do not indicate specifically how new technologies are to be introduced at the workplace, various clauses do address the staffing of new positions, the restructuring of jobs, criteria for workers selected for layoffs, changes in compensation systems, and so forth.

Case study evidence shows, for example, that in both offices and factories, current employees were usually retrained and assigned to the highly-skilled jobs created with the adoption of newly emerging technologies. The pool from which these workers were drawn, however, often differed. In factories, negotiated contract clauses on job security and seniority tended to weight the selection decision in favor of those workers who had been displaced by the technology. In contrast, when relatively high-skill positions were created by office automation, the clerical workers most directly affected by the changes tended to be laterally transferred rather than assigned to the new jobs. Instead, usually based on aptitude test results or management interviews and references, workers from other departments in the firm were generally transferred into the better positions. These workers were subsequently provided the required skills in company-sponsored training programs.

Facing growing displacement of their workers in recent years due to plant closings and various technological changes, several unions have accepted concessions in work rules and more flexible job assignments and work procedures, in exchange for a greater commitment on the part of employers to support employment security measures (Cappelli, 1983; Katz, 1985; Kassalow, 1987; Casner-Lotto, 1989). The UAW-GM contract, for example, provides the union advance notice of the adoption of new technologies and the creation of a joint union-management committee to handle layoffs related to technological change. Workers whose jobs are eliminated by technological change are guaranteed employment at full pay and fringe benefits for as long as they are willing to retrain.

Unions have also begun to negotiate educational and retraining services for displaced, as well as active, workers (Kassalow, 1987; Casner-Lotto, 1989). The Ford and General Motors contracts with the United Automobile Workers (UAW), and the AT&T agreement with the Communications Workers of America (CWA) provide for training, counseling and relocation services to workers displaced from the firm. In addition, union-management agreements have resulted in a broadening of the scope of courses eligible under tuition remission programs, to include, for example, the provision of job-related skills useful for employment outside the firm, and of more general personal development courses such as those in computer literacy, written and oral communication techniques, and goal setting and motivation.

While still relatively few in number and too new to evaluate, these innovative agreements demonstrate the potential for union-management cooperation to promote technological change at the workplace through measures designed to enhance flexibility and employment security.

Firm Size

Case studies on technological change generally pertain to relatively large firms. Empirical evidence is scant on how jobs and workers across firm sizes fare when technological adoptions occur. More generally, limited training budgets and relatively small demands for particular skills, make small and medium-sized firms more dependent on external sources -- such as schools and colleges, government training programs and other firms -- to meet their skill requirements. Compared to larger firms that are often able both to develop formal training programs and to offer higher wages and greater promotion opportunities, it would appear that smaller firms would be at a disadvantage in training and in retaining trained workers in areas in which skills are scarce as new technologies develop.

With respect to the adoption process itself, small firms are said to be at a disadvantage due to relatively large costs (Kamian and Swartz, 1982; NSF, 1983). In addition, the batch size of relatively small employers is often too small to effectively exploit the benefits of new technologies (Rees, Briggs and Hicks, 1983; Kelley and Brooks, 1988). Recent reports on flexible manufacturing systems (FMS) suggest that small firms may be at less of a disadvantage with these programmable technologies than with earlier technologies that primarily benefitted the large volume, mass producer (Piore and Sabel, 1984; Nemeta and Fry, 1988). There is little empirical evidence to confirm or refute this hypothesis. At least one study, however, suggests that large, diversified firms, are the greatest beneficiaries of these new technologies, not small employers (Kelley and Brooks, 1988).

Worker and Manager Support

While case studies highlight a variety of conditions (e.g., job security, good communication of expected outcomes, extensive planning, a sufficiently long period between the decision and the installation of the technology, and an adequate retraining program) that facilitate the adoption of new technologies, one characteristic stands out as vital to the successful adoptions: the support of workers and managers for the change. Workers and supervisors supportive of a new technology, for instance, are found to excuse or overlook potentially damaging problems related to the change, such as the failure of management to adequately plan, communicate or retrain workers. In contrast, empirical evidence shows that when workers or supervisors are resistant to the technological change, even relatively minor modifications in skill requirements, job content, or training, become major stumbling blocks. The failure to garner worker or managerial support thwarts technological change even in case studies characterized by extensive planning, workers sympathetic to the reasons for change, and on-going communication among supervisors and other employees.

Consistent with the management and organizational behavior literature more generally, case studies on technological change suggest that perceived changes in job security or career advancement opportunities generate more worker resistance than does the technology itself (Lawrence, 1969; Buchanan and Boddy, 1983). More specifically, firms with stated policies of employment security or 'no layoffs or downgrading due to technological change' rarely encountered significant resistance to adoptions of new technologies.

CONCLUSION

This review of the literature demonstrates that a human resource strategy to facilitate the effective integration of new technologies at the workplace must be comprehensive yet flexible, and be sensitive to the dynamics of technological and organizational change.

A Comprehensive Strategy

The effects of technological change are pervasive: they influence local as well as international markets; high-technology as well as mature industrial sectors; economically depressed as well as 'boomtown' economies; and highly-skilled as well as low-skilled and unskilled workers. Human resource strategies to promote technological competitiveness require a comprehensive approach, rather than one targeted to a particular set of skills, workers or industries.

The life cycle framework highlights the need for policies for both the "upside" and "downside" of technological change. The failure to meet the demands for new, highly skilled labor created by the adoption of new technologies, can hamper the diffusion of new technologies, restrict the productivity of workers and of firms, and undermine industrial competitiveness and economic growth. Failure to minimize the negative impacts of technological change, as jobs are simplified or eliminated can further constrain technological progress.

The nature and extent of human resource adjustments generated by technological changes will vary over the business cycle, as will the extent to which adjustments spill beyond firms into the labor market more generally. Even in prosperous times, however, technological change generates a considerable amount of structural change which disrupts jobs and workers. New training, retraining and other adjustment mechanisms are needed when the economy is strong as well as when it is weak.

The Need for Flexibility

The diversity of impacts of technological change, suggests that while comprehensive, strategies must also provide the flexibility to accommodate a wide range of needs of individual workers, firms and communities. Workers will vary in their needs for job-related skills, basic skills, relocation assistance, information on alternative jobs, income support, and so forth. The evolving nature of technological change also emphasizes the need for firms to be able to adapt to skill and occupational shifts over time. Moreover, the ways in which a community can best integrate technological change depends on its employment base, and its relative cost and resource advantages (Malecki, 1983; Browne, 1983; Flynn, 1984). The attraction of new and emerging "high technology" businesses has been shown, for instance, to be an effective development tool in economically depressed areas. (Flynn, 1984; Oakey, 1984; Malecki, 1986). However, "high technology" employment is not sufficiently large to rescue all such communities (Riche, Hecker and Burgan, 1984. The key to economic renewal for many communities lies in the integration of new technologies into more traditional industries to help them become more competitive (Browne, 1983; Sabel, et al.,)

Technical and Organizational Influences

Understanding the dynamics of technical and organizational change will ease the task of developing effective policies to promote the technological adoptions at the workplace.

When viewed in the life-cycle framework, in which technologies are seen as dynamic phenomena whose skill and training requirements change as they evolve, empirical evidence sheds new light on a variety of recurring issues associated with technological change. From this perspective, the data demonstrate that, while complex, the impacts of technological change are not random. Furthermore, the common patterns and trends that are identified help to reconcile many of the inconsistencies found in previous research.[3]

In the life cycle perspective, empirical evidence suggests that the uncertainties of adopting new technologies are preferable to the known outcomes of failing to remain technologically competitive. Adoptions of technologies while in their earlier phases of development appear to be associated primarily with the positive impacts of technological change. In contrast, the preponderance of negative impacts appear related to adoptions of relatively mature technologies or to the failure of firms to adopt at all.

The adoption of emerging new technologies, for example, offers a relatively wide range of upgrading and job enlargement possibilities at the workplace. In contrast, truncated job ladders and the diminished advancement opportunities are found primarily in cases of adoptions of relatively mature technologies. In addition, mass layoffs and widespread unemployment that accompanied technological changes tend to occur in firms with declining product demand or more generally those in declining industries that offer little opportunity for alternative employment.

The life cycle framework does not, of course, eliminate uncertainty. Consistent with life cycle models or products and technologies, a variety of skill development paths are possible, with their timing and shape a function of levels of uncertainty, standardization and demand (Dhalla and Yuspeh, 1976; Wasson, 1978).[4] Skill-training life cycle (STLC) patterns are, therefore, expected to differ depending on a series of factors including the nature of the "parent" technology, the complexity of skill needs generated, and the rate of diffusion of the technology. The life cycle framework, however, provides a tool for managers, in both the private and public sectors, for assessing how these technical patterns will affect a particular worksite or community.[5]

IMPLICATIONS FOR PUBLIC POLICY

There is a growing body of empirical evidence suggesting that U.S. firms are increasingly losing ground in terms of technological competitiveness (Mowery and Cyert, 1987, 1988; Dertouzos, Lester, and Solow, 1989). Moreover, in contrast, to the unfounded "automation scare" of the 1950s, the United States is not enjoying the economic growth that eased the integration of technological changes during that period. These trends forebode greater likelihood of the negative ramifications of technological change (e.g., mass permanent job loss and unemployment) in the United States, and a diminishing share of the positive impacts (e.g., productivity gains, employment growth, expanding advancement opportunities) associated with such change.

Human resource adjustments to particular technological changes (e.g., training for emerging new technologies, retraining and reassignment of workers whose jobs have been eliminated) occur primarily within firms. However, as highlighted by the life-cycle framework in general and the STLC in particular, there are circumstances when the preparation for, and adjustment to, technological change does not take place at the workplace. The public sector should play a leadership role in these areas, which fall into three categories: (1) skill development to prepare the workforce for technological change; (2) programs to ease the transition of technologically displaced workers caught; and (3) support of research and dissemination of findings on technological competitiveness.

Preparing the Workforce for Technological Change

The dynamic nature of production life cycles and technological change highlights the need for workers who are able to adjust to skill and job shifts over time, and who are capable of absorbing job-related skills provided at the workplace (U.S. Dept. of Labor, *et al.*, 1988; Carnevale, 1989). The education and training system should provide labor market entrants with strong basic skills, (e.g., reading, written and oral communication skills, computational skills, and problem solving skills) and should provide access to basic skill development throughout each individual's working life.

In addition, the education and training system should also seek to prevent major skill shortages and eliminate bottlenecks that would otherwise constrain economic progress and technological advance. Quantitatively, the demands for new, highly skilled labor created by the adoption of new technologies appear small quantitatively compared to total employment needs. The failure to meet these needs, however, can hamper productivity gains and the introduction of new technologies at the workplace.

Firms provide workers with new skills as they initially arise. As skills become more generalized and transferable among employers, these skills can and should be transferred to other components of the education and training system.

Funding for small-scale, innovative, experimental programs facilitate the transfer of new and emerging skills training to the schools (Flynn, 1988). Strong program monitoring and evaluation, and extensive dissemination of the results, helps maximize the spillover benefits from the initial "venture capital". The federal government is a logical candidate to sponsor these experimental programs, in that it can coordinate them nationally, minimize duplication, and provide for widespread dissemination of the findings. In the absence of federal assistance, states should take the initiative in funding experimental programs or in developing mechanisms that encourage a flow of private sector funds for this purpose. State-wide proposal competitions, as opposed to the distribution of these monies by formula, are recommended in the allocation of these limited funds.

Public policy needs to be sensitive to differing time frames between educators and employers, and guard against being so "labor market responsive" as to undermine long-term economic growth and the ability of workers to adjust to structural changes over time. The changing role of institutional providers of skills as technologies evolve, however, highlights the need for on-going communication and cooperation among businesses and schools. For instance, employer input, via participation on advisory committees for various occupational education programs or through cooperative education programs can signal to educators trends in emerging labor market needs, the transferability of skills among workplaces, and skill obsolescence.

In recent years public policy has tried to move in directions that favor a greater understanding of how changing skill needs of workers and employers can be better integrated. For example, the Perkins Vocational Education Act and the Jobs Training Partnership Act (JTPA) have more actively promoted industry-school partnerships and public-private cooperation and coordination.

Employment and training policies in the United States have traditionally focused on schools as the primary source of job skills, while other important sources of skill development have received relatively little attention. The life-cycle framework suggests the need to more fully integrate non-school providers of job-related skills, such as union apprenticeship programs, the military, government training programs, and firms into employment and training programs.

Easing the Adjustment of Workers in Transition

Skill obsolescence, plant closings and worker displacement are seen, in the life-cycle framework, as "natural" consequences of technological progress. Rather than trying to prevent these events, public policies should be geared toward integrating change and facilitating the readjustment of workers caught in the transition.

The bulk of the retraining that occurs in response to deskilling and skill obsolescence as technologies mature, takes place at the workplace. Mass permanent layoffs, plant closings, and plant relocations, however, impede the process whereby most workers acquire skills for alternative employment.

Policies for displaced workers in the past, such as Title III of JTPA, have emphasized rapid redeployment of workers in new jobs. Such policies have failed to provide much opportunity for workers to acquire or strengthen their basic skills (OTA, 1986; Cyert and Mowery, 1987). In addition, while existing unemployment compensation policies provide income support for workers temporarily laid off, they do not deal effectively with the problems of long-term displacement. In many states workers undertaking retraining are ineligible for unemployment compensation.

Experience suggests that the importance of employment security should not be underestimated in terms of its impact on worker support for the adoption of new technologies (Roberts, 1984; Gutchess, 1985; NRC, 1986; Liker, Roitman and Roskies, 1987; Osterman, 1988). Public policy cannot insure employment security. It can, however, seek to provide a better network of support services to ease workers in transition than has been available in the past. Health insurance and pension plan packages that accompany the worker to alternative employment, for example, will indirectly facilitate technological changes at the workplace.

Experience also demonstrates the benefits to workers of advanced notice of permanent job loss, the provision of retraining and reemployment services prior to layoff, and the importance of income support during retraining (OTA, 1986; Cyert and Mowery, 1987). Public policies for displaced workers have been moving in these directions over the past year. The Worker Adjustment and Retraining Notification Act (WARN) of 1988, for example, mandating 60-day employer notice to workers prior to large-scale layoffs, will provide considerably more time than public officials have usually received to implement adjustment programs for workers displaced from their firms. Recent provisions in the Economic Dislocation and Worker Adjustment Assistance Programs (EDWAA) in the Omnibus Trade and Competitiveness Act (OTCA) of 1988 which amends Title III of JTPA provides for rapid response systems to assist workers and communities undergoing major layoffs. Amendments to the Trade Adjustment Act (TAA) also contained in OTCA expand eligibility, require participation in training and increased cooperation with other training and employment programs.

The effects of these changes need to be documented and evaluated. Funding levels raise questions about the potential quantitative impacts these changes can bring about. Moveover, implementation issues remain. For example, while stipends to workers in extended training or education programs were permitted under Title III of JTPA, they were seldom provided (OTA, 1986). Relocation assistance funds also have been found relatively underutilized in the past (OTA, 1986).

Lastly, with respect to economic development, experience confirms that "company towns" and areas in which a substantial share of employment is tied to one or two product lines or to a group of firms with products and technologies in similar phases of development are especially vulnerable to the negative impacts of technological change (Chinitz, 1960; Malecki, 1983; Flynn, 1988). Common sense suggests a policy of industrial diversity, however, market forces can generate the opposite result. The success of a booming, dominant industry, for example, can "crowd out" alternative employment and accelerate the departure of traditional manufacturing from an area.

By understanding firms and jobs that make up the local employment base, and the influence economic, technical and organizational factors have on the impacts of technological change, state and local planners can anticipate and plan for major structural changes before being faced with large-scale layoffs and plant closings.

Research and Dissemination

In spite of an extensive literature on the topic of technological change, critical gaps remain in our understanding of how to foster technological competitiveness among U.S. firms. The public sector should assume the responsibility for widely disseminating research findings and models of "what works" and "what doesn't work" in integrating technological change. The public sector should also take a leadership role in seeking to procure the necessary data, as well as its unbiased analysis, to provide substantive, analytical research in areas dominated by anecdotal evidence or untested hypotheses. For instance, while it is generally assumed that product life cycles are getting shorter -- a trend that suggests that STLCs will accelerate, hastening skill obsolescence -- there is little empirical evidence to either support or refute this premise (Rink and Swan, 1979; Davidson, 1980; Mansfield and Romeo, 1980; Qualls, Olshavsky and Michaels, 1981).

Samples of other potential research topics that emerge from this paper include:

- The feasibility and characteristics of joint ventures among small firms or partnership arrangements involving small and large firms that facilitate technological adoptions.

- Development of a model for systematically assessing the impacts of organizational factors on the impacts of technological change.

- Relationships and interaction among economic, technical and organizational factors affecting the impacts of technological change.

- The role various factors, including skill shortages and labor costs, play in the relatively slow adoption of new technologies by U.S. firms.

- The types of data that, if collected systematically, would best contribute to an understanding of the relationships among training, technological change and productivity.

NOTES

1. Spenner (1985 and 1988) provides a detailed review of aggregate studies on technological change and skill requirements.
2. This section draws heavily upon Chapters 2 and 3 of (Flynn,1988).
3. Despite wide-ranging implications of the "age" of a technology on employment and skills, the technology's stage of development is often neglected in studies on the impacts of technological change. Adding to the confusion is the variety of uses of the term "new technologies" -- the literature may refer to technologies that are new to the firm and its workers, but are relatively mature in terms of the stage of development of the technology. This distinction is vital to unraveling the complex effects of technological change on jobs and workers, and to developing effective policies and programs to implement such change.
4. While the increasing role of multinational, multiproduct firms suggests modifications to the international life-cycle model, levels of risk, standardization or product and equipment, and product demand -- the key features underlying the dynamics of the life-cycle models, continue to play critical roles in determining production and employment patterns. See, Krumme and Hayter, 1975; Vernon, 1979.
5. See Flynn, 1989, for more detail on the implications of the life-cycle perspective on technological change for employers.

REFERENCES

Abernathy, William J., and James M. Utterback. "A general model. In W.J. Abernathy, The Productivity Dilemma. Baltimore MD: The John Hopkins University Press, 1978, Chapter 4.

Adler, Paul. "Rethinking the skill requirements of new technologies," Working Paper HBS 84-27, Cambridge, MA: Graduate School cf Business Administration, Harvard University, 1983.

Attewell, Paul and James Rule. "Computing and organizations: What we know and what we don't know," Communications of the ACM, 27/12., (December 1984): 1184-1192.

Barley, Stephen, R. "Technology as an occasion for structuring: Evidence from observations of CT scanners and the social order of radiology departments," Administrative Science Quarterly 31 (1986): 78-108.

Bartel, Ann P., and Frank R. Lichtenberg. "The comparative advantage of educated workers in implementing new technology." The Review of Economics and Statistics, 69/1(February 1987): 1-11.

Becker, Gary. Human Capital. New York: Columbia University Press, 1964.

Braverman, Harry. Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century New York: Monthly Review, 1974.

Bright, James, R Automation and Management Boston: Harvard University Graduate School of Business Administration, 1958.

Brimson, James A. "How advanced manufacturing technologies are reshaping cost management," Management Accounting (March 1986): 25-29.

Browne, Lynn E. "Can high tech save the great lake states?" New England Economic Review, Federal Reserve Bank of Boston, (November/December 1983): 19-33.

Buchanan, David A., and David Boddy. Organizations in the Computer Age, London: Gower, 1983.

Cappelli, Peter. "Union gains under concession bargaining," unpublished manuscript, 1983.

Carnevale, Anthony, P. Workplace Basics: The Skills Employers Want. Washington, D.C.: American Society for Training and Development, 1989.

Casner-Lotto, Jill and Associates. Successful Training Strategies. San Francisco: Jossey-Bass Publishers, 1988.

Child, John. Organization, 2nd edition. London: Harper and Row, 1984.

Child, John. "Organization structure, environment and performance: the role of strategic choice," Sociology, 6/1(1972): 1-22.

Chinitz, Benjamin. "Contrasts in Agglomeration: New York and Pittsburgh." American Economic Association, Papers and Proceedings, 50/3(1960): 279-289.

Clark, Jon, et al., The Process of Technological Change. Cambridge: The Cambridge University Press, 1988.

Collins, Randall. The Credential Society. New York: Academic Press, 1979.

Cyert, Richard M., and David C. Mowery, (eds.) The Impact of Technological Change on Employment and Growth. New York: Ballinger Publishing Company, 1988.

Cyert, Richard M. and David C. Mowery, (eds.) Technology and Employment Washington, D.C.: National Academy Press, 1987.

Davidson, William H. Experience Effects in International Investment and Technology Transfer. Ann Arbor, MI: UMI Research Press, 1980.

Dertouzos, Michael L., Richard K. Lester, and Robert M. Solow. Made in

America. Cambridge, MA: The MIT Press, 1989.

Doeringer, Peter B., and Patricia M. Flynn. "Manpower strategies for growth and diversity in New England's high technology sector." In John C. Hoy and Melvin H. Bernstein (eds.) New England's Vital Resource: The Labor Force. Washington, D.C.: American Council on Education, 1982, pp. 11-35.

Doeringer, Peter B., and Michael J. Piore. Internal Labor Markets and Manpower Analysis. Armouk, NY: M.E. Sharpe, Inc., 1985.

Dhalla, H.K., and S. Yuspeh. "Forget the product life cycle concept." Harvard Business Review 57/2(March-April 1976): 127-136.

Drucker, Peter F. "The coming of the new organization," Harvard Business Review (January-February, 1988): 45-53.

Enos, J. "Invention and innovation in the petroleum refining industry." In The Rate and Direction of Inventive Activity. Princeton, NJ: University Press for the National Bureau of Economic Research, 1962.

Flamm, Kenneth. "The changing pattern of industrial robot use." In Richard M. Cyert and David C. Mowery (eds.) The Impact of Technological Change on Employment and Economic Growth. New York: Ballinger Publishing Company, 1988, pp. 267-328.

Flynn, Patricia M. Facilitating Technological Change: The Human Resource Challenge. New York: Ballinger Publishing Company, 1988.

Flynn, Patricia M. "Lowell: A high technology success story." New England Economic Review. Federal Reserve Bank of Boston (September/October, 1984): 39-49.

Flynn, Patricia M. "Occupational education and training: Goals and

Performance." In Bruce Vermeulen and Peter B. Doeringer (eds.) Jobs and Training: Vocational Policy and the Labor Market. Boston: Martinus Nijhoff Publishing, 1981, pp. 50-71.

Flynn, Patricia M. "Preparing Workers and Organizations for for Technological Change: The Life-Cycle Perspective." Paper prepared for the National Planning Association, Committee on New American Realities, January 1989.

Ford, David and Chris Ryan. "Taking technology to market." Harvard Business Review (April-May 1981): 117-126.

Freeman, Richard B. The Market for College-Trained Manpower. Cambridge: Harvard University Press, 1971.

Greenbaum, Joan. In the Name of Efficienc,: A Study of Change in Data Processing Work. Philadelphia, PA: Temple University Press, 1979.

Grubb, W. Norton. "The bandwagon once more: Vocational preparation for high technology occupations." Harvard Education Review 54/4 (November 1984): 429-451.

Gutchess, Jocelyn F. "Employment security and productivity? It can be done" National Productivity Review, 4/3(Summer 1985): 275-286.

Harris, Candee S. "Establishing high technology enterprises in metropolitan areas." In E.M. Bergman, (ed.) Local Economies in Transition. Durham, NC: Duke University Press, 1986.

Hartmann, Heidi I., Robert E. Kraut, and Louise A. Tilly, (eds.) Computer Chips and Paper Clips. National Research Council (NRC). Washington, D.C.: National Academy Press, 1986.

Hayes, Robert H. and William J. Abernathy. "Managing our way to decline." Harvard Business Review (July-August 1980): 67-77.

Hayes, Robert H. and Ramchandran Jaikumar. "Manufacturing's crisis: New technologies, old organizations." Harvard Business Review, (September-October 1988): 77-85.

Hayes, Robert H. and Steven C. Wheelwright. "The dynamics of process-product life cycles." Harvard Business Review (March-April 1979(b)) 77-85.

Hayes, Robert H. and Steven C. Wheelwright. "Link manufacturing process-product life cycles." Harvard Business Review, (January-February 1979(a)): 133-140.

Hirschhorn, Lawrence. Beyond Mechanization: Work and Technology in a Postindustrial Age. Cambridge, MA: The MIT Press, 1984.

Hoover, Edgar M. The Location of Economic Activity. New York: McGraw-Hill, 1948.

Hunt, H. Allan, and Timothy. Human Resource Implications of Robotics. Kalamazoo, MI: Upjohn Institute, 1983.

Jaikumar, Ramnchandran. "Postindustrial manufacturing." Harvard Business Review, 64/6(1986): 69-76.

Johnson, H. Thomas, and Robert S. Kaplan. Relevance Lost. Boston: Harvard Business School Press, 1987.

Kamian, Morton I., and Nancy L. Schwartz. Market Structure and Innovation Cambridge: Cambridge University Press, 1982.

Kassalow, Everett M. "Employee training and development: A joint union-management response to structural and technological change." Proceedings of the Industrial Relations Research Association (December 1987): 107-117.

Katz, Harry C. Shifting Gears. Cambridge, MA: The MIT Press, 1985.

Kelley, Maryellen R. "Programmable automation and the skill question: A reinterpretation of the cross-national evidence." Human Systems Management, 6/3(1986): 223-241.

Kelley, Maryellen R., and Harvey Brooks. "The state of computerized automation in U.S. manufacturing." Cambridge, MA: Harvard University, John F. Kennedy School of Government, 1988.

Kraft, Philip. Programmers and Managers: The Routinization of Programming in the United States. New York: Springer-Verlag, 1977.

Krumme, Gunter and Roger Hayter. "Implications of corporate strategies and product cycle adjustments for regional employment changes." In Lyndhurst Collins and Davis Walker (eds.) Location Dynamics of Manufacturing Activities. New York: Wiley, 1975, pp. 325-356.

Leontief, Wassily and Faye Duchin. The Future Impact of Automation on Workers. New York: Oxford University Press, 1986.

Levin, Henry and Russell Rumberger. "The low-skill future of high tech." Technology Review (August/September 1983): 18-21.

Liker, Jeffrey K., David B. Roitman, and Ethel Roskies. "Changing everything all at once: Worklife and technological change." Sloan Management Review (Summer 1987): 29-46.

Malecki, Edward J. "Technology and regional development: A Survey." International Regional Science Review, 8/2(1983): 89-125.

Malecki, Edward J. "High technology sectors and local economic development." In Edward M. Bergman (ed.) Local Economies in Transition Durham, NC: Duke University Press, 1986, pp. 129-142.

Mangum, Garth L. "Curriculum response to occupational trends." In Gerald G. Somers and J.K. Little (eds.) Vocational Education: Today and

Tomorrow. Madison, WI: Center for Studies in Vocational and Technical Education, University of Wisconsin, 1971.

Mansfield, Edwin. The Economics of Technological Change. New York: W.W. Norton, 1968.

Mansfield, Edwin and A. Romes. "Technology transfer to overseas subsidiaries of U.S. based firms." Quarterly Journal of Economics. 95(1980): 737-750.

Markusen, Ann R. Profit Cycles, Oligopoly and Regional Development. Cambridge: The MIT Press, 1985.

Menzies, Heather. Women and the Chip: Case Studies on the Effects of Informatics on Employment in Canada. Montreal: Institute for Research on Public Policy, 1981.

Mowery, David C. "The diffusion of new manufacturing technologies." In Richard M. Cyert and David C. Mowery (eds.) The Impact ofTechnological Change on Employment and Economic Growth. New York: Ballinger Publishing Company, 1988): 481-510.

Nabseth, L., and G.F. Ray. The Diffusion of New Industrial Processes. Cambridge: Cambridge University Press, 1974.

National Commission on Technology, Automation and Economic Progress. Technology and the American Economy. Washington, D.C., 1966.

National Research Council (NRC). Center for the Effective Implementation of Advanced Manufacturing Technology, Manufacturing Studies Board, and the Commission on Engineering and Technical Systems. Human Resource Practices for Implementing Advanced Manufacturing Technology. Washington, D.C.: National Academy Press, 1986.

National Science Foundation (NSF). The Process of Technological Innovation: Reviewing the Literature. Washington, D.C.: NSF, 1983.

Nelson, Richard R., and Victor D. Norman. "Technological change and factor mix over the product cycle." Journal of Development Economics. 4(1977): 3-24.

Nelson, Richard R., and Edmund S. Phelps. "Investment in humans, technological diffusion, and economic growth." American Economic Review, Papers and Proceedings, 56/2(1966): 69-75.

Nelson, Richard R., and S.G. Winter. An Evolutionary Theory of Economic Change. Cambridge: Harvard University Press, 1982.

Nemetz, Patricia L., and Louis W. Fry. "Flexible manufacturing organizations: Implications for strategy formulation and organization design." Academy of Management Review 13/4 (1988): 627-638.

Oakey, Ray. High Technology Small Firms. New York: St. Martin's Press, 1984.

Office of Technology Assessment (OTA), U.S. Congress. Automation of America's Offices. Washington, D.C.: U.S. Government Printing Office, 1985.

Office of Technology Assessment (OTA), U.S. Congress. Technology, Innovation and Regional Economic Development. Washington, D.C.: Government Printing Office, 1984.

Office of Technology Assessment (OTA), U.S. Congress. Structural Unemployment: Reemploying Displaced Adults. Washington, DC: U.S. Government Printing Office, 1986a.

Office of Technology Assessment (OTA), U.S. Congress. Technology and the American Economic Transition. Washington, D.C.: U.S. Government Printing Office, 1988.

Osterman, Paul. Employment Futures: Reorganization, Dislocation and Public Policy. New York: Oxford University Press, 1988.

Piore, Michael J., and Charles F. Sabel. The Second Industrial Divide. New York: Basic Books, 1984.

Qualls, William, Richard W. Olshavsky, and Ronald E. Michaels. "Shortening of the PLC -- An empirical test." Journal of Marketing. 45(Fall 1981): 76-80.

Ray, George F. The Diffusion of Mature Technologies. Cambridge: Cambridge University Press, 1984.

Rees, John, Ronald Briggs and Donald Hicks. "New technology in the American machinery industry: Trends and implications." A study prepared for the Joint Economic Committee of Congress, September 1983.

Riche, R.W., D.E. Hecker, and J.U. Burgan. "High technology today and tomorrow." Monthly Labor Review, 1983.

Rink, David R., and John E. Swan. "Product life cycle research: A literature review." Journal of Business Research (September 1979): 219-242.

Roberts, Markley. "A labor perspective on technological change." In Eileen L. Collins and Lucretia Dewey Tanner (eds.) American Jobs and the Changing Industrial Base. New York: Ballinger Publishing Company, 1984, pp. 183-205.

Rosenberg, Nathan. Inside the Black Box: Technology and Economics.

Cambridge, ENG: Cambridge University Press, 1982.

Rosenberg, Nathan. Perspectives on Technology. Armouk, NY: M.E. Sharpe, Inc., 1976.

Rosenfeld, Stuart A., Emil E. Malizia, and Marybeth Dugan. Reviving the Rural Factory: Automation and Work in the South. Research Triangle Park, NC: The Southern Technology Council of the Southern Growth Policies Board, 1988.

Rosow, Jerome M. and Robert Zager. Training - The Competitive Edge. Jossey-Bass Publishers, 1988.

Sabel, Charles F., Gary Herrigel, Richard Kazis and Richard Geeg. "How to keep mature industries innovative." Technology Review 90/3(April 1987): 26-35.

Shanklin, William L., and John K. Ryans, Jr. Marketing High Technology. Lexington, MA: Lexington Books, 1984.

Somers, Gerald G. "The response of vocational education to labor market changes." Journal of Human Resources (Supplement 1968): 32-58.

Spenner, Kenneth I. "The upgrading and downgrading of occupations: Issues, evidence and implications for education." Review of Educational Research, 55/ 2,(1985): 125-154.

Spenner, Kenneth I. "Technological change, skill requirements and education: The case for uncertainty." In Richard M. Cyert and David C. Mowery (eds.) The Impact of Technological Change on Employment and Economic Growth. New York: Ballinger Publishing Company, 1988, pp. 131-184.

Starr, Martin K., and Alan J. Biloski. "The decision to adopt new technology - effects on organizational size." In E. Rhodes and D.

Wield (eds.) Implementing New Technologies. New York: Basil Blackwell, 1985, pp. 303-315.

Taylor, Robert E., Howard Rosen and Frank Pratzner (eds.) Responsiveness of Training Institutions to Changing Labor Market Demand (Columbus, OH: The Center for Research in Vocational Education, Ohio State University, 1983.

Technology Management Center. "The use of advanced manufacturing technology in industries impacted by import competition An analysis of three Pennsylvania Industries." Unpublished report. Philadelphia, PA.

U.S. Department of Labor, U.S. Department of Education, and U.S. Department of Commerce. Building a Quality Work Force. Washington, D.C.: U.S. Government Printing Office, 1988.

U.S. General Accounting Office (U.S. GAO). Dislocated Workers: Extent of Business Closures, Layoffs and the Public and Private Response, (Washington, D.C.: U.S. Government Printing Office, 1986.

Utterback, James M., and William J. Abernathy. "A dynamic model of process and product innovation." Omega 6(1975): 639-656.

van Auken, K.G., Jr. "Personal adjustment to technological change." In Howard B. Jacobson and Joseph S. Roucek (eds.) Automation and Society. New York: Philosophical Library, 1959.

Vernon, Raymond. "The product life cycle hypothesis in a new international environment." Oxford Bulletin of Economics and Statistics. 41/4 (1979): 255-267.

Wasson, Chester R. Dynamic Competitive Strategy and Product Life Cycles. 3rd edition. Austin, TX: Austin Press, 1978.

Wilkinson, Barry. The Shopfloor Politics of New Technology. London: Heinemann, 1983.

Wilms, Wellford W. "The nonsystem of education and training." In Peter B. Doeringer and Bruce Vermeulen (eds.) Jobs and Training in the 1980s. Boston: Martinus Nijhoff Publishing, 1981, pp. 19-49.