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CANADA IN THE 21ST CENTURY

II. RESOURCES AND TECHNOLOGY

THE IMPLICATIONS OF TECHNOLOGICAL CHANGE FOR HUMAN RESOURCE POLICY

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II. RESOURCES AND TECHNOLOGY

THE IMPLICATIONS OF TECHNOLOGICAL CHANGE FOR HUMAN RESOURCE POLICY

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PREFACE

AS A NEW MILLENNIUM APPROACHES, Canadians are going through a time of dramatic economic change. Markets are becoming global and economic activity across nations is becoming increasingly integrated. Revolutionary developments in computer and communications technology are facilitating globalization, and are also altering a great deal the workplace and the lifestyles of Canadians. At the same time, largely as a consequence of the information revolution, knowledge-based activities are becoming increasingly important within the Canadian economy and the economies of other industrialized nations.

These and related major transformations of the economic environment invite a comparison with the Industrial Revolution of the 1800s. As in the earlier time, major structural changes are giving rise to uncertainties. Firms and workers are struggling to find their place in the new economic order. Canadians collectively face the question of whether their nation's physical, human and institutional resources will provide a firm foundation for continued prosperity. Many see Canada's prospects as being much less secure than in earlier years, when the country's rich natural resources played a major role in shaping the Canadian economy.

To examine fully the medium to longer-term opportunities and challenges of these developments, the Micro-Economic Policy Analysis Branch of Industry Canada asked a group of experts to provide their "vision" for Canada in the 21st Century on a number of important issues. Each author was required to undertake two formidable tasks: first, to identify major historical trends and develop scenarios to illustrate how developments in his/her respective area might unfold over the next ten to fifteen years; and second, to examine the medium-term consequences of these developments for the Canadian economy.

The papers coming out of this exercise are now being published under the general heading of "Canada in the 21st Century". This series consists of eleven papers on different aspects of Canada's medium-term outlook. The papers are divided into three major sections. The first section, *Scene Setting*, focuses on important developments that are going to shape the medium-term economic environment in Canada. The second section, *Resources and Technology*, looks at trends among some important components of Canada's wealth creation and considers the actions needed to ensure that these factors provide a firm foundation for continued prosperity. The last section, *Responding to the Challenges*, explores individual, corporate and government responses to the medium-term challenges and offers some options for appropriate course of action.

As part of the *Resources and Technology* section, this paper by Professor Julian Betts of the University of California in San Diego, reviews labour market issues arising from investment in computer-related technologies. The author finds that technological change has not produced a significant decline in jobs in Canada. As in other countries, wages and employment have risen more in innovative than non-innovative firms within a particular industry. Recent technological advances in microelectronics have also increased skills requirements, contributing to a widening of the wage gap between university-trained and less-educated workers. In addition, there are indications that the new technologies are adversely affecting older workers, who have less incentive than younger workers to invest in re-training.

The demand for skilled workers is expected to continue to grow, while shortages of adequately trained workers can delay the adoption of advanced technologies and thereby slow productivity growth. Accordingly, the author proposes a number of policies. To better train youth for the new work environment, he recommends: the raising of secondary-school academic standards; the provision of extensive computer training at public schools; a major revamping of vocational education to better prepare youths unlikely to attend university for the job market; and the development of national standards in various certificate programs offered by community colleges. Above all, the author emphasizes the importance of co-operation between the three main players: the post-secondary institutions which provide training, the business community which provides knowledge about market requirements and governments which set academic standards and provide financial support for education and training.

SUMMARY

THE PAPER STUDIES THE INTERACTION between new technologies and the labour market. The central focus of the paper is an analysis of how new computer-related technologies have affected wages, employment and the demand for skilled workers relative to less-skilled workers.

The first section provides a non-technical discussion of the relevant economic theory. The predictions one can make based on this theory vary widely depending on the type of technological change considered. To give just one example, a firm which adopts a labour-saving technology may in fact increase employment and wages as a result. Any job losses may occur at other firms in the industry which fail to innovate. Employment in other industries could either rise or fall, as the effects of innovation in one industry alter the demand for labour, raw materials and other inputs across the economy.

The second section analyzes the impact of recent computer-based innovations on employment, wages, and the demand for skilled workers relative to unskilled workers. Evidence from a number of sources suggests that technological change has not produced a significant decline in employment in Canada. If anything, technology-adopting firms seem to increase both wages and employment relative to non-innovating firms in the same industry. Studies based on data for the United States and France have yielded similar results. It appears that recent technological advances related to microelectronics have increased skill requirements, contributing to a significant widening of the wage gap between university-educated workers and those with a lower level of educational attainment in the United States; a similar but much smaller increase in the wage gap between these categories of workers is observed in Canada.

The third section considers the extent to which the characteristics of the labour market have impeded the rate of technological change. Several surveys of Canadian firms suggest that a lack of sufficiently trained or educated workers slowed the rate at which firms adopted microelectronics-based technologies during the 1980's.

The fourth and fifth sections outline probable trends in technology over the next fifteen years, as well as strategies for coping with related changes. Research suggests that massive unemployment resulting from technological progress is very unlikely, given the gradual rate at which micro-electronic technologies have been adopted. But technology will continue to affect the labour market in important ways. In particular, the rate of skills obsolescence will keep rising and the demand for skilled workers is likely to continue to grow.

A number of policies aimed at dealing with technological change are proposed. For youth, measures are needed to strengthen the school-to-work transition. High and uniform educational standards across Canada could do much to ensure that students are well prepared for the labour market. Other policies likely to help youth are increased expenditures on computer training in high school, an overhaul of vocational education, and a better interface between

community colleges and local businesses. An important role for the federal government with regard to the last of these proposed policies would be to encourage the development of national standards for a series of certificate programs.

A number of initiatives are suggested to reduce the adverse impact of technological change on older workers, including experience-based unemployment insurance premiums and better support for the community college system.

Cooperation between the private sector, government and postsecondary institutions is likely to produce the most effective responses to changing skills needs and structural unemployment. The key to success is that local educational establishments obtain constant feedback from local businesses to ensure that courses and programs keep pace with the requirements of technology. Given evidence that Canadian industry adopted microelectronics at a slightly slower pace than other developed countries in the 1980's, and that a lack of skilled workers is often mentioned by Canadian firms as an obstacle to innovation, such tripartite policies could succeed not only in training young workers and re-training older workers in the skills most in demand, but they might also increase the overall rate of innovation and productivity growth in the Canadian economy.

INTRODUCTION

TECHNOLOGICAL CHANGE HAS LONG BEEN A KEY CONTRIBUTOR to economic development. The Industrial Revolution, which spurred the massive economic expansion of Europe, derived in large part from a number of key inventions, such as Watt's development of the steam engine in 1785.[1] While technological change has always been with us, over the last 15 to 20 years the microelectronics revolution has increased the rate of innovation and the severity of ongoing structural changes in the economy.

A widespread perception holds that the current wave of computer-related innovations might severely affect the labour market, by causing mass unemployment, by deskilling jobs and thereby reducing wages, or by increasing skill requirements and therefore aggravating income inequality between workers with different levels of education and training. These concerns each represent a valid hypothesis, but none is new to our age. In the early 1800s, the Luddite movement in England violently protested the mechanization of the textile industry, over fears that traditional craftsmen would be thrown out of work. More recently, the move towards automation in American factories caused many to speculate that massive unemployment was likely to ensue. At least in this instance, the record is clear: ongoing automation in the 1950s and 1960s did not coincide with high and increasing rates of unemployment in North America.

This article is intended for a non-technical audience interested in policy issues related to current technological changes. It surveys what we have learned about the labour-market impacts of recent technological changes, sketches general trends likely to ensue in the coming 15 years, and discusses the role of government in facilitating technical change without causing adverse labour-market impacts.

In the first section, we outline the predictions of economic theory. In the second section, we discuss in detail the evidence accumulated over the last thirty years concerning the extent of technical change and its impact on employment, wages, and skill requirements. In the third section, we ask whether the characteristics of the labour market can themselves influence the rate at which new technologies spread. In the fourth section, we extrapolate these trends to provide a broad outline of likely future developments in workplace technology. Finally, in the last section, we present a number of policies that might increase the rate of technical change while facilitating workers' adjustments to technology shocks.

An Introduction to the Economic Analysis of Technological Change and the labour Market

A central finding in the theory of technological change is that new technologies can take many forms and that their impact on the labour market can work through direct and indirect channels. The impact of technological change on employment and wages is exceedingly difficult to capture in practice because, for example, the implementation of a new technology in one factory may influence wages and employment in other factories thousands of miles away. Furthermore, in a market system in which prices in tens of thousands of inter-connected markets continually adjust to the ebb and flow of supply and demand, workers who are affected by the technological change may not even be in the same industry as the one undergoing the technological change.

The Theoretical Impact of Technological Change on the Overall Level of Employment and Wages

This article uses the terms technological change and technical change interchangeably.[2] A technological change is said to occur when a firm changes the way it operates to increase its productivity. A technological change may:

- alter a firm's work systems by entailing the purchase of new equipment or by introducing a change in process;
- increase the productivity of a firm's labour or capital or both;
- lead to job losses, depending on the conditions in which the local labour market operates; and
- involve the introduction of a new product rather than a change in work systems.

Each of these subtle aspects of technical change is described more fully below.

Changing Equipment or Changing Processes – Embodied vs. Disembodied Technical Change

A technical change is "embodied" if the only way a plant can implement it is to buy new equipment. A good example of embodied technical change is provided by the advent of word processors. The technology, which improved typists' efficiency, could not be implemented unless computers were purchased to replace typewriters. A technical change is disembodied if existing machinery, or "capital stock", can be made more efficient by implementing a new idea. An example of a disembodied technical change is found in the use of modern computers. A new version of software, once installed on an existing computer, can often increase the computer's efficiency without necessitating any outlay for new equipment.

Arrow (1962) advanced the notion of learning by doing, which states that, as an industry gains experience with producing a given item, it learns better ways of doing things. Often such technical changes result from a series of incremental improvements discovered by workers and managers on the plant floor. Enos (1962) provides evidence of exactly this sort of disembodied technical change in the petroleum industry. He finds that the major reductions in production costs occasioned by new techniques such as thermal cracking did not come when the technique was first implemented, but in later years as the industry, in effect, learned by doing. Many of these innovations were disembodied, in that they did not require new capital equipment.

Rosenberg (chapter 6, 1982) provides detailed examples of how "learning by using" reduced the costs of operating jet aircraft as experience with the characteristics of new plane designs and new engines grew. Although some of the cost reductions came about through embodied technical changes such as the redesign of wing flaps, other cost reductions were disembodied.

The distinction between embodied versus disembodied technical change is potentially important for labour markets. Embodied technical changes can entirely change the nature of work within an industry. A good example is the telephone industry, where the introduction of direct distance dialling reduced Bell Canada's demand for operators by approximately half between 1955 and 1972.

Although it may affect the demand for labour over the long term, by its very nature, embodied technical change is unlikely to cause massive layoffs. Investment in new capital equipment takes time; given normal turnover through quits and retirements, firms should in theory be able to manage employment reductions of several percentage points a year without resorting to layoffs.

Disembodied technical change, on the other hand, can proceed quickly, especially if the innovation is developed in-house, so that there are no royalties to be paid to an outside inventor. If the disembodied technical change takes the form of an unpatented idea that quickly becomes general knowledge, firms could adopt the idea at little or no cost. Such changes could, in theory, reduce employment very quickly.

Increasing the Productivity of Labour or Capital or Both – Neutral Versus Biased Technical Change

The impact of a new technology on employment and wages depends crucially on whether the innovation is neutral or biased. Consider a firm which uses two inputs, capital and labour (K and L), to produce a single good. A neutral technical change is one that increases the productivity of both inputs proportionately. Possible outcomes are illustrated in Figure 1. The isoquant is the convex solid line denoted Q_0; it shows combinations of K and L which will produce Q_0 units of output. The isocost is the straight solid line tangent to the isoquant. It shows combinations of the two inputs that cost the firm the same amount. To minimize costs, the firm will produce at a point of tangency between the isoquant and an isocost because isocost curves closer to the origin (to the "southwest") represent lower costs.

A neutral technical change will move the isoquant inward in a parallel fashion. The firm will react by moving from point A, which yields output Q_0 at the least cost to the firm, to point B, which represents the point on the new isoquant Q_0' that will produce Q_0 units at the lowest possible cost. The ratio of the price of capital to labour, K/L, will be identical at the new equilibrium. This definition of a neutral technological change is referred to as "Hicks-neutral."

This example of a neutral technical change suggests that employment will drop from L_a to L_b. Is it therefore inevitable that technical progress means that firms will lay off workers? The answer is no, because after the firm has adopted the technology, its output may increase. Even if all firms in the industry adopt the technology, each firm may sell more because it can pass on the cost savings to consumers, who are willing to buy more of the product once the price drops. Alternatively, if the firm is the only one, or one of the few that adopt the cost-saving technology, the likelihood is greater that employment at the innovating firm will rise.

The dotted lines in Figure 1 illustrate a case where, after the innovation, the firm's sales rise from Q_0 to Q_1, increasing the firm's demand for both capital and labour. Because a technological change may lead to increased sales, we cannot predict whether it will reduce employment, even if it reduces the labour required to produce one unit of output.

Figure 2 shows an example of a "biased" technical change. A technological change is said to be biased if, holding input prices constant, it changes the ratio of the amount of one input used to that of another input. For instance, if the capital-to-labour ratio, K/L, rose after the technical change, this would be an example of a "labour-saving" technological change. This definition of a biased technical change is referred to as "Hicks-biased."

After the innovation, the isoquant for producing Q_0 units shifts down in a non-parallel fashion. If the ratio of the price of capital to labour, K/L, remains constant, then the slope of the isocost lines will remain the same. As drawn, the firm after the technical change will reduce employment (from L_a to L_b) by a proportionately greater amount than its capital stock (from K_a to K_b). The ratio of the price of capital to labour, K/L, will, therefore, rise after the new invention. Such a technical change is more likely than a Hicks-neutral technical change to reduce employment since it calls for a greater reduction in labour than in capital. It is possible, however, that the cost reductions brought about by the technical change will cause demand to rise, so that employment might not fall and, in fact, could rise.

FIGURE 1

A NEUTRAL TECHNICAL CHANGE

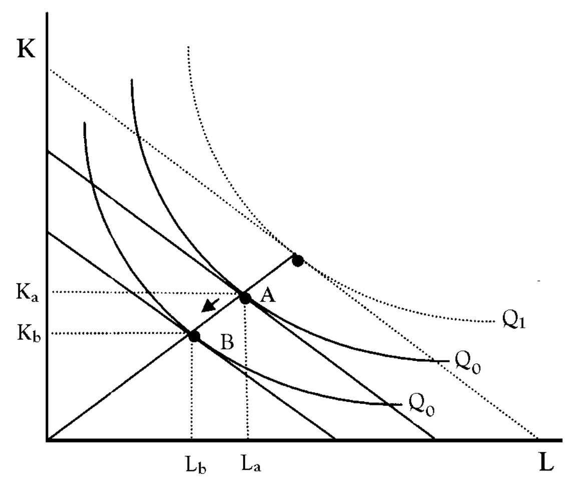
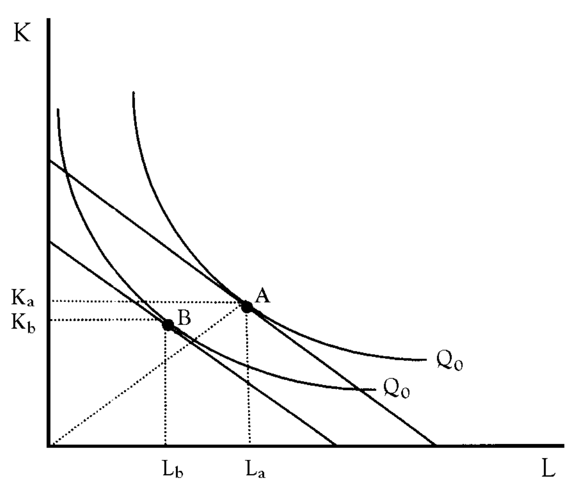


FIGURE 2

A BIASED (LABOUR-SAVING) TECHNICAL CHANGE

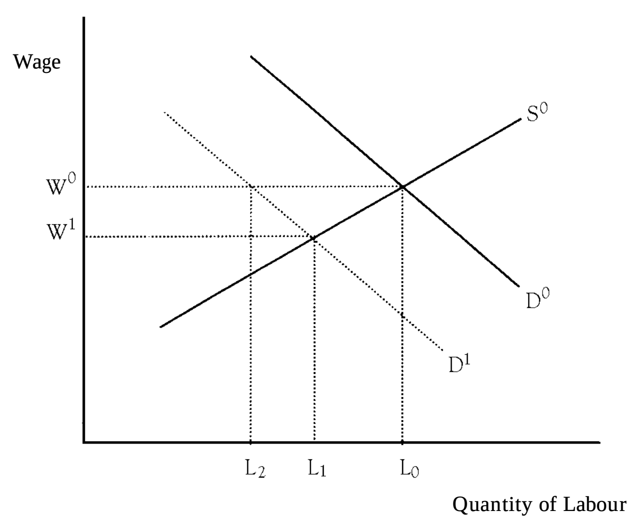


Having the Flexibility to Respond to Productivity Changes – Technological Change in the Presence of Wage Rigidities

The above analysis assumes that wages and prices adjust quickly to ensure that all workers can find employment. An innovation may decrease the amount of labour that industry demands by, for example, 5 percent at given wages and prices, but this does not mean that employment must drop by 5 percent. In practice, wages will fall, which in turn will reduce the number of workers that industry will lay off. The final outcome of such a 5 percent shift in the demand for labour might be a 2 percent reduction in employment and a corresponding reduction in wages. No worker is involuntarily unemployed in the sense that, at the new wage level, anybody who wants to work can find a job. This scenario is illustrated in Figure 3, where a new technology reduces the quantity of labour demanded at any wage (from the solid line D_0 to the dotted line D_1). Instead of reducing employment alone (from L_0 to L_2), the technological change simultaneously lowers employment and wages (from L_0 to L_1 and from W_0 to W_1). According to this view, innovation causes wages to drop for those workers who choose to remain employed, while employment drops because some workers choose not to work at the new lower wage.

FIGURE 3

THE IMPACT OF A TECHNOLOGICAL CHANGE ON WAGES AND EMPLOYMENT



This scenario assumed that wages and prices can change readily. If wages are rigid in the short run, however, a reduction in the demand for labour could have much more negative effects on employment. A 5 percent reduction in the quantity of labour demanded, at given wages and prices, could lead to a full 5 percent reduction in employment if wages are rigid. (In Figure 3, employment would drop from L_0 to L_2.) All of the workers who were laid off would be involuntarily unemployed in the sense that they are willing to work at the prevailing wage but cannot find jobs.[3]

Why might wages fail to decrease after an adverse shock to labour demand or in the face of job losses? One explanation might be wage contracts. When a firm has signed a collective bargaining agreement with a union representing its workers, such a contract typically stipulates the wage at which workers must be hired, but does not commit the firm to a stated level of hires. In such a situation, a labour-saving innovation at the firm might lead to quite large reductions in employment if the firm is not able to adjust wages to reflect workers' marginal product – the contribution to output of the last worker hired. Another source of wage inflexibility might be government regulations such as minimum wages, which at certain points in time and for certain firms might be above the "market-clearing" wage at which demand equals supply (such as W_1 in Figure 3). The result will be more layoffs for workers after a labour-saving innovation than if wages had been fully flexible.

In summary, different economies might react in different ways to the same labour-saving innovation. In an economy with flexible wages, the result might be a combined reduction in employment and wages. The adverse impact on the labour market is thus shared among all workers to some extent – those who continue to work are paid lower wages, while some decide not to work at all. In another economy, the same innovation might have no short-term impact whatsoever on wages, since institutionalized arrangements, such as collective bargaining agreements or government regulation of the labour market, preclude wage decreases. In this case, the drop in employment will be larger. In such an economy the negative impact of technological change is not distributed across all workers. Only those who are laid off suffer from the innovation, while those who remain employed see no change in their wages.[4]

Introducing a New Technological Product – Process vs. Product Innovation

The above discussion has focused on "process" innovations, which refer to innovations that reduce the cost of making an existing product. A second type of technological change, known as "product" innovation, involves the development of new products. The implications of product innovation for the labour market are in general quite different from those of process innovation. If a firm develops a new product, it is almost sure to increase employment at its factories, unless the new product is drawing sales away from its other product lines.

Chapters 4 and 5 of Katsoulacos (1986) theoretically analyze the employment effects of product innovations. The first benefit that accrues to the economy is an increase in the welfare of workers as employment rises because of the increase in consumer choice. The employment gains are weakened, however, by the extent to which the new product is a substitute for existing goods.

Product innovation is a hallmark of new computer-related technological changes. Consider for instance how microelectronics have revolutionized the entertainment industry, the number of innovative new products and services that have appeared in the telephone industry over the last two decades, and how educational computer-based games have started to create entirely new ways of teaching children. Such innovations, by creating new markets, are much more likely to increase than to reduce overall employment.

The Interconnections of Firms and Industries – Extensions to General Equilibrium

The discussion above has implicitly assumed that the impact of a new technology in one firm or industry does not spill over into other firms or industries. Such assumptions are not realistic. Virtually all firms and workers in the economy are interconnected through the prices they face and the wages they earn. General-equilibrium theory formalizes this idea, showing how a shock to one firm or industry, such as a technological innovation, can ripple through the economy, altering wages and prices faced by all firms and workers, and hence altering their decisions. In contrast, partial-equilibrium theory examines one firm, or perhaps industry, in isolation from the rest of the economy.

Consider first the extension of a partial-equilibrium model – of a technological shock occurring at a single firm – to a general-equilibrium model which examines the behaviour of all the firms in the industry. The technological change at firm *A* may reduce labour demand at that firm. However, as illustrated in the discussion of neutral versus biased technical change above, if the firm's sales rise considerably due to its lower costs after introducing a labour-saving innovation, employment could increase. What will happen at the other firms in the industry? If they do not adopt the new technology, they risk losing market share. Indeed, faced with an innovative competitor which has just reduced its costs, the absolute level of sales may slump at the firms that fail to innovate. This in turn will necessitate layoffs. This fact leads to an important observation for any empirical investigation of technical change and employment:

> If only one or some of the firms in an industry adopt a new technology, regardless of whether it is labour-saving or neutral, then the effect on employment could be most negative not at the firm(s) that innovate, but at those that fail to innovate.

The empirical researcher must recognize that the level of aggregation of his or her study may influence the conclusions reached. The study of innovation at the firm level can capture the employment effects at the firm that adopts a new technology, but it may miss the larger employment effects occurring at the firms that fail to keep up with the innovating firm. In contrast, industry-level studies can capture the overall or net effect of technical change on employment in an industry. Of course they will not succeed in illustrating the differential effects on employment between innovators and non-innovators. The only way for researchers to obtain an accurate and complete view of the impact of technology on employment is to conduct both firm-level and industry-level studies.

Impact on Unrelated Industries

General-equilibrium analysis entails much more than recognizing that the actions of one firm will affect other firms in the industry. Examination of the input-output tables of Canada reveal that, even when using disaggregated definitions of industries, apparently unrelated industries are in fact affected as they purchase intermediate inputs – the products of other industries – for use in production. If industry *A* buys the output of industry *B* to produce its output, then an innovation in industry *A* will almost surely affect the output of industry *B*. The effect could be either positive or negative. For instance, suppose that the technical change in industry *A* is labour-saving but material-using. Such an innovation may increase the quantity of industry A's purchases from industry *B*. Seen in this context, the employment consequences of a labour-saving innovation in industry *A* are not as negative as partial-equilibrium analyses might indicate. Even though some workers in industry *A* may lose their jobs, increased demand may lead to a rise in employment in industry *B*. Of course, the innovation in industry *A* may reduce the requirements for the materials produced in industry *B*, suggesting a decline in employment in industry *B*.

Suppose that there is another industry *C*, which does not directly supply anything to industry *A*. It too could be affected by an innovation in industry *A* because one or more of the suppliers to that industry, such as industry *B*, purchase materials from industry *C*. In this way, even industries that appear unconnected in the input-output tables are interconnected.

One way in which economists have modelled these interactions is through input-output analysis. Input-output analysis explicitly takes account of the fact that, directly or indirectly, every industry demands the output of every other industry in the economy. Examples of the application of this analysis to Canadian labour markets include Betts and McCurdy (1993), who analyze changes in employment by industry in the 1960s and 1970s, and more recently, Gera and Mang (1997) and Gera and Massé (1996) who analyze employment growth in the 1970s and 1980s. However, it should be pointed out that input-output analysis involves some fairly restrictive assumptions. The most important of these is that, barring technological change, the ratio of each input, such as labour, to output, is assumed constant. In reality, if wages doubled relative to the prices of other inputs such as capital, firms would likely substitute away from labour and towards these other inputs over time.

Economy-Wide Impacts

General-equilibrium theory pays attention to how the relative prices of different inputs influence the mix of inputs, including labour, that a firm demands. This approach recognizes that all industries are linked through the prices of inputs. If a shock in one industry increases the demand for labour in that industry, it is likely that wages will rise in *all* industries that must compete with each other for workers. Thus, another way in which innovation in one industry can affect employment in other industries is through the markets for raw materials and labour themselves.

If industry *A* grows rapidly due to cost reductions occasioned by process innovation, or expanding markets achieved through product innovation, it may increase the overall demand for labour or raw materials. Both of these effects are likely to reduce output, and hence employment, in other sectors, because these industries now face higher input prices. In an economy with fully flexible prices, and no market “imperfections” such as a costly job search that might prevent workers from finding a new job once unemployed, total employment might not change after an innovation in industry A. But wages might rise or fall *throughout the economy*, and not just in industry A, depending on the nature of the innovation: if all employers hire from the same pool of workers, any large increase or decrease in labour demand in one industry will spill over into other industries.

Unfortunately, empirical work has yet to capture all of these possible inter-industry effects of technological change in a statistically coherent framework.

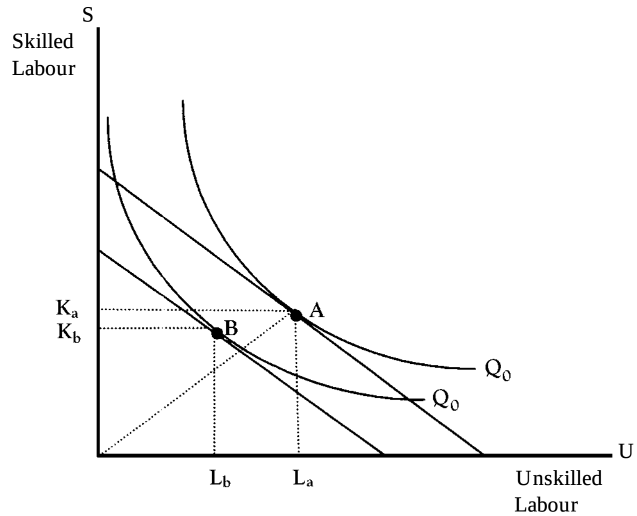
Technological Change and the Skills Mix

The discussion to this point has assumed that all workers are identical in skills and training, so that one can think of an overall labour market that is homogeneous. In reality, of course, workers differ in many ways, including the occupations in which they work, and the type of training that they have received. If the labour market consists of several distinct markets, and if firms cannot easily substitute one type of labour for another, then a shock in one market may have little immediate effect on employment or wages in other markets. This is especially true in the short run, before workers can retrain to enter labour markets where there are shortages of workers.

Technological change can affect different occupations differently. New technologies may be “skill-biased”. This means that, with wages of different classes of workers held constant, a firm that has adopted a new technology would want to change the ratio of more-skilled to less-skilled workers.

FIGURE 4

OPTIMAL CHOICE BETWEEN SKILLED AND UNSKILLED LABOUR



This idea is illustrated in Figure 4, which shows the firm's optimal choice of two types of labour, skilled and unskilled. The vertical and horizontal axes of the figure are labelled "skilled labour" and "unskilled labour". A "skill-using" innovation would shift the isoquant to the southwest in a non-parallel fashion as shown. If the prevailing wages paid to each type of worker are constant, then the firm would shift toward more skilled workers once it adopted the new technology. The opposite would be true of a "skill-saving" invention.

Given the heterogeneity of labour markets over time, both skill-using and skill-saving technical changes could change employment and wage ratios between more- and less-skilled workers. And, to the extent that workers in one skill class – whether delineated by years of schooling or training specific to an occupation – cannot be substituted for workers in another skill class, the possibility of *structural unemployment* emerges. Structural unemployment refers to unemployment that arises due to a mismatch between the types of job vacancies and the types of workers looking for jobs. If a new technology greatly reduces the employment of a certain type of worker such as a keypunch operator, it may take considerable time before such workers can re-train to work in other occupations where demand remains high. Thus, the possibility of involuntary technological unemployment emerges if workers must retrain in order to move between skill classes or occupations.[5]

Theoretical Implications of Skill-Biased Technological Change on Workers of Different Ages

New technologies might have considerably different effects on young and old workers. Middle-aged workers may bear the brunt of adjustments in the labour market when a new technology changes the types or levels of skills required.

Human capital theory suggests that workers who choose how much education and training to obtain will make most of these investments while young, to maximize the present discounted value of their lifetime earnings. The rationale is clear: the longer a payback period there is, the better will be the return on an investment. If a university degree increases a person's wage by 30 percent over that of a high school graduate, it is best to obtain the university degree while young.

A second reason why it is optimal for a worker to acquire training and education while young has to do with opportunity cost. The opportunity cost of time spent training or in school refers to the wages foregone while the person is out of the labour market. Since wages tend to increase significantly with the person's labour market experience, the opportunity cost of training or schooling will rise with the number of years spent in the work force. Training and education will, therefore, look more attractive to the worker while young, when his or her foregone wages will be relatively low.

Although in most developed economies education is heavily subsidized by government, university students still pay tuition fees and "pay" the wages from foregone work. Thus even if tuition is free, workers still pay an opportunity cost when obtaining education. Similarly, workers will typically pay for at least a portion of training received from their employer. In practice, the worker does not in general literally pay the employer for training; rather, the wage paid to young workers while training will be low, reflecting the costs to the firm of providing the training. Once trained, the worker's wage will adjust to reflect the post-training productivity. In fact, Becker (1964) has shown that if the skills imparted by training are "general," in that they are equally useful at other firms, then the firm providing the training must make the worker pay all of the costs of training. This model is discussed more fully in the final section, entitled The Case for Cooperation among Community Colleges, Universities, Business and Governement.

Since workers will typically bear at least part of the cost of education and training, it follows that most will prefer to train when young, both to increase the payback period of the investment, and also to minimize the opportunity cost. Older workers, who face higher opportunity costs for education and training and a shorter time horizon before retirement, may resist the re-training needed to learn a new technology. Young workers, who have most of their career paths ahead of them and face lower opportunity costs, are more likely to find it worthwhile to re-train to use the new technology.

With very young workers who have just entered the labour market, and who have no formal job training, *re-training* is not even an issue. In summary, younger workers have a much greater incentive to retrain in order to adopt new technologies than do older workers. For this reason, any negative impacts of technological change, such as wage reductions or job losses, might be more visible among those nearing retirement.[6]

Summary

THIS SECTION HAS OUTLINED THE PREDICTIONS that economic theory has yielded about the impact of new technologies on the labour market. Three important distinctions between types of technological change emerge.

Disembodied technical changes, which do not require investment in new capital, in theory could create more labour displacement than embodied technical changes. Since embodied technological changes require investment in new equipment, they are likely to proceed gradually.

The bias of technical change can play a major role in determining how wages and employment evolve after an innovation. A labour-saving innovation is more likely to reduce employment than is a neutral innovation, but, in either case, overall employment at the innovating firm could either rise or fall. If the cost reductions accompanying the new technology generate sufficient additional sales, employment could rise at a firm that installs a new technology.

Product versus process innovation presents another important distinction between types of technical change. A process innovation enables firms to produce an output with fewer inputs. It will reduce employment unless consumers respond by increasing their purchases by a more-than-proportionate amount. Product innovation, on the other hand, creates an entirely new product and is almost sure to increase employment at the given firm. However, by reducing the market share of competing products, a product innovation could reduce employment elsewhere.

Neoclassical economic theory suggests that technical change alters, in a smooth, continuous fashion, the amount of labour that workers are willing to supply and the amount of the firm's product that the market will buy. In theory, there is no possibility of involuntary unemployment, which economists define as unemployment among workers who are willing to work at the current wage but who are unable to find a job. The effect of a labour-saving innovation, for instance, will be to reduce wages and hence employment. However, as shown in Figure 3, those who no longer work after the innovation choose not to work at the new lower wage. If wages or prices are rigid in the short run, then an innovation could generate involuntary unemployment. A key example occurs when a collective bargaining agreement prevents the wage from dropping. After a labour-saving innovation, the firm, unable to lower wages, might lay off workers.

The overall direction of changes in employment and wages caused by a new innovation is unclear. It is possible that both wages and employment will fall after a technological change. But to the extent that the innovation spurs higher sales, through either lower costs engendered by a process innovation, or new markets engendered by a product innovation, then both higher employment and wages could result.

Perhaps the most subtle aspect of the theoretical analysis of technical change and the labour market concerns the general-equilibrium implications. As discussed above, if one firm in an industry adopts a new technology, employment and wages may change, not only at that firm, but also at competing firms in the industry. In particular, any employment losses associated with the new technology may occur in the industry at the competing firms *that fail to innovate*. This insight suggests that, to capture the overall effect of technological change, industry-level studies are needed in addition to firm-level studies.

An innovation in one industry may affect employment and wages in other industries. This can occur because the products from these other industries are used either directly or indirectly in the industry that is innovating.

Even if industry *B*'s products are not purchased by innovating industry A directly or indirectly through intermediate industries, industry *B* may be affected by the technological change at industry *A*. This is because industry *B* may be affected by price changes in its labour market or for other inputs. If, for example, the innovating industry vastly increases the demand for labour in a certain part of the country, this will raise the costs, and hence reduce the employment, in most other competing industries in the region.

Technical change may affect different workers in different ways. One especially important example is the possibility of innovations that are skill-using or skill-saving. A skill-using innovation will tend to increase the employment of, and the wage premium earned by, more-skilled workers relative to less-skilled workers. If workers cannot quickly acquire new skills, such technical changes could create structural unemployment due to the mismatch between workers' skill levels and skill types and the needs of employers. A skill-using innovation is also likely to have more adverse effects on older workers than younger workers.

The next section studies the state of empirical knowledge about technological change and the labour market. Very little work has been done to capture complex general-equilibrium interactions across industries. However, there has been considerable research on how recent technical changes have affected wages and employment at the firm and industry level, and their distribution between skilled and unskilled workers.

A Survey of Applied Research on New Technology and the Labour Market

The Extent of Technological Change in Canada, the United States and Other Developed Countries

Before discussing the impact of innovation on the labour market, it is important to confirm that technological progress has occurred in Canada and other developed countries.

It is exceedingly difficult to quantify the rate of technological change, because to the extent that it occurs through disembodied technological change, it is an unseen process. This section summarizes what is known about the rate of technological progress, as measured by various methods.

One can infer something about the rate of technological change by attempting to measure the overall rate of productivity growth in the economy. This method is imperfect since it is vulnerable to measurement error: A country undergoing rapid technological change might not show immediate gains in productivity, because it takes some time for industry to learn how to use a new technology efficiently. David (1990) argues that the current “productivity paradox” of slow growth while computers are spreading throughout the economy reflects the many years it takes before an economy can fully adopt a new technology and use it most efficiently. At the turn of the century, he notes, the rate of electrification of industry was slow and did not lead to an immediate increase in productivity because industry needed to restructure radically.

In the second part of the section below, we will review surveys that provide more direct evidence on the rate of technological change by measuring the rate at which firms have adopted new technologies.

Econometric Evidence

The two oil shocks induced by the Organization of Petroleum Oil-Exporting Countries (OPEC) in the 1970s are widely credited for a slowdown in the rate of productivity growth in the 1970s relative to the 1960s. Morrison (1992) attempts to explain differences in this productivity-growth slowdown between Canada, the United States and Japan. She carefully controls for, among other factors, the tendency for productivity to fall during recessions, and the possibility of economies of scale. After correcting for changes in productivity that reflect business cycles and economies of scale, she finds that all three countries exhibited increasing productivity over the two-decade period under study. However, annual productivity growth in Canada was rather low, at 0.062 percent over the 1960-1982 period, compared to 0.359 percent in the United States and 0.987 percent in Japan over the 1960-1981 period.

Denny, Bernstein, Fuss, Nakamura and Waverman (1992) study productivity growth in Canada, the United States and Japan and find that, in general, Japan's productivity growth has been higher than Canada's. This study, along with that of Mullen and Williams (1994) provide evidence that Canadian productivity has in general converged toward that of the United States in the postwar period. Denny et al. also conclude that this convergence stalled in the 1970s and early 1980s. Neither study controls for scale effects or sub-equilibrium effects, as done in Morrison (1992).[7]

Between 1960 and 1973, the year of the first OPEC oil shock, productivity growth was very similar in Canada and the United States. Morrison states that the divergence occurred during the 1974-1982 period, during which Canadian productivity growth was negative, while in the United States it did not fall substantially.

Morrison's finding does not lend itself to a portrayal of the Canadian economy as having undergone a rapid and continual period of technological change between 1973 and 1984.

Evidence From Surveys

Productivity growth provides an indirect measure of technological change. But a number of surveys of firms' use of technology provide a more direct picture of how quickly new techniques diffuse. The international nature of the surveys also allows for some very rough estimates to be made of the relative rates of technology adoption between industrialized countries.

Researchers have conducted a number of surveys of technology use in Canada. The Economic Council of Canada (1987) reported the results of a 1985 survey of approximately 1,000 firms. The survey reports the proportion of firms using a variety of computer-based technologies, such as computer-aided desing and manufacturing (CAD/CAM) and the computerization of office work. The survey, called the Working With Technology Survey (WWTS), found that approximately two-thirds of the instances of computerization reported involved the purchase of computers for office work. Automation on the factory floor was found to be proceeding much more slowly. As of late 1985, only 43 percent of the manufacturing firms in the survey reported any process automation.

The Economic Council of Canada study also compares its survey findings with others.[8] It reports that, as of 1984, the ratio of robots used for flexible automation per 10,000 employees was 3.7 in Canada, 4.7 in the United States and 32.1 in Japan.

The Council also reports that Canada lagged behind West Germany, Britain and France in its rate of adoption of microelectronics in manufacturing. A Canadian survey taken four years after the WWTS, the Survey of Manufacturing Technology, gathered information about the use of 22 technologies based on microelectronics, at approximately 2,900 individual manufacturing plants. When these are aggregated into six broad groups, the adoption rate of most of these technologies appears to be quite high. Baldwin and Rafiquzzaman

(1996) report that, as a percentage of manufacturing shipments, 52 percent of plants had adopted "design and engineering" technologies such as CAD/CAM. Similar percentages had adopted technologies related to "fabrication and assembly", such as flexible automation and computer-numerically controlled (CNC) machine tools. These numbers are not directly comparable to the earlier numbers cited in the 1985 study by the Economic Council, but it appears that during the four-year intervening period manufacturing plants continued to adopt these technologies slowly but steadily.

Evidence from the United States also indicates that micro-chip-based technologies have diffused less than instantaneously. Brynjolsson and Hitt (1996), for example, look at a panel of 600 American Fortune 1000 firms, over the period 1987 to 1994. The average share of computer costs in terms of total sales is approximately 1 percent. This number seems small, but it is not insignificant compared to the average 34 percent cost share of non-computer capital.

Baldwin and Rafiquzzaman (1996) report that, by 1989, about 40 percent of Canadian manufacturing firms had installed a local-area network, and 35 percent had installed an inter-firm network. In contrast, Motohashi (1996) reports that, in Japan, a 1991 survey of 23,000 firms revealed that about 80 percent used a local-area network, about 65 percent had installed an intra-firm network, and 44 percent had installed a network that enabled communications with other businesses. This comparison is not exact, however, since the Japanese figures refer to all industries, not just to manufacturing firms, and the survey was taken two years later than the Canadian survey. But the data suggest that Canada may have fallen behind Japan in the installation of computer networks.

It appears that new technologies may have diffused slightly more quickly in the United States and much more quickly in Japan than in Canada. This finding accords with the observation in the previous section, that rates of productivity growth in Canada have been closer to those of the United States, but have lagged behind those in Japan.

More recent surveys show that, in Canada and other developed countries, the level of adoption of computer-related technologies rose in the latter part of the 1980s, but even in the 1990s a large proportion of workers still do not work directly with these technologies. For instance, Grayson (1993) analyzes the General Social Survey of 1989, which surveyed 9,338 Canadians on a wide number of issues. Respondents were asked the following question: "In the last 5 years, how much has your work been affected by the introduction of computers or automated technology?". While 28 percent said "greatly", 15 percent of respondents said "somewhat", 14 percent said "hardly", and 42 percent said "not at all". This finding, that even by 1989 only a minority of Canadian workers felt that their work had been affected at least somewhat by computers, suggests that the spread of computer technologies did not occur instantly by any means. This is consistent with the theory examined in the first section, that when new technologies are embodied, the cost of buying the necessary equipment can limit the diffusion rate of the new technology. As will be seen in the ment can limit the diffusion rate of the new technology. As will be seen in the next section, this slow diffusion has an impact on employment and wages.

In France, Greenan and Mairesse (1996) have analyzed the results of a survey of workers conducted in 1987, 1991 and 1993. They report that the proportion of French workers who use a personal computer or computer terminal at work increased from 25 percent in 1987 to 43 percent in 1993. While the French workplace is steadily becoming computerized, it would be an over-statement to claim that jobs that do not require use of a computer are about to disappear.

Although the empirical literature provides two distinct methods of measuring technological change – measures of productivity growth and surveys of technology use – it would be reassuring to confirm that advanced technologies have indeed contributed to productivity growth. Brynjolsson and Hitt's (1996) U.S. study and Greenan and Mairesse's (1996) French study test for a correlation between the use of computer technology and firms' rate of productivity growth. The first paper finds that multifactor productivity growth in American firms is positively related to computer use, although the bulk of the productivity gains accrue several years after the initial investment. Greenan and Mairesse suggest that computer investments have increased labour productivity in France. They also find that total factor productivity is positively related to computer usage. However, this relationship is not statistically significant once they control for unobserved variations in labour quality across firms. They make the assumption that the quantity of labour is proportional to total wages paid, not to the total number of workers.

In a study of Canadian manufacturing based on the 1989 Survey of Manufacturing Technology, Baldwin, Diverty and Sabourin (1996) establish that labour productivity tended to be significantly higher in plants that reported the use of advanced technologies. Interestingly, in most cases, the ratio of labour productivity in these plants, compared to those that did not report the use of technology, rose significantly between 1981 and 1989. Of course, the increases in labour productivity might also have reflected a rise in the capital-to-labour ratio.

In contrast to these studies, Motohashi's (1996) study of computer networks in Japanese firms finds at best a weak relationship between network use and productivity at the firm level.

Of the four studies, the U.S. study by Brynjolsson and Hitt (1996) is perhaps the most persuasive because it identifies the contribution of technology to productivity growth by tracing the changes in computer usage and productivity over time at individual firms, instead of using differences in productivity or computer usage at a point in time.

To sum up, estimates of productivity growth provide indirect evidence that technological change has been occurring in North America and Japan. More direct studies, which examine the diffusion of microchip-based technologies, suggest that advanced technologies are slowly but steadily spreading in the workplace. Several studies have confirmed a positive link between the use of advanced technologies and productivity levels or productivity growth. Using information on the adoption of micro-chip technologies, it appears that Canada's rate of technological change may lag behind those of the United States, Japan and some European countries. Comparisons of productivity growth rates between Canada, the United States and Japan do not always concur, but Morrison's estimates, which control for business-cycle effects and economies of scale, suggest that Canada's rate of productivity growth has indeed lagged behind those of the United States and Japan.

HAVE NEW TECHNOLOGIES REDUCED EMPLOYMENT AND WAGES?

IN THE INTRODUCTION, we emphasized that a new technology, even if it were labour-saving, could lead to increased employment if the innovating firm's sales rise sufficiently after the technological change. Studies of employment trends at individual plants can address this issue. We also stressed that the main employment consequences of new technologies might occur at plants that fail to innovate, since the market share of industry laggards will likely shrink over time. For this reason, studies of employment and wages at the industry level can help to measure the overall industry effect of technical change. This section summarizes the current state of knowledge on these matters, first for Canada and then for other developed countries.

Denny and Fuss (1983) study employment at Bell Canada between 1952 and 1972. They model the impact of direct distance dialling on employment in different occupations and establish that this labour-saving technology was the dominant factor depressing labour demand over this period. In particular, the reduction in operators' share of total hours worked dropped from 38.7 percent in 1952 to 18.3 percent in 1972. This was mainly due to the new technology, rather than price-induced labour-labour substitution or the substitution of capital for labour. Rapid increases in output limited the reduction in the demand for operators to about 3 percent per year though, implying that Bell Canada could have accomplished much of the employment reductions through normal turnover. Although this example of technical change is not identical to the micro-chip-based innovations of the 1980s and 1990s, it does provide a powerful example of how significantly a labour-saving technology can alter the composition and level of the workforce over two decades.

In its survey of Canadian firms, the Economic Council of Canada (1987) asked respondents to describe how computer-based innovation had changed the nature of labour demand. About two-thirds of the firms in the survey reported that, between 1980 and 1985, technology had created excess labour, but only 10.4 percent said that they had introduced layoffs to solve the problem. The most common response, listed by 44.0 percent of firms, was to transfer redundant workers to other parts of the company.

Betts (1997) estimates translog-cost models of 18 Canadian manufacturing industries over the period 1962 to 1986. An advantage of this technique is that the demand for labour, energy, materials and capital is estimated in a way that controls for the substitution of one input for another as relative input prices change, and for economies of scale. The paper finds that, over the period, technological change slightly reduced labour's cost-share. The predicted job losses due to technological change for white-collar workers were near zero, while for blue-collar workers the predicted job losses over the period 1962-1986 were approximately 50,000. This represents a modest reduction in employment which should have been easy for firms to manage without recourse to layoffs.

Baldwin, Diverty and Sabourin (1996) combine data from the Survey of Manufacturing Technology and the Census of Manufactures between 1982 and 1989 to compare growth in market shares, wages and employment in Canadian plants that had adopted advanced technologies, relative to growth in plants that had not. The authors find that adopters had significantly higher growth rates in market share than non-adopters. The authors also find that for most types of technology, innovators' employment share grew at an insignificant rate during this period. It would appear, therefore, that the adoption of computer-related technologies in the 1980s did not have a large impact on employment shares. This analysis of *shares* cannot address the overall impact on employment however. This is because, for example, a 10 percent reduction in employment among adopting plants due to increased labour productivity, and among non-adopting plants due to decreased market share, would leave the employment share unchanged.

More direct evidence on rates of employment growth by industry is presented by Gera and Massé (1996), who compare high-, medium- and low-knowledge Canadian industries. This categorization of industries is based on work by Lee and Has (1996), who base their definitions on research and development (R&D) spending, education of employees, and the ratio of scientists and engineers to total employment. Gera and Massé (1996) find that employment growth in the 1970s and 1980s has been largest in the high-knowledge industries. They also find that, between 1971 and 1991, employment growth was most rapid in "high-technology" industries, defined as those with the highest rate of R&D spending.

According to the Baldwin, Diverty and Sabourin (1996) work, the relative wage difference between adopters and non-adopters in Canadian manufacturing grew by between two and eight percent during the period 1982-1989, depending on the type of advanced technology examined. It is important to recognize that, as the authors state, without information about the types of workers employed at each plant, one cannot distinguish between two alternative explanations for the rising wage ratio. The first is that labour productivity grew more quickly in innovating plants; the second is that the new technologies have required firms to hire more-skilled – and hence more expensive – workers.

Related work from other countries confirms the general conclusion that the direct impact of technological change on employment and wages at the plant level is small, and may in fact be positive. The panel study of American

Fortune 1000 firms by Brynjolfsson and Hitt (1996) finds that employment at the firm is positively and significantly related to computer-capital and R&D spending. Greenan and Mairesse (1996) report that wages are significantly and positively related to computer usage in their samples of French workers. O'Farell and Oakey (1993), in a British study, found large employment gains at individual plants that adopted CNC machine tools. Their data suggest that negative employment effects might only arise at plants that do not innovate and therefore lose market share. They found little difference between the wages of those operating CNC machine tools and those operating other machine tools in plants that had not upgraded.

The existing evidence contradicts the notion that new technologies must drastically reduce employment and wages. The overall employment impact is likely to be positive in firms that innovate. Relatively little is known, however, about the impact of technical change on non-adopting firms within an industry. Industry-level studies, such as that by Betts (1997), suggest that the job losses caused by technological change have been small. As for wages, evidence from Canada and France implies that technical change might increase wages, rather than reduce them.

Evidence on Technical Change and Skill Upgrading

The above results suggest that employment levels and wages have not changed radically as a result of technical changes over the last several decades. This section reviews a large body of evidence that suggests that new technologies have altered the relative demand for skilled and unskilled workers.

First, indirect evidence that the demand for more highly educated workers relative to less educated workers has risen in the 1970s and 1980s is provided for the United States by Katz and Murphy (1992) and for Canada by Freeman and Needels (1993). In both cases, the authors observe that, if the ratio of highly educated workers to less-educated workers increases over time while relative demand stays constant, the ratio of wages of highly educated to less-educated workers should decrease. But the opposite has happened in the United States, which in the 1980s witnessed the largest increase in the college-wage premium – the difference between wages paid to college graduates and wages paid to high school graduates and dropouts – in the period since World War II.[9] The implication is that, during the 1970s and 1980s, the demand for highly educated workers must have grown more quickly than did the demand for less-educated workers. This trend is consistent with skill-using technological change, but other interpretations are possible. For instance, Griliches (1969) firmly established the existence of capital-skill complementarity, which implies that, as an economy grows and capital is accumulated, firms will require more highly skilled workers than in the past.

The observation that workers are becoming more educated does not necessarily imply that skill requirements are increasing. Workers may be increasingly overqualified for the jobs they hold. But a separate information source suggests that these trends reflect some increases in skill needs. Howell and Wolff (1991) combine observations on the evolution of the distribution of jobs by occupation, with detailed information on the skills required in different jobs, based on a survey of firms. They conclude that, in the United States, firms' skill requirements have indeed increased over the last few decades. Myles (1988) provides similar conclusions from an analysis of Canadian data.

Berman, Bound and Griliches (1994) examine employment trends among production (blue-collar) and non-production (white-collar) workers in 450 U.S. manufacturing industries. They find a trend toward increasing employment of non-production workers relative to less-skilled production workers in the 1980s. They also find an increasing share of non-production workers in the total wage bill. They perform several tests to distinguish between competing hypotheses for these trends, including skill-biased technical change and foreign competition, and conclude that the former explanation is the more likely. For instance, they find that R&D spending and computer investment are both positively correlated with changes in white-collar workers' share of the wage bill between 1979 and 1987.[10] Using a similar approach and a thirty-industry level of aggregation, Machin, Ryan and Van Reenen (1996) find similar evidence of increasing employment and wage shares for non-production workers in Denmark, Sweden and, in particular, the United Kingdom. They interpret these changes in relative wages and employment as largely due to technical change.

Other studies on the United States concur. Bartel and Lichtenberg (1987) find that the relative demand for more highly educated workers was higher in industries with more recent vintages of capital. To the extent that newer technologies are embodied – able to be introduced on the plant floor only by buying new capital equipment – this finding suggests that new technologies increase the demand for highly skilled workers.

Tan (1990) runs log-wage regressions for cross-sections of male workers in Japan and the United States, and interacts the returns to job tenure with previously estimated measures of total factor productivity (TFP) growth in the worker's industry. Since human capital theory predicts that firms will require workers to share the costs of training, Tan argues that if higher TFP growth is associated with lower initial earnings and higher returns to tenure, this provides indirect evidence that faster rates of technical change spur greater investments in worker training. Tan finds precisely this pattern in the United States and Japan. He also finds that the returns to an extra year of education are higher in industries with higher rates of TFP growth in the United States, but not in Japan, suggesting that more innovative U.S. industries require more highly educated workers.

Economic theory provides a variety of explanations for why wages may increase with tenure at the firm, only one of which explains rising wage profiles in terms of on-the-job training. The other theories suggest that wage profiles that rise with age can be used by firms to prevent shirking on the job, and to reduce quits. Tan attempts to distinguish between these indirectly, by testing whether U.S. workers in industries with higher TFP growth rates are more likely to receive training. The results are not uniform but suggest that it is true in many cases. This finding seems to confirm Tan's assertion that a positive coefficient on the interaction between TFP and tenure in the wage equation suggests that technical change encourages firms to upgrade workers' skills.

Considerable evidence on technically induced changes in skill requirements has also been amassed for Canada. Betts (1997) finds that, in over half of Canadian manufacturing industries, technical change during the period 1962 to 1986 was skill-using: the change in white-collar labour's share of total costs due to technical change exceeded the corresponding change in blue-collar's cost share. In some cases, white-collar labour's share of total costs increased due to technical change; in others, it declined by an insignificant amount. Technical change almost always caused blue-collar's cost share to decline. The overall shift toward white-collar labour was very small though, and should have been manageable through attrition among blue-collar workers.

Similarly, studies of individual workers and firms suggest that more often than not, recent innovations have increased skill requirements. First, Grayson's (1993) study of the 1989 Canadian General Social Survey revealed that more-skilled workers were more likely to report that technical change had affected their jobs. Second, the Ontario Task Force on Employment and New Technology (1985), in a survey of Ontario firms, reports that many occupations were listed by at least 50 percent of firms as requiring more skills than in the past due to technical change. There were no occupations for which more than 50 percent of firms stated that technical change had deskilled the job. Similar results obtained for questions about the training requirements of occupations and the knowledge of the firm's operations that was required: no occupations were listed by a majority of firms as requiring fewer skills or knowledge due to technical change, while several were listed as requiring more skills. The only exception was drafting, which firms believed would require less on-the-job training as a result of new technologies.

Peitchinis (1978), in a 1976 survey of 104 Canadian firms, finds similar evidence that firms believed that in the previous five years technical change had increased skill requirements. The evidence is not as unequivocal as in the Ontario Task Force report, which perhaps is to be expected given that the Peitchinis study was carried out before the microelectronics revolution was in full swing.

Bolton and Chaykowski (1990), in a study of a Canadian telecommunications facility in 1988, found that the move to digital-switching technology vastly changed the skills required in each job description, but it was unclear whether, overall, skill requirements had risen or fallen.[11]

Evidence from Europe also points towards skill upgrading. Northcott, Rogers, Knetsch and de Lestapis (1985), in a survey of 3,800 manufacturing firms in Britain, Germany and France, find that workers with expertise in microelectronics represented the main labour shortage in all three countries. Other skill shortages mentioned by firms were far less common. O'Farrell and Oakey (1993) found that 14 percent of machine tool operators in Britain saw increases in skills after the introduction of computer-numerically controlled machine tools in a sample of firms in the United Kingdom; only two percent experienced deskilling of jobs.

Given the evidence listed above that recent technical changes have increased skill requirements, what are plausible explanations for skill upgrading? The findings of Bartel and Lichtenberg (1987) are particularly enlightening. Their observation that highly skilled workers are favoured in industries with newer vintages of capital suggests that new methods are innately hard to implement; highly educated workers are better able to adapt to the new techniques. A similar positive correlation between education levels and ability to adopt new agricultural technologies has long been observed in studies of individual farmers around the world.[12] Of course, this raises the question of whether a new technology *permanently* raises skill requirements, or whether it is simply the change in technology that temporarily creates a need for highly skilled workers during the implementation period. This is a moot point if new technologies continually appear.

Another reason why new technologies based on microelectronics might require more highly skilled workers is the sheer cost of attempting to design electronic devices that are easy to learn. Binkin (1988) offers a revealing account of attempts by the U.S. Air Force to reduce the training requirements of front-line aircraft mechanics by incorporating electronic test circuitry into aircraft. The theory driving this trend was that, when a malfunction occurred, the test circuitry would find and report the problem immediately, eliminating the need for highly trained technicians to be present in combat situations. In reality, the replacement of manual labour with test equipment did not reduce skill requirements at all, because the test equipment itself was so sophisticated and subject to down time that it required constant attention from highly trained workers.

Doeringer and Piore (1971) offer a novel explanation for why skill upgrading might be more common than deskilling. Based on a series of plant visits, they concluded that engineers charged with choosing among competing technologies often performed a cost analysis using the average wage rate for all workers in the plant. This procedure led to frequent errors in the estimates of labour costs. The practice biased the selection criteria in favour of technologies that employed a few highly skilled workers over technologies that may have been cheaper, but that employed a larger number of less-skilled workers. Most of the engineers interviewed by Doeringer and Piore "accepted this view."

Another explanation for why computerization has led to skill upgrading is that it has combined formerly separate jobs into one. Whereas in the past, preparation of advertising copy, technical journals, newspapers, or for that matter, professors' manuscripts, required contributions from typesetters, graphic artists and photographic specialists, it is now quite possible for one person to do 90 percent of these jobs on a single well equipped computer. The catch is that the person who does this must be highly proficient with a variety of software programs. Through this synthesis of skills, computers may in a sense be reversing the "division of labour" which Adam Smith long ago identified as a traditional key to productivity growth. A number of social scientists, including Braverman (1974) and Marglin (1982) have suggested that the ongoing division of labour must result in the deskilling of work. It may well be that computers are reversing the trend towards greater specialization and, in so doing, are increasing the range of skills required by workers.[13]

The Impact of Technology on Workers of Different Ages

In the section entitled Theoretical Implications of Skill-Biased Technological Change on Workers of Different Ages above, we reviewed the theoretical prediction that new technologies, to the extent that they require different skills than existing techniques, may adversely affect older workers in particular, given their higher opportunity cost of training and their shorter time horizons before retirement. It is also possible that older workers have more difficulties switching from their accustomed ways of doing a job. Limited empirical evidence on this subject tends to confirm the hypothesis.

The following example illustrates. Rosenberg (1988) quotes the manager of a car dealership in Massachusetts as follows: "It's very hard to teach a mechanic who has been in business 25 or 30 years how to use computer test equipment. It makes training more difficult. So we have the older guys doing noncomputer jobs and the younger ones becoming electronics specialists."

More formally, Mueller et al. (p. 52, 1969) in a 1967 survey of American workers, find that the proportion of those who in the previous five years had accepted a position that involved working with different machinery tended to decline sharply with age. Fully 30 percent of workers under age 25 had accepted such a position compared to just 10 percent of those aged 60-64.

The Economic Council of Canada (1987), in its survey of firms, provides insights into whether new technologies are likely to affect adversely older workers to a greater degree than younger workers. About two-thirds of firms reported that new technologies had led to redundancies over the period 1980-1985. As mentioned earlier, 44.0 percent of firms reported that redundancies had led to the transfer of workers to other work. But 6.4 percent of firms reported that early retirement programs had been used to reduce the work force when a new technology had been adopted. This finding suggests that older workers may indeed be disadvantaged relative to younger workers when new technologies emerge.

Bartel and Sicherman (1993) find evidence that in the United States technical change can be most difficult for older workers with only a few years to retirement. Using industry-level measures of productivity growth, and information on retirement decisions from the National Longitudinal Survey of Older Men, they test two hypotheses. The underlying assumption for both of these hypotheses is that industries with higher rates of productivity growth require more highly trained workers. The hypotheses are:

- Technological change that is correctly anticipated causes workers to retire later, so that workers can have a sufficient payback period for the additional training required.
- Unanticipated technological change causes older workers to retire earlier, because the re-training required is not worth it, given the shorter payback horizons.

They find support for both hypotheses. Thus technical change, at least that which is unanticipated, often poses a significant re-training challenge, the cost of which workers (and perhaps firms) sometimes find hard to justify.

The notion that older workers are less likely to be willing to re-train to use a new technology is not limited to computer technology. Harley (1973) studies the displacement of the wooden shipbuilding industry by the advent of iron ships. He cites the Hall Report on the state of industry in Maine in 1880. The report finds that young and old workers reacted differently to declining job opportunities in towns where wooden shipbuilding was a key industry. The younger workers, in the face of declining wages and employment, tended to migrate to find jobs in different industries, even if it meant learning a new set of skills, while the older workers tended to remain on in the shipyards.

These illustrations of the declining incentive to re-train as the worker ages implies that the costs of technical change may be borne primarily by middle-aged and older workers, rather than the young.

TECHNOLOGY, TRADE, AND FOREIGN DIRECT INVESTMENT

TWO OF THE MAIN SCHOOLS OF THOUGHT on the causes of the steep rise in the returns to education in United States and the much smaller rise in Canada focus on skill-biased technical change and changing trade patterns.

Lawrence and Slaughter (1993) and Borjas and Ramey (1994) offer differing views on the impact of trade on wage inequality in the United States. One problem with the trade hypothesis is noted by Berman, Machin and Bound (1994). According to standard trade theory, as the world moves from no trade to free trade, the relative wage of skilled workers to unskilled workers should rise in developed countries, but within each industry the relative employment of skilled workers should fall, as firms substitute towards the newly cheap unskilled workers. Such a substitution did not occur in developed countries. Moreover, in developing countries, where unskilled labour is more abundant, free trade should have caused the opposite movements in relative wages and within-industry relative employment. Yet when the authors examine a large set of countries they find increases in the share of non-production workers in both developing and developed countries. The authors conclude that the global diffusion of skill-using technical change is more consistent with this fact than is increasing trade between developed and developing countries.

Lee (1996) and Baldwin and Rafiquzzaman (1996) analyze employment and wage trends of blue-collar and white-collar workers in Canadian manufacturing, in an attempt to untangle the effects of trade and technical change. Lee (1996) finds that technical change has contributed to changing relative employment between white-collar and blue-collar labour in Canadian manufacturing, expanding employment shares of non-production workers while lowering somewhat their relative wages. He finds less clear evidence on whether import penetration has affected the labour market in Canada.

Baldwin and Rafiquzzaman (1996) regress the non-production/production worker-wage ratio on net export intensity and technology indicators in Canadian manufacturing. They conclude that both trade and technology have contributed to changes in the wage ratio. An increase in imports or a fall in exports is predicted to increase the non-production worker wage premium. But actual changes in net export intensity can explain only between 1 percent and 17 percent of the observed change in the non-production worker wage premium, depending on the sector.

Can one discuss technological shocks and trade shocks separately? It is quite possible that the two are causally intertwined. For example, changes in trade patterns may reflect changing comparative advantage between domestic producers and foreign competitors. On the other hand, changes in trade patterns may induce technical changes at home and abroad. Anecdotal evidence suggests that, in the United States, both the textile and the steel industries became quite uncompetitive during the 1970s. A spate of investment in newer computer-related technologies in both of these industries ensued in the 1980s. But it should be noted that even if technical change is induced by changing trade patterns, or vice versa, it is still necessary to study the impact of these innovations on wage and employment patterns.[14]

Can Labour Market Traits Affect the Rate and Nature of Innovation?

Induced Innovation

Induced innovation refers to technological change that is instigated by changing relative prices. An excellent example is the oil price shocks in the 1970s, which encouraged the development of smaller, more fuel-efficient cars. If the skill bias of innovation creates a similar shortage – of skilled workers – firms would have a powerful incentive to implement skill-saving technologies. This raises the possibility that new technologies cannot forever increase skill requirements.

There is considerable empirical support for the idea that a shortage of skilled workers has delayed implementation of new technologies. The Ontario Task Force on Employment and New Technology (1985), in a survey of Ontario firms, found that the most-often cited barrier to the implementation of new technologies was a "lack of skills and/or know-how to implement". In the manufacturing sector, 12 percent of firms cited this reason as the key barrier to innovation, while 38 percent rated it as one of the three most important barriers.

While the 1985 Economic Council of Canada survey found that the most commonly cited barrier to innovation was the high cost of equipment, the two second-most commonly cited obstacles, each mentioned by just under one third of the sample, were lack of technically qualified personnel, and low returns on investment. (Economic Council of Canada, 1987, pp. 79-80, and Betcherman and McMullen, 1986, p. 34)

Low returns on investment may themselves be due in part to a "lack of technically qualified personnel". Landry (1989) reports that a study by Nolan, Norton and Company found that, of firms' spending on personal computers, each year "...fully 70 percent goes to training and support". Similarly, Globerman (1986) finds that the rate of diffusion of electronic data processing in Canadian insurance firms was slowed by a lack of computer programmers and systems analysts.

It is not only a shortage of workers with sufficient training that has slowed the pace of innovation, but also a shortage of workers with sufficient education. In a 1989 survey of 338 firms by the Conference Board of Canada, 31 percent of respondants said that illiteracy among workers had caused difficulties in the introduction of new technology (Gibb-Clark, 1989).

In the face of such skill shortages, it is reasonable to expect that, in the future, firms will favour technologies that do not require heavy doses of worker training. Indeed, much of the efforts in the development of office-related software in the last ten years were aimed at replacing command-driven software that is difficult to learn, such as DOS and WordPerfect 5.1, with intuitive user interfaces and programs such as Windows and most of the popular word processing programs released in the 1990s. Another commonplace example is the grocery store checkout scanner, which eliminates the need for cashiers to memorize prices. If skill shortages become serious, many more technologies of this sort can be expected.

Similarly, as mentioned above, changing trade patterns can induce domestic firms to invest in newer technologies to prevent being closed out of the world market. Such episodes are likely to occur on a continuing basis. Canada is a developed country with large supplies of well trained and educated workers relative to developing countries. It is, however, becoming more closely integrated with developing countries through, for instance, the recent extension of the free trade agreement to Mexico. Canadian industries that employ mainly unskilled workers will encounter stiff competition from abroad. Technical change and new investment are likely required to shift firms' labour demand away from relatively expensive unskilled labour and towards more skilled workers, especially if regulations such as minimum wage laws prevent factor-price equalization.

Competition from low-wage developing countries may represent a crucial stimulus to skill upgrading in the Canadian economy over the next two decades. On the other hand, some firms may prefer to leave their labour forces intact, but to use technology to increase the productivity of their less-skilled workers. In this way, they may be able to justify maintaining the wages paid to these workers, relative to the much lower wages of workers in Mexico and other developing countries.

For both of these reasons, the skill bias of technical change is not inexorably upward. Shortages of skilled workers or the rigours of international competition could conceivably spur skill-saving innovations in the future.

Technology, Investment and Unions

Evidence from the United States (Hirsch, 1991) and Canada (Odgers and Betts, forthcoming) suggests that unions reduce investment, perhaps by capturing firms' quasi-rents through collective bargaining agreements. To the extent that technological change is embodied in equipment, the negative effect of unions on investment may translate into a negative effect on the rate of technological change. In particular, craft unions representing narrow occupational groups are likely to feel threatened by labour-saving innovations.

On the other hand, union members may recognize the need to innovate to remain internationally competitive, in which case the impact of unions on technical diffusion could be nil or even positive. Freeman and Medoff (1984) argue that unions can increase a firm's productivity by giving workers a "voice" through which they can channel suggestions or grievances about work practices.

Evidence that directly assesses how unions affect firms' attempts to implement new technologies is limited. On the whole it suggests that unions play a neutral role in the process. Bemmels and Reshef (1991) find that Canadian managers who introduced new technologies between 1980 and 1988 typically reported that unionization heightened worker resistance to innovation. Similar evidence is presented in Reshef, Stratton-Devine and Bemmels (1994). Yet a survey of Canadian plants finds that only 20 percent reported that employee reluctance was an obstacle to technological change, and that fewer than 10 percent of firms cited "restrictive collective agreement provisions" (Economic Council of Canada, 1987).

Betcherman (1991) finds that the premium of union wages over wages paid to non-union workers was lower in firms that had innovated, suggesting that unions were not capturing rents from new technology. But there is a problem of interpretation here: did firms that innovated have lower union wage premiums to begin with?

Evidence from other countries suggests that unions do not necessarily impede innovation. Using American data, Taymaz (1991) models the proportion of numerically-controlled (NC) machine tools in total purchases of machine tools in selected three-digit manufacturing industries between 1979 and 1983. He finds that the extent of unionization did not influence the diffusion of NC machine tools. Keefe (1991) reports, based on plant-level U.S. data for the non-electrical machinery industry, that union plants and non-union plants were equally likely to have adopted a number of technologies including CAD/CAM, NC and CNC machine tools.

These studies suggest that in the 1980s unions had no effect on the implementation of new technologies. Of course, given that manufacturing, especially in Canada, was only slowly embracing new micro-chip based technologies in the early 1980s, the 1990s may prove quite different.

The Organization of Work as a Determinant of the Rate of Technical Change

Carmichael and MacLeod (1993) suggest that most innovations derive from workers themselves rather than management. If management divides labour in the sense that each worker is trained in only a very narrow task, it becomes less likely that the worker will volunteer ideas on how to improve efficiency, for fear of making his or her job redundant. Against this perhaps stereotypical depiction of the American workplace, the authors provide evidence that in Japan workers receive training in multiple tasks. The model predicts that workers in a multi-task environment will be more likely to come forward with suggestions, even if they make one task redundant, because they know that their broad training makes their jobs secure. Hence, rotating workers between jobs, and training them in each task, may accelerate the rate of technical change.

A recent paper by Ichniowski, Shaw and Prennushi (1995) reports on a multi-year study of 36 individual production lines in steel mills across the United States. The authors find that if management introduces a variety of workplace reforms, the plant's productivity is significantly higher. The reforms studied are diverse, but fall under the general theme of increasing incentives for workers, including profit-sharing, and an emphasis on such things as work teams, employment security and training for workers. Although it is not yet clear whether these findings apply to steel mills beyond the 36 production lines studied, or to other industries, the research suggests that technological change and the labour market may be causally linked in both directions – not only do exogenous innovations affect workers, but the way in which workers are organized and managed by firms may influence the level of productivity.

LIKELY TRENDS IN TECHNOLOGY AND LABOUR MARKETS OVER THE NEXT FIFTEEN YEARS

IT IS EXTREMELY DIFFICULT TO MAKE SPECIFIC FORECASTS on technologies likely to diffuse quickly over the next 15 years, as volatility in the stock market prices of technology firms amply demonstrates. Nevertheless, the broad outlines of likely future technical change are fairly clear. It appears that Canada lags behind the United States by several years in technology adoption. Some of the trends that are already apparent in Canada are likely to strengthen, as has happened in the United States.

- Microprocessors will continue to spread throughout the factory floor, beginning by automating simpler repetitive tasks, and then by taking over more complex tasks.
- "Just-in-time" technology to minimize inventories will continue to spread. This type of innovation represents a substitution of capital (partly computer investment) and skilled labour (programmers, people trained in operations research, etc.) for materials.
- Ongoing improvements in telecommunications will accelerate the trend toward geographically distributed production. One implication of this trend is that, in the future, high-skill jobs may not be limited mainly to major cities. This is particularly true of the service industry, where transport costs are small or non-existent. For example, anecdotal evidence suggests that American high-technology firms are increasingly hiring software programmers in such far flung locations as India. And, to facilitate round-the-clock work on projects, an engineering firm in San Diego is reportedly planning to open up three research offices, spaced evenly around the world.
- The rate of obsolescence of both capital and skills has risen, and will continue to rise. For example, Oliner (1996) estimates that the service lives of machine tools diminished in the 1980s because computer-numerically controlled machine tools began to make the older machine tools obsolete. The 1990s has seen a major investment in new computing paradigms, in particular away from mainframes toward client-servers, intranets and data warehousing. Once a firm has made such a transition, it makes future transitions easier to handle. This is likely to occur as computer-operating systems evolve, and the relative merits of different systems change over time. All of these trends suggest that workers will require constant re-training, unlike in past decades.
- Considerable evidence suggests that the overall thrust of recent innovations has been to increase skill requirements. But this trend could level off if firms find it to their advantage to invent or adopt technologies that require less training than in the past.

Policy Responses in a World of Quickly Evolving Technologies

Policies for Youth: Improving the School-to-Work Transition

Given the slow but steady trend toward increasing skill requirements, the need is greater than ever before for policies that help university-bound youth and other youth to embark successfully on careers. Eight specific policy directions are suggested and described below.

Higher Educational Standards

First, higher educational standards in public schools, backed up by testing, could help to prepare students for the work force. In several Canadian provinces and most American states, the requirements that students need to fulfill before leaving grade school are minimal. Public schools are clearly not helping students by allowing them to drop out, or even to graduate from high school without testing for competency in verbal and written expression and in mathematics.

Academic standards do make a difference. Using a representative national sample of American students, Betts (1996) finds that students learn significantly more quickly in schools with higher standards. Indeed, a change in grading standards appears to have a greater impact on the rate of increase in test scores than changes in class size or teacher characteristics.

Another way of implementing standards is by instituting graduation exams. As of 1991 British Columbia, Alberta, Quebec and Newfoundland had provincial exams that students must pass to graduate from high school. New Brunswick had similar exams in language arts and mathematics. The other five provinces did not have curriculum-based graduation exams (Bishop, 1994). Bishop analyzes the math and science scores of 42,000 Canadian students who participated in the 1991 International Assessment of Educational Progress. He finds that students from the provinces with curriculum-based external examinations earned significantly higher scores. Such policies could well be extended to other provinces. Standards should also be set for school-leavers.

Extensive Computer Training

Second, minimum levels of competency with computers will increasingly be necessary in entry-level jobs, both in services and manufacturing, and, to a lesser extent, in the primary sector. Furthermore, computers in schools appear to increase the rate at which students learn. Betts (1995) studies the growth in mathematics and science test scores of a representative sample of American high school students, and finds that computers in the science or math class have a large positive impact on rates of learning. Thus, providing students with extensive computer training would probably do much to ensure that they make a successful transition into the working world.

Stronger Vocational Training Programs

Third, vocational education programs in secondary schools should be strengthened. Evidence from the United States, where workers with a high school diploma or less have seen sharp declines in their earnings since the late 1970s, suggests that less-educated workers will be particularly vulnerable to skill upgrading in the labour market, regardless of whether technical change or changing international trade patterns is the cause. This suggests the need for a radical revamping of vocational education in high schools for youths who are unlikely to attend university. Certificate programs are one possibility. Experiments with business internships for high school and postsecondary students present another possibility. In the United States, the National Assessment of Vocational Education (1989) found that, in the early 1980s, American high school graduates who had taken the vocational track were using only a small proportion of these courses once they started to work after high school. An implication is that the involvement of business in helping to set the curriculum of vocational courses in high school would do much to ensure that the courses are up to date and meet the needs of local employers.[15]

More specifically, what skills should vocational training programs seek to provide? Extensive research has been conducted on vocational education for youth in the United States over the last 35 years. The literature finds no “magic bullets”, especially when it comes to high school dropouts and those unlikely to attend postsecondary institutions. For instance, in a detailed review of American research over the 1960s and 1970s, Mangum and Walsh (1980) report that government-sponsored “work experience” programs for those enrolled in school or for recent dropouts provided no significant gains in earnings to participants. Perhaps surprisingly, some of the more successful programs trained workers in “soft skills”, such as punctuality. Disadvantaged youth in particular appear to gain from training on methods to search for a job. Some programs that subsidized private-sector jobs for youth appeared to be successful, the authors report, especially if the job was not a make-work job and the young workers were well supervised.

Stronger Community Colleges

Fourth, provinces would do well to focus on strengthening an already rich network of community colleges. As in the United States, community colleges in Canada account for almost half of postsecondary enrollment (Statistics Canada, 1991, pp. 121-127). They provide an alternative route into university for some students, remedial education for other students, and general interest courses to the public at large. But perhaps the most important function of community colleges is to provide technical training in a variety of certificate and non-certificate programs lasting a year or longer.

Developed countries differ markedly in the way in which they provide such postsecondary vocational training. Germany has developed a much more organized, but rigid, system whereby young people who have decided to follow a technical vocation attend a vocational institute at the same time as they pursue internships with firms. In almost 400 occupations, a person requires a nationally recognized certificate before he or she can practice fully (Kinzer, 1993). It is not clear that Canadian community colleges should adopt an identical system. The North American approach, which emphasizes flexibility, has much to recommend it. But even the United States, where community colleges grant nationally recognized Associate Degrees in a wide variety of fields, has a more structured certification system.

Certificate Programs and Technical Degrees

These insights lead to a fifth recommendation: the expansion of certificate programs, and the development of degree programs in technical areas. Both measures could do much to alleviate the shortages of skilled labour reported in the Canadian surveys described in the section entitled Induced Innovation above.

National Standards

Sixth, the federal government would do well to encourage the provinces and industry to develop *national standards* in a series of certificate programs. Although this represents a radical departure from the past, the advantages are clear: if enough input is received from industry, the standards will help young workers find a first job. To the extent that these certificates and degrees can be standardized within and between provinces, both workers and firms will benefit because it will reduce the informational problems that make recruiting young workers such an uncertain process. Furthermore, national standards would reduce provincial barriers to the movement of workers. Although this might seem like a hidden subsidy for the more industrialized provinces, which could now recruit from less industrialized provinces with surer knowledge of workers' training background, the resulting flows of workers are hard to predict. For instance, the knowledge that in less developed regions of the country a large number of workers were receiving nationally recognized certificates in technical fields each year might prompt many businesses to open new plants there. Over time, supply could well generate its own demand.

The federal government has a crucial role to play in the setting of national standards. It is difficult for private firms to set standards because such standards represent a "public good" – the creation of standards will benefit all employers, not just those that take the time and effort to design them. Due to the potential for market failure, government must become integrally involved in setting up skill standards.

While some may argue that individual provinces should set standards, there are powerful reasons to believe that the overall economy will function more efficiently if standards are recognized nationally. The idea of national standards in occupational licensing has long been practised successfully in Japan and Germany. More to the point, the European Community has taken steps to ensure that all member nations will recognize diplomas requiring three or more years of education or training, regardless of the member nation in which a worker obtained the credential.[16] Indeed, given the growing internationalization of the world's economies, it seems likely that *international* standards in certification for skilled occupations are likely to emerge in the next century. The countries that will do best in attracting multinational firms to their shores will include those that can provide these prospective employers with a well administered, easily understood, and *consistent* system for certifying workers' credentials. A national system of licensing or certificates would go a long way in that direction.

Competency Testing

Seventh, since national standards and the expansion of certificate programs are both designed in part to help signal information to employers about the skills possessed by workers, a rigorous system of competency testing is required. For certificate programs that are taught at postsecondary institutions, testing should be easy to implement, although if standards are to be national, then a nationwide body might be created to set examinations. For certificates that workers earn largely through apprenticeships in the private sector, the establishment of competency tests would require more effort. Community colleges provide an obvious candidate for hosting such tests, as they represent "neutral ground" outside the individual firm.

Again, government, either provincial or federal, should play a key role in setting up and running these competency exams, since individual firms will have little incentive to administer such a system, given that the benefits will diffuse throughout the whole economy. As already mentioned, government plays a key role in the widely admired German system of occupational certification. Another example comes from Japan, where the central government administers competency tests required for certification in almost 500 occupations. Furthermore, Japan views licensing as more than a one-time hurdle designed to train the youngest workers. For instance, welders in Japan must retake a written and practical exam once every three years. Firms strongly support this re-licensing, because it signals to customers that their employees maintain high standards.[17]

Information on Success Rates of Training and Educational Programs

Eighth, given that the steady pace of technological change is constantly changing the nature of labour demand, it is important that young people have access to detailed and up-to-date information on the success rates of students who have participated in various educational and training programs. To this end, it is important to collect and disseminate information on graduation rates, employment rates, and perhaps earnings, for students in secondary and post-secondary vocational programs and apprenticeships. Such information could also be of use to all levels of government in that payments to private and public institutions involved in vocational training could be made contingent upon the success rates of each program. At the postsecondary level, the federal government already gathers detailed information on how graduates fare in the labour market after leaving their university or community college. This survey, the National Graduate Survey, could provide the basis for such evaluations.

Policies for Older Workers: Re-training

Older workers, whose education and training have become partly obsolete due to computer-related innovations in the workplace, may be most threatened by technological change. A number of policies may help to protect older workers against technologically induced unemployment.

Tax Credits

First, government should encourage businesses to retrain such workers through tax credits for training.

Re-licensing System

Second, a re-licensing system similar to Japan's would also ensure that older workers maintain and upgrade their skills. Such a policy would reduce the chances that older workers will be laid off as new technologies emerge. It is also likely that re-licensing would increase firms' willingness to hire older workers who become unemployed.

Experience-rated Unemployment Insurance Premiums

Experience-rated unemployment insurance premiums are a third possibility. This policy, used in the United States, calls for firms that have laid off a smaller-than-average proportion of their workers in the past to pay less-than-average premiums into the fund that finances the unemployment insurance program. A beneficial side effect of such a policy might be to encourage firms to re-train redundant workers rather than to lay them off. To be fair, it should be stressed that according to the survey conducted by the Economic Council of Canada (1987), in the mid 1980s, Canadian firms were already preferentially using re-training or transfers rather than layoffs to deal with redundancies.

Re-training for Laid-off Workers

What about mid-career workers who are laid off as new technologies are adopted, even if the above policies were implemented? Again, community colleges should play a pivotal role in re-training these workers. Betts and McFarland (1995) document that in the United States enrollment in community colleges burgeons during recessions. They find that enrollment is more sensitive to the adult unemployment rate than to the youth unemployment rate, which implies that older workers may be particularly likely to enroll in community colleges during times of recession. Indeed, the National Assessment of Vocational Education (1989) reported that in 1986, 39 percent of students enrolled in public vocational institutions in the United States were age 30 or older, and 34 percent of students in all two-year public institutions were 30 or older. These figures compare to just 14 percent of students in four-year institutions. One reason why older workers may be particularly attracted to community colleges is the duration of the typical certificate program. Given that older workers have a shorter time horizon before retirement, they will be more likely to enroll in re-training if the program lasts a short period. Community colleges can – and already do – also help to prevent layoffs in the first place by providing refresher courses for mid-career workers.

An exhaustive review of evidence on training programs for displaced workers in several developed countries by Leigh (1990) shows that classroom training and subsidized on-the-job training for displaced workers have not in general led to significantly higher earnings or probabilities of employment. One policy which Leigh does identify in many American demonstration projects as having a statistically significant and positive effect is job-search assistance. Job-search assistance typically refers to short-term classes in job-hunting techniques, practice at interviewing, and in some cases, job referral services.

Leigh includes in his analysis a review of several studies of the effectiveness of Canadian government programs to aid displaced workers. These studies, conducted in the 1980s, come to conclusions similar to those found in American studies: classroom training and on-the-job training offered as part of Canada's National Institutional Training Program did not significantly increase earnings of workers after they had participated in the program. However, in some cases small sample size might be to blame for the lack of statistical significance. One of the most interesting findings reported by Leigh is that small firms in Canada are much more likely to participate in government programs to retrain displaced workers.

One reform that might make government training programs for displaced workers more effective would be to move away from short-term classroom training or on-the-job training programs. Instead, government could subsidize unemployed workers who enroll in community colleges or similar institutes that provide longer, more thorough training, and that confer upon the worker a well-recognized certificate or degree at the end of the program.

Human Resource Policy From the Point of View of Business: Policies to Enhance Productivity Growth in the Private Sector

Worker Training

Evidence suggests that the training of workers is essential in the global marketplace. As documented in the section entitled Evidence on Technical Change and Skill Upgrading above, new technologies appear to have increased the importance of training. There are some actions that firms can take on their own to make their labour force more productive.

Multi-skilled Production Teams

In the section entitled The Organization of Work as a Determinant of the Rate of Technical Change above, we reviewed theoretical evidence suggesting that the way in which firms organize their workforce can have a significant impact on their rate of productivity growth. In particular, team production, in which each worker receives training in multiple tasks, has been shown both in theory and practice to have tangible benefits. Workers become more flexible and more knowledgeable about how the firm functions. They are also likely to be more willing and able to suggest productivity enhancements, because they know that even if their suggestion makes one of their "jobs" redundant, they have already been trained to work in other jobs within the team.

Worker Incentives

American evidence also suggests that a package of worker incentives such as profit-sharing can increase productivity growth substantially.

The Case for Cooperation Among Community Colleges, Universities, Business and Government

The evidence marshalled above makes clear that new technologies have tended to increase skill requirements, while a lack of sufficiently trained and educated workers is a predominant barrier to innovation. But from a public policy perspective, who should pay for training: firms, workers or government? If training provides “general skills”, that is, skills that are widely applicable in many firms, then it does not make sense for firms to bear the costs of such training.

Becker (1964) demonstrates that, unless a firm pays a worker his or her true “marginal product” during training, it risks losing the worker later. Suppose that a firm subsidizes the worker during training in the hope of recouping training costs by paying the worker less than he or she is worth after the training. Such a policy is naive if other firms find the training equally useful, for they can pay a higher wage to poach the worker from the firm that has provided the training. Becker argues that, if training provides skills that are useful only at the given firm, then sharing the costs between the worker and the firm makes sense. Realistically, almost any training program will provide at least some general skills, which creates the above dilemma: a firm that subsidizes training may lose its workers after they have finished their training.

But if firms should not in general subsidize training, can the worker always bear the cost? Two important problems suggest that a market failure can result, in which workers acquire too little training. The first problem is liquidity constraints: if a worker is short of money, taking time out of the labour force to go to university or a community college may not be feasible, regardless of the wage gains that are likely to result after finishing the program. The second problem has to do with incomplete information among workers, combined with risk aversion. If workers cannot be sure that a job awaits at the end of a long training program, the program’s attractiveness will diminish greatly.

Government Role in a Cooperative Training System

For these reasons, perhaps the biggest improvements in worker training and firms’ productivity will result from a *cooperative* effort between business, higher education and government. Government can reduce the first problem – liquidity constraints – by continuing to subsidize vocational education. Government tax credits for training provided by firms, or for training courses purchased by workers, are one example of how such a policy could be carried out. Other countries have recognized that a key government role is to subsidize training to respond both to liquidity constraints among workers and the unwillingness of firms to pay for their general training. Japan represents a good example of a country where government plays a predominant role in training. Dore and Sako (1989) estimate that, in Japan during the period 1984-1986, government paid for approximately three times as much training as did firms.

Canada has already achieved much in the way of cooperative programs between government, postsecondary institutions and business. The idea behind programs such as the National Training Program and the Canadian Jobs Strategy, both initiated in the 1980s, was to combine government subsidization for training, largely at community colleges, with significant input and guidance from business, labour and the broader community.

Past research has indicated that subsidies to Canadian firms have succeeded in increasing the extent of training. Simpson (1984) analyzes the effects of government assistance for training in Canada in 1979. He finds that firms that received government assistance were significantly more likely to train workers. However, he found that the probability that a firm would use government assistance to train workers increased significantly with the firm's size. It is not clear whether this size effect indicates a lack of willingness among smaller firms to train their workers, or whether it indicates that smaller Canadian firms failed to use government training assistance for other reasons, such as a lack of information about the government program or liquidity constraints. Leigh (1990) reports the results of a survey of Canadian firms that found that smaller firms that accepted government training subsidies were much more likely than larger firms to report that they would not have been able to provide the training without government support.

The Role of Business in Providing Information

Firms can improve the effectiveness of vocational education by providing constant feedback to educators about the changing skill requirements on their shop floors. In a study of American postsecondary vocational education, Depietro et al. (1989) confirm that the best postsecondary programs, as judged by employers, were more likely to have maintained direct links with local employers and professionals.

Internship Programs in Educational Institutions

The expansion of internship programs, in which students divide their time between formal study in a community college or university and placements with local firms, can further reduce the risk that the student's training will be out of touch with the needs of the labour market. Universities such as Waterloo already have a sterling reputation for such programs. There are additional advantages to the sharing of training between postsecondary institutions and firms. The colleges, by providing the facilities for training, save the firms substantial fixed costs. At the same time, the participation of community colleges or universities in the joint provision of training can reduce the risk to government that tax credits offered to firms for training purposes might generate huge subsidies for activities that in fact had nothing to do with training.[18]

The idea of cooperation between the private sector and government to smooth young workers' transitions into well paying and stable jobs has taken hold in the United States, where Congress passed the School to Work Opportunities Act in 1994. Informal apprenticeships, or "work-based learning", often beginning in Grade 12, are being designed to introduce students to the working world. Cooperation from the private sector is the linchpin of the entire program. However, a preliminary analysis by the U.S. Office of Technology

Assessment (1995) reported that one of the biggest hurdles to the program has been the slow rate at which local employers have signed up. The report indicates that subsidies for training youth apprentices might increase employer participation. A second complaint made by many firms in a survey performed by the Office of Technology Assessment was inadequate academic preparation among the students. This finding suggests that increasing educational standards must go hand in hand with any attempt to implement informal or formal apprenticeships for young workers.

Business Input to National Standards

Business should play a major role in developing national standards for certificate and degree programs in technical fields, and should regularly be invited to participate in revisions to those standards.

Educational Institutions Involved in Re-licensing

Postsecondary institutions could also become involved in the re-licensing of workers in certain occupations, as was recommended above.

Educational Institutions and Business Involved in Refresher Courses

Finally, in recognition of the constant evolution of skill requirements, universities and community colleges should institute or expand a series of mid-career "refresher" courses for workers who have previously received degrees or certificates. To ensure that such courses are useful and continue to be so, industry should regularly be involved in drafting an updated syllabus for refresher courses in each field.

CONCLUSIONS

THE NOTION OF A TECHNOLOGICAL REVOLUTION THAT HAS LED TO MASS unemployment and plummeting wages is not borne out by recent experience. A better characterization of the impact of computer- and electronics-based innovations over the last twenty years is that they have caused a continual evolution in the types of jobs, and a corresponding rise in the skill requirements within given types of jobs. These changes have been gradual, suggesting that in cases where certain workers become redundant, normal attrition – rather than layoffs – can enable firms to adjust to changing needs. Plants that implement new technologies do not seem to reduce employment by large amounts, perhaps because the ensuing gains in productivity lead to increased market share. Indeed, it may be that job losses from innovation result mainly at firms that fail to adopt new technologies.

Just as a new technology can affect the labour market, the labour market might influence the overall rate of productivity growth. Canadian firms report that a shortage of skilled workers is a predominant barrier to the implementation of new technologies. This evidence may help to explain why Canadian firms have adopted new technologies slightly more slowly than firms in other developed countries. On a related note, an American study has established that a firm's level of productivity can be influenced by the way in which it trains workers and provides them with incentives. It follows that improved training, along with incentives such as profit sharing, could actually increase the rate of technical change in Canadian industry.

Government has a major role to play in this process to ensure that the ongoing stream of technological changes within firms does not create layoffs, but rather induces retraining, skill upgrading, and, hopefully, higher wages for a continually more productive labour force. An emphasis on education and training, both in the public sector for young people who have yet to enter the labour force, and within firms, community colleges, and universities for those already engaged in careers, is the key to ensuring that the labour force stays current with technology. Success in this endeavour will require cooperation between postsecondary institutions as purveyors of training and education, provincial and federal governments as subsidisers of education and the setters of standards in certificate and degree programs, and business, which plays a crucial role in guiding the country's training efforts toward the areas of greatest need.

NOTES

1 For a pithy summary of the history of technological progress up to 1900, see chapter 4 of Heertje (1973).
2 Technological change differs from economists' concept of an "invention". An invention is a new idea about how firms might produce a good or service; firms may or may not decide to adopt a new invention, and so an invention may or may not lead to a technological change.
3 For a much more detailed analysis, see Neary (1981), who uses a simple neoclassical framework to show that the employment implications of a technological change depend very much on the extent to which prices and wages in the economy are flexible in the short run.
4 For a good non-technical review of the history of economic thought on technological unemployment, see Standing (1984).
5 For a theoretical model of the impact of technological change on the distribution of earnings in a world with heterogeneous labour, see Betts (1994).
6 See chapter 7 of Betts (1990) for a theoretical analysis of the diffusion of technologies through the labour market. He shows that older workers will in general have less incentive to invest in the skills specific to new technologies, thus slowing the diffusion of the new technology. But if the technological change increases productivity by a sufficiently large amount, then older workers may be as likely as younger workers to acquire the new set of skills.
7 See also the comparisons of multifactor productivity growth between Canada and the United States in Statistics Canada (1989, pp. 90-95). The calculations suggest that productivity growth in the two countries was nearly identical from 1960 through 1985, but that productivity growth in the United States substantially exceeded that observed in Canada between 1986 and 1990.
8 At pages 78 and 79.
9 For documentation on this trend in American wages, see Katz and Murphy (1992) and Blackburn, Bloom and Freeman (1990). Freeman and Needels (1993) document a similar, but much smaller, increase in the returns to a university education in Canada during the 1980's. See Beach and Slotsve (1996) for a careful analysis of trends in inequality in Canada. They find that after controlling for business cycle effects, the increase in inequality in wages in Canada has been much smaller than in the United States.
10 See Section IV of Berman, Bound and Griliches (1994) for a review of other, mostly American, studies which come to similar conclusions.
11 For a fuller summary of the Canadian evidence on trends in skill requirements, including many case studies, see chapter 3 of Betts (1990). See also Muszynski and Wolfe (1989).
12 See for instance Feder, Just and Zilberman (1985).
13 For several examples of case studies that suggest that computers have led to a synthesis of job tasks, and hence skill upgrading, see pages 47-50 of Betts (1990).
14 See Mowery and Rosenberg (chapter 10, 1989) for a discussion of the interdependence of trade and technology, and the increasingly blurred distinction between trade policy and technology policy.
15 For a thought-provoking review of recommendations for change in the American vocational education system, see Boesel and McFarland (1994).

16 See Commission of the European Communities, 1993, chapter 2.

17 See Dore and Sako, 1989.

18 More broadly, a common complaint in studies evaluating government-sponsored training programs is that what appears to be a training subsidy given directly to a firm may in fact be a wage subsidy, in that the firm would have provided the training with or without government assistance. See for instance chapter 6 of Mangum and Walsh (1980) for a summary of such findings in U.S. research.

BIBLIOGRAPHY

Arrow, K. "The Economic Implications of Learning by Doing." *Review of Economics and Statistics*, 29 (1962): 155-73.

Baldwin, J., B. Diverty and D. Sabourin. "Technology Use and Industrial Transformation: Empirical Perspectives." In *Technology, Information and Public Policy*. Edited by T. Courchene. Kingston, Ontario: John Deutsch Institute for the Study of Economic Policy, Queen's University, 1996.

Baldwin, J. R. and M. Rafiquzzaman. "The Effect of Technology and Trade on Wage Differentials Between Nonproduction and Production Workers in Canadian Manufacturing." Manuscript, Micro-Economics Analysis Division, Statistics Canada, 1996.

Bartel, A. P. and F. R. Lichtenberg. "The Comparative Advantage of Educated Workers in Implementing New Technology." *Review of Economics and Statistics*, 69 (1987): 1-11.

Bartel, A. P. and N. Sicherman. "Technological Change and Retirement Decisions of Older Workers." *Journal of Labor Economics*, 11 (1993): 162-83.

Beach, C. M. and G. A. Slotsve. "Are We Becoming Two Societies? Income Polarization and the Myth of the Declining Middle Class in Canada." *The Social Policy Challenge*, 12, Toronto: C.D. Howe Institute, 1996.

Becker, G. S. Human Capital: *A Theoretical and Empirical Analysis, with Special Reference to Education*. General series, 80. New York: National Bureau of Economic Research, Distributed by Columbia University Press. 1964.

Bemmels, B. and Y. Reshef. "Manufacturing Employees and Technological Change." *Journal of Labour Research*, 12 (1991): 231-46.

Berman, E., J. Bound and Z. Griliches. "Changes in the Demand for Skilled Labor within U.S. Manufacturing: Evidence from the Annual Survey of Manufactures." *Quarterly Journal of Economics*, 109 (1994): 367-97.

Berman, E., S. Machin and J. Bound. "Implications of Skill Biased Technological Change: International Evidence." Manuscript, Department of Economics, Boston University, 1994.

Betcherman, G. "Does Technological Change Affect Union Wage Bargaining Power?" *British Journal of Industrial Relations*, 29 (1991): 447-62.

Betcherman, G. and K. McMullen. *Working with Technology: A Survey of Automation in Canada*. Ottawa: Economic Council of Canada, 1986.

Betts, J. R. "Technological Change and the Labour Market: Explorations in the Theory of Human Capital." Ph.D. Dissertation, Kingston, Ontario: Queen's University, 1990.

—— "Technological Change, Sectoral Shifts, and the Distribution of Earnings: A Human Capital Model." *Economica*, 61 (1994): 475-92.

—— "Which Types of Public School Spending are Most Effective? New Evidence on the School Quality Debate." Discussion Paper 95-03, Dept. of Economics, University of California, San Diego, 1995.

—— "Do Grading Standards Affect the Incentive to Learn?" Manuscript, University of California, San Diego, Department of Economics, 1996.

—— "The Skill Bias of Technological Change in Canadian Manufacturing Industries." *Review of Economics and Statistics*, 79 (1997): 146-150.

Betts, J. and T. H. McCurdy. "Sources of Employment Growth by Occupation and Industry in Canada." *Relations Industrielles*, 48 (1993): 285-304.

Betts, J. R. and L. L. McFarland. "Safe Port in a Storm: The Impact of Labor Market Conditions on Community College Enrollments." *Journal of Human Resources*, 30 (1995): 741-65.

Binkin, M. "Technology and Skills: Lessons from the Military." In *The Impact of Technological Change on Employment and Economic Growth*. Edited by Richard M. Cyert and David C. Mowery. Cambridge: Ballinger Publishing Co., 1988.

Bishop, J. H. "The Impact of Curriculum-Based Examinations on Learning in Canadian Secondary Schools." Manuscript, School of Industrial and Labor Relations, Cornell University, 1994.

Blackburn, M. L., D. E. Bloom and R. B. Freeman. "The Declining Economic Position of Less Skilled American Males." *In A Future of Lousy Jobs? The Changing Structure of U.S. Wages*. Edited by G. Burtless. Washington, D.C.: The Brookings Institution, 1990.

Boesel, D. and L. McFarland. *National Assessment of Vocational Education, Final Report to Congress: Summary and Recommendations*. Vol. 1. Washington, D.C.: Office of Research, Office of Educational Research and Improvement, United States Department of Education, 1994.

Bolton, N. J. and R. P. Chaykowski. "The Impact of Technological Change on Work Organization and Wages: A Case Study in the Canadian Telecommunications Industry." Discussion Paper # 90-7, Industrial Relations Centre, Queen's University, 1990.

Borjas, G. J. and V. A. Ramey. "Time Series Evidence on the Sources of Trends in Wage Inequality." *American Economic Review*, 84 (1994): 10-16.

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

Brynjolfsson, E. and L. M. Hitt. "Computers and Productivity Growth: Firm-Level Evidence." Manuscript, Sloan School of Management, Massachusetts Institute of Technology, 1996.

Carmichael, H. L. and W. B. MacLeod. "Multiskilling, Technical Change and the Japanese Firm." *Economic Journal*, 103 (1993): 142-60.

Commission of the European Communities. *Guide to the European Community Programmes in the Fields of Education, Training, Youth*. 2nd ed. Luxembourg: Office for Official Publications of the European Communities, 1993.

David, P. A. "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox." *American Economic Review*, 80 (1990): 355-61.

Denny, M., J. Bernstein, M. Fuss, S. Nakamura and L. Waverman. "Productivity in Manufacturing Industries, Canada, Japan and the United States, 1953-1986: Was the Productivity Slowdown Reversed?" *Canadian Journal of Economics*, 25 (1992): 584-603.

Denny, M. and M. Fuss. "The Effect of Factor Prices and Technological Change on the Occupational Demand for Labor: Evidence from Canadian Telecommunications." *Journal of Human Resources*, 17 (1983): 159-76.

Depietro, R., L. Tornatzky, J. Jacobs and M. Woods. *Predictors of High Quality Vocational Education*. NAVE Contractor Report. Ann Arbor, MI: Industrial Technology Institute, 1989.

Doeringer, P. B. and M. J. Piore. *Internal Labor Markets and Manpower Analysis*. Lexington, MA: Heath Lexington Books, 1971.

Dore, R. P. and M. Sako. *How the Japanese Learn to Work*. London: Routledge, 1989.

Economic Council of Canada. *Innovation and Jobs in Canada*. Ottawa: Supply and Services Canada, 1987.

Enos, J. *Petroleum, Progress and Profits*. Cambridge, MA: MIT Press, 1962.

Feder, G., R. E. Just and D. Zilberman. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change*, 33 (1985): 255-98.

Freeman, R. B. and J. L. Medoff. *What Do Unions Do?* New York: Basic Books, 1984.

Freeman, R. B. and K. Needels. "Skill Differentials in Canada in an Era of Rising Labor Market Inequality." In *Small Differences That Matter: Labor Markets and Income Maintenance in Canada and the United States*. Edited by D. Card and R. B. Freeman. Chicago: University of Chicago Press, 1993.

Gera, S. and K. Mang. The *Knowledge-Based Economy: Shifts in Industrial Output*. Working Paper No. 15, Industry Canada, 1997.

Gera, S. and P. Massé. *Employment Performance in the Knowledge-Based Economy*. Working Paper No. 14, Industry Canada, W-97-9E/F, Human Resources Development Canada, 1996.

Gibb-Clark, M. "Study Finds Illiteracy Affecting Third of Firms." *The Globe and Mail* (1989):B1, B6.

Globerman, S. "Formal Education and the Adaptability of Workers and Managers to Technological Change." In *Adapting to Change: Labour Market Adjustment in Canada*. Edited by W. C. Riddell. The Collected Research Studies, Royal Commission on the Economic Union and Development Prospects for Canada. Vol. 18. Toronto: University of Toronto Press, 1986.

Grayson, J. P. "Skill, Autonomy, and Technological Change in Canada." Work and *Occupations*, 20 (1993): 23-45.

Greenan, N. and J. Mairesse. "Computers and Productivity in France: Some Evidence." Manuscript, Institut National de la Statistique et des Études Économiques (INSEE), Paris, 1996.

Griliches, Z. "Capital-Skill Complementarity." *Review of Economics and Statistics*, 51 (1969): 65-68.

Harley, C. K. "On the Persistence of Old Techniques: The Case of North American Wooden Shipbuilding." *Journal of Economic History*, 33 (1973): 372-98.

Heertje, A. *Economics and Technical Change*. London: Weidenfeld and Nicholson, 1973.

Hirsch, B. T. *Labor Unions and the Economic Performance of Firms*. Kalamazoo, MI: W. E. Upjohn Institute for Employment Research, 1991.

Howell, D. R. and E. N. Wolff. "Trends in the Growth and Distribution of Skills in the United States." *Industrial and Labor Relations Review*, 44 (1991): 486-502.

Ichniowski, C., K. Shaw and G. Prennushi. "The Effects of Human Resource Management Practices on Productivity." Working Paper No. 5333, National Bureau of Economic Research, 1995.

Katsoulacos, Y. S. *The Employment Effect of Technical Change: A Theoretical Study of New Technology and the Labour Market*. Brighton, U.K.: Wheatsheaf Press, 1986.

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

Keefe, J. H. "Do Unions Influence the Diffusion of Technology?" *Industrial and Labor Relations Review*, 44 (1991): 261-74.

Kinzer, S. "Germans' Apprentice System is Seen as Key to Long Boom." *New York Times* (1993):1, 5.

Landry, R. "Where's the PC Payoff?" *PC World* (1989): 19-20.

Lawrence, R. Z. and M. J. Slaughter. "International Trade and American Wages in the 1980's: Giant Sucking Sound or Small Hiccup?" *Brookings Papers on Economic Activity.* (1993): 161-210.

Lee, F. C. "Implications of Technology and Imports on Employment and Wages in Canada." Working Paper No. 12, Industry Canada, 1996.

Lee, Frank C. and H. Has. "A Quantitative Assessment of High-Knowledge Industries Versus Low-Knowledge Industries." In *The Implications of Knowledge-Based Growth for Micro-Economic Policies*. Edited by Peter Howitt. Calgary: University of Calgary Press, 1996.

Leigh, D. E. *Does Training Work for Displaced Workers? A Survey of Existing Evidence*. Kalamazoo, MI: W. E. Upjohn Institute for Employment Research, 1990.

Machin, S., A. Ryan and J. Van Reenen. "Technology and Changes in Skill Structure: Evidence from an International Panel of Industries." Manuscript, University College, London, 1996.

Mangum, G. and J. Walsh. *Employment and Training Programs for Youth – What Works Best for Whom?* Youth Knowledge Development Report 2.2. Washington, D.C.: United States Department of Labor, 1980.

Marglin, S. A. "What Do Bosses Do? The Origins and Functions of Hierarchy in Capitalist Production." *In Classes, Power, and Conflict: Classical and Contemporary Debates*. Edited by A. Giddens and D. Held. Berkeley: University of California Press, 1982.

Morrison, C. J. "Unraveling the Productivity Growth Slowdown in the United States, Canada and Japan: The Effects of Subequilibrium, Scale Economies and Markups." *Review of Economics and Statistics*, 74 (1992): 381-93.

Motohashi, K. "Use of Information Networks, Organizational Changes and Productivity: Firm Level Evidence in Japan." Manuscript, Economic Analysis and Statistics Division, OECD, Paris, 1996.

Mowery, D. C. and N. Rosenberg. *Technology and the Pursuit of Economic Growth*. Cambridge: Cambridge University Press, 1989.

Mueller, E., J. Hybels, J. Schmiedeskamp, J. Sonquist and C. Staelin. *Technological Advance in an Expanding Economy: Its Impact on a Cross-Section of the Labor Force*. Ann Arbor: Institute for Social Research, University of Michigan, 1969.

Mullen, J. K. and M. Williams. "Convergence, Scale and the Relative Productivity Performance of Canadian-U.S. Manufacturing Industries." *Applied Economics*, 26 (1994):739-50.

Muszynski, L. and D. A. Wolfe. "New Technology and Training: Lessons from Abroad." *Canadian Public Policy*, 15 (1989): 245-64.

Myles, J. "The Expanding Middle: Some Canadian Evidence on the Deskilling Debate." Research Paper Series, 9, Analytical Studies Branch, Statistics Canada, 1988.

National Assessment of Vocational Education. *Final Report: Summary of Findings and Recommendations*. Vol. 1. Washington, D.C.: United States Department of Education, 1989.

Neary, J. P. "On the Short-Run Effects of Technological Progress." *Oxford Economic Papers*, 33 (1981): 224-33.

Northcott, J., P. Rogers, W. Knetsch and B. de Lestapis. *Microelectronics in Industry – An International Comparison: Britain, Germany and France*. London: Policy Studies Institute, 1985.

Odgers, C. and J. R. Betts. "Do Unions Reduce Investment? Evidence from Canada," *Industrial and Labor relations Review*, (forthcoming).

O'Farell, P. N. and R. P. Oakey. "The Employment and Skill Implications of the Adoption of New Technology: A Comparison of Small Engineering Firms in Core and Peripheral Regions." *Urban Studies*, 30 (1993): 507-25.

Office of Technology Assessment. *Learning to Work: Making the Transition from School to Work*. Washington, D.C.: United States Government Printing Office, 1995.

Oliner, S. D. "New Evidence on the Retirement and Depreciation of Machine Tools." *Economic Inquiry*, 34 (1996): 57-77.

Ontario Task Force on Employment and New Technology. *Employment and New Technology*. Toronto: Government of Ontario, 1985.

Peitchinis, S. G. "The Effect of Technological Changes on Educational and Skill Requirements of Industry." Research Report 45, Technological Innovation Studies Program, Technology Branch, Department of Industry, Trade and Commerce, Canada, 1978.

Reshef, Y., K. Stratton-Devine and B. Bemmels. "The Impact of Manufacturing Employees on Technological Changes." *Economic and Industrial Democracy*, 15 (1994): 505-30.

Rosenberg, N. I*nside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press, 1982.

Rosenberg, R. "Running on High Tech: Cars Too Complex for Many Mechanics." *Boston Globe* (1988): 1, 6.

Simpson, W. "An Econometric Analysis of Industrial Training in Canada." *Journal of Human Resources*, 19 (1984): 435-51.

Standing, G. "The Notion of Technological Unemployment." *International Labour Review*, 23 (1984): 127-47.

Statistics Canada. *The Input-Output Structure of the Canadian Economy in Constant Prices*, 1961-1981. Ottawa: Minister of Supplies and Services Canada, 1987.

—— *Aggregate Productivity Measures*. Ottawa: Statistics Canada, 1989. Catalogue 15-204E.

—— *Canada Year Book 1992*. Ottawa: Minister of Industry, Science and Technology, 1991.

Tan, H. W. "Technical Change and Human Capital Acquisition in the U.S. and Japanese Labor Markets." *In Productivity Growth in Japan and the United States*. Edited by C. R. Hulten. Chicago: University of Chicago Press, 1990.

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