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The Implications of Technological Change for Human Resource Policy

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Executive 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 changed wages, employment and the demand for skilled workers relative to less skilled workers.

Section 2 provides a non-technical outline of the relevant economic theory. The predictions of 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 affect the demand for labour, raw materials, and other inputs across the economy.

Section 3 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 led to significant declines in employment in Canada. Firms which adopt new technologies seem, if anything, to increase both wages and employment relative to non-innovating firms in the same industry. Researchers have obtained similar results in American and French studies. It appears that recent technological advances related to microelectronics have increased skill requirements, and have thus contributed to a large increase in the wage gap between university-educated and less educated workers in the United States, and a similar but much smaller increase in the wage gap in Canada.

Section 4 considers the extent to which the traits 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 diminished the rate at which firms adopted microelectronics technologies during the 1980's.

Sections 5 and 6 outline likely trends in technology for the next fifteen years, and strategies for coping with these changes. Research suggests that massive unemployment resulting from technological change 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 obsolescence of skills will continue to increase, and the demand for skilled workers is likely to continue to grow.

A number of policies to deal with technological change are presented. For youth, policies 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 improved articulation between community colleges and local businesses. An important role for the federal government in the last of these policies is to encourage the development of national standards in a series of certificate programs.

A number of policies are suggested to reduce the adverse impact of technological change on older workers, including experience-based insurance premiums and expanded 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 institutions obtain continual feedback from local businesses to ensure that courses and programs evolve with the needs of technology. Given evidence that Canadian industry adopted microelectronics at a slightly slower pace in the 1980's than did other developed countries, and that a lack of skilled workers is often mentioned by Canadian firms as an obstacle to innovation, such tripartite policies can succeed not only in training young workers and re-training older workers with the skills most in demand, but might also increase the overall rate of innovation and productivity growth in the Canadian economy.

1. 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, there is a widespread perception that over the last 15 to 20 years the microelectronics revolution has increased the rate of innovation -- and the severity of structural changes ongoing in the economy.

A second widespread perception holds that the current wave of computer-related innovations might severely affect the labour market, perhaps by causing mass unemployment, perhaps by deskilling jobs and thereby reducing wages, or perhaps by increasing skill requirements, which would increase income inequality between workers with different levels of education and training. These concerns each represent valid hypotheses. But again, many of these concerns are not new to our age. In the early 1800's, 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 1950's and 1960's did not coincide with high and increasing rates of unemployment in North America.

[1] For a pithy summary of the history of technological progress up to 1900, see Chapter 4 of Heertje (1973).

This article is intended for a non-technical audience interested in policy issues related to current technological changes. It will survey what we have learned about the labour-market impacts of recent technological changes. General trends likely to ensue in the coming 15 years will be sketched, and in this light the role of government in facilitating technical change without causing adverse labour-market impacts will be discussed. The next section will outline the predictions of economic theory. Section 3 will 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. Section 4 asks whether the characteristics of the labour market can themselves influence the rate at which new technologies spread. Section 5 will extrapolate these trends in order to provide a broad outline of likely future developments in workplace technology. Section 6 will present a host of policies that might not only increase the rate of technical change but also facilitate workers' adjustments to technology shocks.

2. An Introduction to the Economic Analysis of Technological Change and the Labour Market

As will be shown below, 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 many channels, some direct and some indirect. In particular, the impact of technical change on employment and wages is exceedingly difficult to capture in practice, because the implementation of a new technology in one factory may influence wages and employment in other factories thousands of miles away.[2] 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 need not even be in the same industry as the one undergoing the technological change.

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

A technological change occurs when the application of a new idea allows a firm to increase its output without increasing any of its inputs, such as capital, labour, energy and materials. This loose definition of technical change misses many subtleties, though. Below I list some of these complications.

i) Embodied vs. Disembodied Technical Change

A technical change is 'embodied' if the only way a plant can implement the new technology is to buy new equipment. A good example is provided by the advent of word processors, which improved the efficiency of typists, but could not be implemented unless computers were purchased to replace typewriters. In contrast, a disembodied technical change occurs when existing machinery, or 'capital stock', can be made more efficient by implementing a new idea. In particular, Arrow (1962) advanced the notion of

[2] This article will use the terms "technological change" and "technical change" interchangeably to refer to any change in the way which a firm operates that is designed to increase its productivity. Technological change differs from economists' concept of an "invention". An invention is a new idea about how firms

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 continual 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 in petroleum refining resulting from new techniques such as thermal cracking did not come at the time of the first implementation of the technique but in later years as the industry, in effect, learned by doing. Many of these innovations were largely 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 operating characteristics of new plane designs and new engines grew. Although some of the cost reductions came about through embodied technological changes, such as the redesign of wing flaps, other cost reductions were clearly disembodied. A more recent example comes from the computer industry, where new versions of software, once installed on an existing computer, can often increase the computer's efficiency without necessitating any outlays for new equipment.

The distinction between embodied vs. 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 dialing in the mid 1950's reduced the demand for

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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.

operators by approximately half between 1955 and 1972 at Bell Canada.[3] But 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.[4] 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. Alternatively, if the disembodied technical change takes the form of an unpatented idea, which quickly becomes general knowledge, firms could adopt the idea at little or no cost. Such changes in theory could reduce employment very quickly.

ii) Neutral vs. 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 which 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 straight solid line which is tangent to the isoquant is the isocost line, showing combinations of the two inputs which cost the firm the same amount. In order to minimize costs, the firm will want

[3] Denny and Fuss (1983). Section 3.2 will discuss this paper in more detail.

[4] For instance, suppose that a firm has equal representation in its work force among all ages between 18 and 65. Then retirements alone could reduce employment at the firm by 2.1% per year.

Figure 1
A Neutral Technical Change

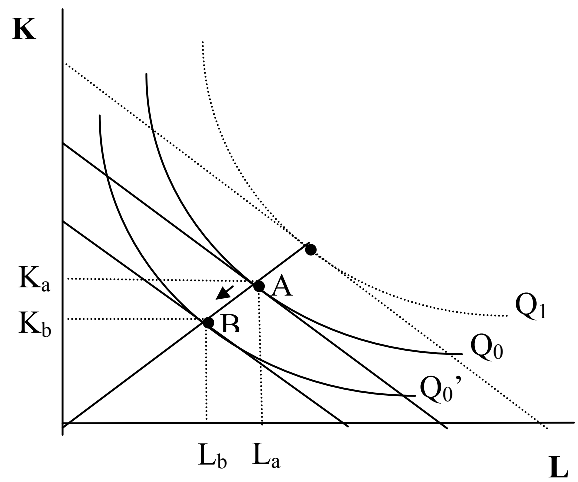
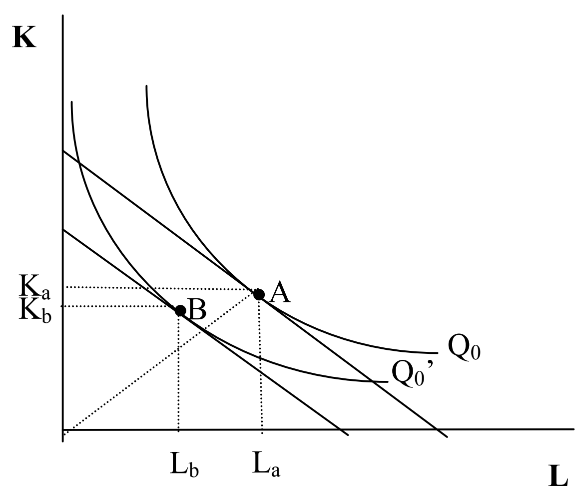


Figure 2
A Biased (Labour-Saving) Technical Change



to produce at a point of tangency between the isoquant and an isocost, as shown, 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 produces output Q_0 at the least cost to the firm, to point B, which represents the point on the new isoquant Q_0' which will minimize costs of producing Q_0 units. The capital-labour ratio, K/L, will be identical in the new equilibrium.

Although this example is one of 'neutral' technical change, it 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, it is possible that the firm will increase output. For instance, 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, the likelihood that employment at the innovating firm may rise after the technical change is greater if the firm is the only one, or one of the only ones, to adopt the cost-saving technology. The dotted lines in the Figure illustrate one such possibility, where after the innovation the firm's sales rise from Q_0 to $Q_1 > Q_0$, increasing the firm's demand for both capital and labour. The central point is clear: we cannot predict that a technological change, even if it reduces the labour required to produce one unit of output, will reduce employment, given that total sales may rise as a result.

Figure 2 shows an example of a 'biased' technical change. A technological change is said to be 'biased' if it changes the ratio of the amount of one input used to that of another input, holding constant input prices. For instance, if K/L rose after the technical change, this would be an example of a 'labour-saving' technological change.[5] 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 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, and will reduce its capital stock from K_a to K_b. The capital-labour ratio, K/L, will 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. As before though, it is possible that the cost reductions brought about by the technical change will cause the quantity of output demanded to rise, so that employment might not fall at all, and in fact could rise.

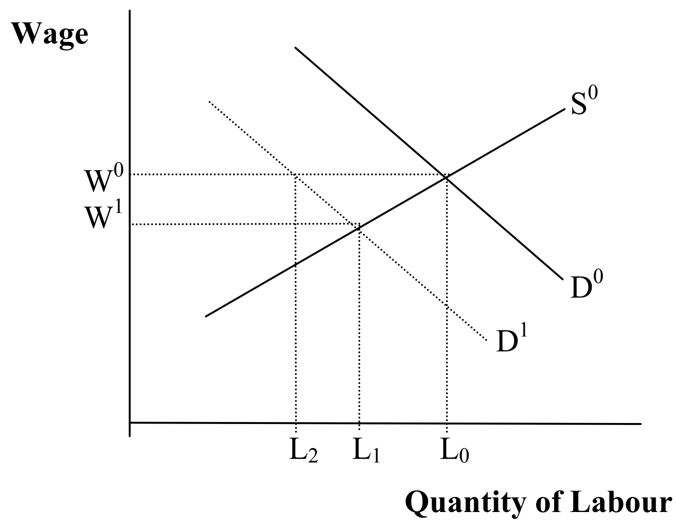
iii) Technological Change in the Presence of Wage Rigidities

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 which industry demands by, for example, 5% at given wages and prices, but this does not literally mean that employment must drop by 5%. 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% shift in the demand for labour might be a 2% reduction in employment and a 2% reduction in wages. No worker is involuntarily unemployed in the sense that at the new wage level,

[5] This definition of neutral vs. biased technical change is referred to in the literature as Hicks-neutral or Hicks-biased technical change. Alternative definitions, based on the ratio of inputs to outputs, are referred

to in the economics literature as Harrod-neutral or Harrod-biased.

Figure 3
The Impact of a Technological Change on Wages and Employment



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 from L^0 to L^2, the technological change simultaneously lowers employment and wages, leaving employment at L^1 and wages at W^1. According to this view, innovation causes wages to drop from W^0 to W^1 for those workers who choose to remain employed. In addition, employment drops because some workers (L^0-L^1 to be precise) to choose not to work at the new lower wage.

But this story assumes that wages and prices move readily to ensure that anybody who wants to work can find a job. If wages are rigid in the short run, then a reduction in the demand for labour could have much more negative effects on employment. The above example of a 5% reduction in the quantity of labour demanded, at given wages and prices, could indeed lead to a full 5% 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. 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.

If a labour-saving technical change is more likely to cost jobs if wages are not flexible, what are some possible reasons why wages will not drop after an adverse shock to labour demand? 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 pre-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 the new marginal product of workers. (The marginal product refers to 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 one economy with flexible wages, the result might be a combined reduction in employment and in wages. The adverse impact on the labour market is thus shared among all workers to some extent -- some decide not to work at all, while those who continue to work are paid lower wages. In another economy, the same innovation might have no short-term impact whatsoever on wages, since institutions such as collective bargaining agreements or government regulation of the labour market precludes 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.[6]

iv) Process vs. Product Innovation

[6] For a good non-technical review of the history of economic thought on technological unemployment, see Standing (1984).

The above discussion has focused on 'process' innovations, which refer to innovations which 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 cannibalizing sales 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, due to the increase in consumer choice. This is likely to increase employment. In general employment will rise, but to the extent that the new product is a substitute for existing goods the employment gains are weakened.

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 which 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 overall employment than to reduce it.

v) 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 and wages that they face. 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 1 may reduce labour demand at that firm, but as discussed under point ii) above, it is quite likely that employment could increase after a labour-saving innovation at the firm, because the firm will now increase its sales considerably due to its lower costs. 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 by an innovative competitor which has just reduced its costs, the absolute level of sales may slump at the firms which fail to innovate, which 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) which innovate, but at those which fail to innovate.*

Consequently, the empirical researcher has to 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 that result at the firm which adopts a new technology, but it may miss the larger employment effects that occur at the firms which 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, but of course they will not succeed in illustrating the differential effects on employment among innovators or non-innovators. It seems reasonable to conclude that the only way for researchers to obtain an accurate view of the impact of technology on employment is to conduct both firm-level and industry-level studies.

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 intricately related by the purchase of intermediate inputs -- the product of one industry -- for use in production in other industries. [7] 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 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, employment will likely rise in industry B due to the increased demand for the materials produced by 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, does purchase materials from industry C. In this way, even industries which appear unconnected in the input-output tables are virtually guaranteed to be interconnected.

One way in which economists have modeled these interactions is through input-output analysis, which 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 1960's and 1970's and more recently, Gera and Mang (1995) and Gera and Massé (1996) who analyze employment growth in the 1970's and 1980's. 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.

General equilibrium theory pays attention to how the relative prices of different inputs influence the mix of inputs, including labour, which a firm demands. This

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[7] See for instance Statistics Canada (1987).

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, which 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 either cost reductions related to process innovation or expanding markets 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 costly search which 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. In other words, if all employers hire from the same pool of workers, any large increase or decrease in labour demand in one industry which results from technical change will spill over into other industries, since all firms hire from the same pool of labour.

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

2.2 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, workers differ in many ways, including the occupation in which they work, and the type of training which 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 shortages of workers might have arisen.

A clear possibility, and a focus of much recent empirical research, is that technological change can affect different occupations differently. In particular, it seems likely that new technologies may be "skill-biased", meaning that, holding constant wages of different classes of workers constant, a firm would want to change the ratio of more skilled to less skilled workers after it has adopted the new technology.

This idea is simple to illustrate using a re-labeled version of Figure 2, which showed how a labour-saving innovation could increase the capital to labour ratio. If that figure had instead illustrated the firm's optimal choice of two types of labour, such as skilled and unskilled, then the vertical and horizontal axes of the figure would be labeled "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, skill-biased technical change of either type could cause both employment ratios and wage ratios between more and less skilled workers to change substantially over time. Furthermore, to the extent that workers in one skill class cannot be substituted for workers in another skill class (whether skill classes are delineated by years of schooling or training specific to an occupation) the possibility of *structural unemployment* induced by technological change emerges. Broadly speaking, structural unemployment refers to unemployment which 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, say, keypunch operators, it may take considerable time before such workers can re-train to work in other occupations where demand remains high. Thus, the possibility of technological unemployment seems much more likely once one allows for heterogeneous labour, with costs to workers from moving between skill classes or occupations. Such re-training costs could make involuntary technological unemployment much more likely.[8]

[8] For a theoretical model of the impact of technological change on the distribution of earnings in a world with heterogeneous labour, see Betts (1994).

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

New technologies might have considerably different effects on young and old workers. Human capital theory suggests that workers who choose how much education and training to obtain will make most of these investments while young, in order 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% 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 which the worker has participated in the work force. For this reason, training and education will look more attractive to the worker while young, when the foregone wages will be relatively low.

Although in most developed economies education is heavily subsidized by government, university students still must pay tuition fees, and also must '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.[9]

Since a worker will typically bear at least part of the cost of education and training, it follows that the worker will prefer to train when young, both to increase the payback period of the investment, and also because the opportunity cost of training will rise with working experience.

In this setting, a technological change which changes the skills required to work in a given occupation may affect young and old workers differently. The older workers, since they have a higher opportunity cost of education and training, combined with a shorter time horizon before retirement, may resist the re-training needed to learn the new technology. Young workers, in comparison, who have most of their career paths ahead of them, and who have lower opportunity costs, are more likely to find it worthwhile to re-train to use the new technology. Of course, 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.

Of course, government must take care to provide an initial set of knowledge and skills to younger generations through public education which is designed to equip them to work well with current technologies. The point of the above paragraphs is to indicate that middle-aged workers, rather than the young, may bear the brunt of adjustments in the labour market when a new technology changes the types or levels of skills required.[10]

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[9] 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. Becker's model is described more fully in Section 6.4.

[10] 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

2.4 Summary

This section has outlined the predictions which 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 the latter require investment in new equipment, and so 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 which installs a new technology. Product versus process innovation represents a third important distinction between types of technical change. A process innovation, which enables firms to produce an output with fewer inputs, will in general reduce employment, unless consumers respond by more than proportionately increasing their purchases. Product innovation, on the other hand, creates an entirely new product, and hence 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.

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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.

Neoclassical economic theory suggests that the effects of a technical change are to alter wages and prices, thus altering the amount of labour which workers are willing to supply and the amount of the firm's product which the market will buy, both in a smooth continuous fashion. In this context, 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, is not possible. The effect of a labour-saving innovation, for instance, will be to reduce wages and hence employment. As shown in Figure 3, those who no longer work after the innovation *choose* not to work at the new lower wage. This type of model may not be entirely realistic. If wages or prices are rigid in the short run, then it becomes possible that 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 becomes 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 (process innovation) or new markets (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 at the competing firms in the industry *which fail to innovate*. This insight suggests that industry-level studies are needed in addition to firm-level studies in order to capture the overall effect of technological change. Second, an innovation in one industry may affect employment and wages in other industries because the products from these other industries are used either directly or indirectly in the industry which is innovating. Third, even if another industry appears to be completely unrelated to the industry which has undergone the technical change, in the sense that the innovating industry does not purchase any of the products of the non-innovating industry either directly or through other intermediate industries, the non-innovating industry may experience changes in prices in its labour market or the market for other inputs. For instance, if 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, of 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 which are not skill-neutral. For instance, a skill-using innovation will tend to increase both the wage premium earned by skilled workers relative to less skilled workers, while increasing the relative employment of more 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. Finally, as discussed in Section 2.3, a skill-using innovation is 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 which fully captures the complex general-equilibrium interactions across industries alluded to above. But research on how recent technical changes have affected wages and employment at the firm and industry level, and how it has affected the distribution of wages and employment among skilled and unskilled workers, has received considerable attention.

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

3.1 The Extent of Technological Change in Canada, the U.S. 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 through various methods. First, 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 sensitive to measurement error. A second problem is that 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. Indeed, David (1990) argues that the "productivity paradox" of stagnant productivity growth at a time when 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. Similarly, he notes, the rate of diffusion of electrification at the turn of the century was very slow, because industry needed to restructure radically, and so electrification of industry did not lead to immediate increases in productivity.

Thus, the second sub-section below will review more direct evidence on the rate of technological change, that is based on surveys which attempt to measure the rate at which firms have adopted new technologies.

3.1.1 Econometric Evidence

The two oil shocks induced by the Organization of Oil Exporting Countries (OPEC) in the 1970's are widely credited for a slowdown in the growth rate of productivity in the 1970's relative to the 1960's. Morrison (1992) attempts to explain differences in this productivity growth slowdown in Canada, the U.S. and Japan, while carefully controlling for a number of factors including the tendency for productivity to fall during recessions and the possibility of economies of scale, under which productivity rises with the level of production. After correcting for changes in productivity that reflect business cycles and economies of scale, she finds that over the 1960-1982 period, productivity growth in Canada was rather low, at 0.062% per year, compared to 0.359% and 0.987% per year over 1960-1981 in the United States and Japan respectively. Between 1960 and 1973, the year of the first OPEC oil shock, productivity growth was very similar in Canada and the United States. 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, according to Morrison.

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. Nevertheless, it appears that all three countries in Morrison's study have exhibited increasing productivity over the two decade period under study.[11]

3.1.2 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 survey of approximately 1000 firms across Canada, conducted in late 1985.[12] The survey reports the proportion of firms using a variety of computer-based technologies, such as computer-aided drafting and manufacturing (CAD/CAM) and the computerization of office work. The survey, called the Working with Technology Survey, found that approximately two-thirds of the instances of computerization reported involved the purchase of computers for office work. About two-thirds of the firms reported at least some office automation. Automation on the factory floor was proceeding much more

[11] For other comparisons of productivity growth between Canada and the United States see Denny, Bernstein, Fuss, Nakamura and Waverman (1992) and Mullen and Williams (1994). The former, which also studies Japanese productivity growth, finds that in general Japan's productivity has grown more quickly than Canada's. Both of these studies provide evidence that Canadian productivity has in general converged toward that of the United States in the postwar period. The latter paper concludes that this convergence stalled in the 1970's and early 1980's. Neither study controls for scale effects or sub-equilibrium effects, as done in Morrison (1992). 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 in Canada between 1986 and 1990.
[12] This paragraph is based on Chapter 6 of Economic Council of Canada (1987).

slowly. As of 1985, only 43% of the manufacturing firms in the survey reported any process automation.

The Economic Council of Canada study compares the use of certain technologies from its survey with levels found in other surveys. (Economic Council of Canada, 1987, pages 78-79.) It reports that as of 1984, the ratio of robots used for flexible automation per 10,000 employees was 3.7 in Canada, compared to 4.7 in the U.S. and 32.1 in Japan. Similarly the Council reports that Canada lagged behind West Germany, Britain and France in its rate of adoption of microelectronics in manufacturing.[13] A 1991 survey of 23,000 Japanese firms revealed that about 80% used a computer network; about 65% had installed an intra-firm network and 44% had installed a network that enabled communications with other businesses. See Motohashi (1996). By way of comparison, Baldwin and Rafiquzzaman (1996) report that about 40% of Canadian manufacturing firms had installed a local area network by 1989, and that 35% had installed an inter-company computer network. This comparison is not exact, since the Japanese figures refer to all industries, and also refer to 1991, not 1989. But the data suggest that Canada may have fallen behind Japan slightly in the installation of computer networks. Thus, it appears that new technologies may have diffused more quickly in the U.S. and in Japan than in Canada. This finding accords with the observation in Section 3.1.1 that rates of productivity growth in Canada have lagged behind those in the United States and 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 1980's, but even in the 1990's a large proportion of workers still do not work directly with these

[13] The corresponding study of the adoption of microelectronics in these three European countries is described in Northcott, Rogers, Knetsch and de Lestapis (1985).

technologies. For instance, Grayson (1993) analyzes the General Social Survey of 1989, which surveyed 9338 Canadians on a wide number of issues. Respondents were asked "In the last 5 years, how much has your work been affected by the introduction of computers or automated technology?". Of these respondents, 28% said 'greatly', 15% said 'somewhat', 14% said 'hardly', and 42% replied 'not at all'. This finding, that even by 1989 only a minority of Canadian workers felt that their work had been affected by computers, suggests that the spread of computer technologies has not occurred instantly by any means. As mentioned in Section 2.1, when new technologies are embodied, the cost of buying the necessary equipment can limit the diffusion rate of the new technology. This will be important to bear in mind when considering the evidence surveyed in the next section on the impact of innovation on employment and wages.

Another 1989 Canadian survey, the Survey of Manufacturing Technology, gathered information about the use of 22 technologies (all based on microelectronics) at approximately 2900 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% 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 4 year intervening period manufacturing plants had 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. For instance Brynjolsson and Hitt (1996) compile a panel of 600 American firms in the Fortune 1000 covering the period 1987 to 1994. The average share of computer costs in terms of total sales is approximately 1%.[14] This number seems small, but it is not insignificant compared to the average cost share of non-computer capital of 34%.

Greenan and Mairesse (1996) analyze the results of a survey of French 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 0.25 in 1987 to 0.43 in 1993. While the French workplace is steadily becoming computerized, it would be an over-statement to claim that jobs which do not require use of a computer are about to disappear.

Although the empirical literature provides two distinct methods of measuring technological change -- productivity growth measures and surveys of technology use -- it would be reassuring to confirm that advanced technologies have indeed contributed to productivity growth. The studies by Brynjolsson and Hitt (1996) and Greenan and Mairesse (1996) are unusual in that they 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 only several years after the initial investment. The latter study by Greenan and Mairesse suggests that computer investments have increased labour productivity in France. The paper also finds that total

[14] The authors include in computer costs the estimated rental price of all computers from mainframes to personal computers but do not include software expenses, computer staff or telecommunications

factor productivity is positively related to computer usage, but the relation is not statistically significant once they control for unobserved variations in labour quality across firms (in which the assumption is made that the quantity of labour is proportional to total wages paid, not the total number of workers). In a Canadian context, Baldwin, Diverty and Sabourin (1996), in a study of Canadian manufacturing based on the 1989 Survey of Manufacturing Technology, establish that labour productivity tended to be significantly higher in plants which reported use of advanced technologies. Interestingly, the ratio of labour productivity in plants which in 1989 reported usage of advance technology to those that did not in most cases rose significantly between 1981 and 1989. Of course, increases in labour productivity could reflect a rise in the capital to labour ratio, as well as technological change itself. In contrast to these studies, Motohashi's (1996) study of computer networks in Japanese firms finds at best a weak relation between network use and productivity at the firm level. Of the four studies, the one by Brynjolsson and Hitt (1996) is perhaps the most persuasive because it traces the changes in computer usage and changes in productivity over time at individual firms, rather than using differences in productivity or computer usage at a point in time, in order to identify the contribution of technology to productivity growth.

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 and/or productivity growth. Using information on adoption of micro-

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equipment.

chip technologies, it appears that Canada's rate of technological change may lag behind that in 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 that in the United States or Japan.

3.2 Have New Technologies Reduced Employment and Wages?

Section 2.1 emphasized that a new technology, even if it was 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. Section 2.1 also stressed that the main employment consequences of new technologies might occur at the plants which 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 dialing on employment of different occupations. They establish that this labour-saving technology was the dominant factor depressing labour demand over this period. In particular, the reduction in the share of operators in total hours worked from 38.7% in 1952 to 18.3% in 1972 occurred mainly due to the new technology, rather than price-induced labour-labour substitution or substitution of capital for labour. Rapid increases in output limited the reduction in the demand for operators to about 3% 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 1980's and 1990's, 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.

The aforementioned survey of Canadian firms by the Economic Council of Canada (1987) directly 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% of this 66.5% said that layoffs had been used to solve the problem. The most common response, listed by 44.0% of firms, was to transfer redundant workers to other parts of the company.

Betts (forthcoming) 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 which controls for 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 reduced the cost share of labour slightly. 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 in order to compare growth between 1982 and 1989 in market shares, wages and employment in Canadian plants which had adopted advanced technologies relative to growth in plants which had not adopted. 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, the employment share of innovators grew slightly during 1982-1989, but there was no statistically significant difference in employment share in 1989 relative to 1982. In other words, adoption of computer-related technologies in the 1980's did not appear to have large effects on employment shares. This analysis of *shares* cannot address the overall impact on employment, though, since an equally large reduction in employment, say 10%, among adopting plants (due to increased labour productivity) and non-adopting plants (due to decreased market share among the non-adopters) 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 and 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 1970's and 1980's 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 where high-technology industries are defined as those with the highest rate of R and D spending.

According to the Baldwin, Diverty and Sabourin (1996) work, the relative wage between adopters and non-adopters in Canadian manufacturing grew by about 2-8% during the period 1982-1989, depending on the type of advanced technology examined. It is important to recognize, as the authors state, that 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 explanation is that labour productivity has grown more quickly in innovating plants; the second explanation is simply that the new technologies have required hiring of 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 and 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 which adapted CNC machine tools. Their data suggest that the only negative employment effects might arise due to job losses at plants which do not innovate, and therefore which lose market share. They found little difference between the wages of those operating CNC machine tools and those operating machine tools in plants which had not upgraded.

Overall, 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 the firms which innovate. Relatively little is known about the impact of technical change on non-adopting firms within the industry, though. Industry-level studies, such as that by Betts (forthcoming), suggest that overall, 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.

3.3 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 which 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 1970's and 1980's is provided for the United States by Katz and Murphy (1992) and for Canada by Freeman and Needels (1993). Both sets of authors observe that if the ratio of highly educated workers to less educated workers increases over time, while relative demand stays constant, this trend should decrease the ratio of wages of highly educated to less educated workers. But the opposite has happened in the United States, which in the 1980's witnessed the largest increase in the college wage premium (i.e. the difference between wages paid to college graduates and wages paid to high school graduates and/or dropouts) in the period since World War II.[15] The implication is that during the 1970's and 1980's 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.

[15] 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

The observation that workers are becoming more educated does not necessarily imply that skill requirements are increasing, if workers are increasingly overqualified for the jobs which they hold. But a separate information source suggests that these trends reflect at least in part genuine increases in skill needs. By combining observations on how the distribution of jobs by occupation has evolved with detailed information on the skills required in different jobs (based on a survey of firms), Howell and Wolff (1991) conclude that in the United States the skill requirements of firms 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 trends in employment of production and non-production (blue-collar and 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 1980's, along with 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 and D spending and computer investment are both positively correlated with changes in white collar workers' share of the wage bill between 1979 and 1987.[16] 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

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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.

[16] See Section IV of Berman, Bound and Griliches (1994) for a review of other, mostly American, studies which come to similar conclusions.

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 of 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 can be introduced on the plant floor only by buying new capital equipment (i.e. to the extent that technical change is embodied), 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 U.S., and interacts the returns to job tenure with previously estimated measures of total factor productivity growth (TFP) in the worker's industry. Since human capital theory predicts that firms will require workers to share the costs of firm-specific 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 State (but not in Japan), suggesting that at least in the United States more innovative industries require more highly educated workers.

Unfortunately, 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 in the United States workers in industries with higher TFP growth rates are more likely to receive training. The results are not uniform but suggest that in many cases this is true. This finding suggests that Tan's assertion that the finding of 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. The aforementioned paper by Betts (forthcoming) finds that in over half of manufacturing industries in Canada, technical change during the period 1962 to 1986 was skill-using: the change in the share of white collar labour in 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 some cases, it declined but insignificantly. For blue collar workers 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.

While the above study gives an overall picture of the extent of skill upgrading, it is useful to confirm at the firm level that new technologies have tended to increase skill requirements. The literature is far from unanimous, but the overall conclusion is that more often than not, recent innovations have increased skill requirements. For instance, 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.

Similarly, the Ontario Task Force on Employment and New Technology (1985), in a survey of Ontario firms, found that many occupations were listed by at least 50% of firms as requiring more skills than in the past due to technical change. There were no occupations for which more than 50% 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 not surprising given that the Peitchinis study was carried out in the middle of the 1970's, 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.[17]

Evidence from Europe also points towards skill upgrading. Northcott, Rogers, Knetsch and de Lestapis (1985), in a survey of 3800 manufacturing firms in Britain Germany and France, find that workers with expertise in microelectronics represented the

[17] 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).

main worker shortage in all three countries. Other skill shortages mentioned by firms were far less common. O'Farrell and Oakey (1993) found in Britain that 14% of machine tool operators saw increases in skills after the introduction of computer numerically controlled machine tools in a sample of firms in the U.K., compared to deskilling for only 2%.

Given the evidence listed above that recent technical changes have increased skill requirements, what are plausible reasons for why skill upgrading has occurred? The findings of Bartel and Lichtenberg (1987) are particularly enlightening. Their observation that more skilled workers are favoured in industries with newer vintages of capital suggests that perhaps new methods are innately hard to implement; highly educated workers are better able to adapt 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.[18] 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. In a sense this is a moot point if new technologies continually appear.

Another reason why new technologies based on microelectronics might require more skilled workers is the sheer cost of attempting to design electronic devices which are simple to learn. Binkin (1988) offers a revealing account of attempts by the United States 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 that deskilling. Based on a series of plant visits, they concluded that often engineers in charge of choosing among competing technologies 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 which employed a few, highly skilled, workers over possibly cheaper technologies which 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 in particular has led to skill upgrading is that it has combined formerly separate jobs into one. Whereas in the past preparation of ad copy, technical journals, newspapers, or for that matter, professors' manuscripts, required contributions from typesetters, graphic artists and photographic specialists, it is now quite literally possible for one person to do 90% 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

[18] See for instance Feder, Just and Zilberman (1985).

reversing the trend towards greater specialization, and in so doing, are increasing the range of skills required by workers.[19]

3.4 The Impact of Technology on Workers of Different Ages

Section 2.3 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 survey of American workers conducted in 1967, find that the proportion of workers who in the previous five years had accepted a position which involved working with different machinery tended to decline sharply with age. For instance, 30% of workers under age 25 had accepted such a position compared to just 10% of those aged 60-64.

[19] For several examples of case studies which suggest that computers have led to a synthesis of job tasks, and hence skill upgrading, see pages 47-50 of Betts (1990).

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% of firms reported that redundancies had led to transfers of workers to other work. But 6.4% of firms reported that early retirement programs had been used to reduce the work force when a new technology had been invented. This finding suggests that older workers may indeed be disadvantaged relative to younger workers when new technologies arrive.

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: 1) Technological which is correctly anticipated causes workers to retire later, so that workers can have a sufficient payback period for the additional training required. 2) 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.

3.5 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) are skill-biased technical change and changing trade patterns. See Lawrence and Slaughter (1993) and Borjas and Ramey (1994) for 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. The latter 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 blue-collar and white-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 and 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 1-17% 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 U.S., both textiles and steel mills became quite uncompetitive during the 1970's. A spate of investment in newer computer-related technologies in both of these industries ensued in the 1980's. But note 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. 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.

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

4.1 Induced Innovation

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

The idea that a shortage of skilled workers has delayed implementation of new technologies garners considerable empirical support. 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". For instance, in the manufacturing sector 12% of firms cited this reason as the key barrier to innovation, while 38% of firms rated it as one of the three most important barriers.

The aforementioned survey by the Economic Council of Canada in 1985 found that the most commonly cited barrier to innovation was the high cost of equipment. Two problems were the second most commonly cited obstacles, each cited by just under one third of the sample. These 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) [20]

Similarly, Globerman (1986) found 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% of firms 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 which 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 have aimed at replacing command-driven software which is difficult to learn (DOS, Wordperfect 5.1 being good examples) with intuitive user interfaces and programs (Windows and almost all popular word processors released in the 1990's). Other commonplace examples are grocery store checkout scanners, which dispense with 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 in order to prevent being closed out of the world market. Such episodes are likely to occur on a continual basis. Canada, as a developed country

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[20] "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'

with large supplies of well trained and educated workers relative to developing countries, will find that closer integration with developing countries, for instance, through the recent extension of the free trade agreement to Mexico, will find stiff competition from abroad in industries which employ mainly unskilled workers. 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. The latter scenario 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 order to justify maintaining the wages paid in Canada to less skilled 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.

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spending on personal computers each year, "...fully 70% goes to training and support".

4.2 Technology, Investment and Unions

Evidence from the United States (Hirsch, 1991) and Canada (Odgers and Betts, 1995) 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 which 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 marshaled in Reshef, Stratton-Devine and Bemmels (1994). Yet a survey of Canadian plants finds that only 20% of plants reported that employee reluctance was an obstacle to technological change, and that "restrictive collective agreement provisions" were cited by less than 10% of firms (Economic Council of Canada, 1987). Betcherman (1991) finds that the union wage premium (over wages paid to non-union workers) was lower in firms which had innovated, suggesting that unions were not capturing rents from new technology. But there is a problem of interpretation here: did firms which innovated have lower union wage premia 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 US 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 1980's 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 1980's, the 1990's may prove quite different.

4.3 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 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 will be more likely to come forward with suggestions, even if they make one task redundant, because they know that their jobs are secure given that they are broadly trained. Hence, rotating workers between jobs, and training them in each task, may in fact 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 emphasizing 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.

5. Likely Trends in Technology and Labour Markets over the Next Fifteen Years

Making specific forecasts on technologies likely to diffuse quickly over the next 15 years is extremely difficult, 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 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.

1) Microprocessors will continue to spread throughout the factory floor, beginning by automating simpler repetitive tasks, and then by taking over more complex tasks.

2) '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.

3) Ongoing improvements in telecommunications will accelerate the trend toward geographically distributed production. One implication of this trend is that high-skill jobs in the future 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.[21]

4) The rate of obsolescence of both capital and skills has grown, and will continue to grow. For example, Oliner (1996) estimates that the service lives of machine tools

diminished in the 1980's because computer numerically controlled machine tools began to make the older machine tools obsolete. The 1990's has seen a major investment in new computing paradigms, in particular away from mainframes toward client-server, 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.

5) Considerable evidence suggests that the overall thrust of recent innovations has been to increase skill requirements. But this trend is not inexorable, and could level off if firms find it to their advantage to invent and/or adopt technologies which require less training than in the past.

6. Policy Responses in a World of Quickly Evolving Technologies

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

Given the slow but steady trend toward increasing skill requirements, policies for helping university-bound youth and non-university-bound youth to embark successfully on careers are needed more than ever.

First, increased educational standards in public schools, backed up by testing of students, could help to prepare students for the work force. In several Canadian

[21] To give a specific example, one engineering firm in San Diego is reportedly planning to open up three

provinces and most American states, the requirements which students need to fulfill before leaving grade school are minimal. Public schools are clearly not helping students by letting them drop out, or even to graduate from high school, without testing for competency in verbal and written expression and 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. Variations in grading standards appear to be more effective in changing rates of increase in test scores than are variations in class size or in teacher traits. Another way of implementing standards is through the institution of graduation exams. As of 1991 British Columbia, Alberta, Quebec and Newfoundland had provincial exams which constituted one of the hurdles students must cross in order 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 then analyzes math and science scores of 42000 Canadian students who participated in the 1991 International Assessment of Educational Progress. He finds that students from the provinces with curriculum-based external examinations score significantly more highly. Such policies could well be extended in other provinces. Standards should also be set for school-leavers.

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 the primary sector. Furthermore, computers in schools appear to increase the rate at which students learn. Betts (1995) studies the growth in math and science test scores of a representative sample of American high school students, and finds that computers in the

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research offices, spaced evenly around the world, in order to facilitate work on projects around the clock.

science or math class have a large positive impact on rates of learning. Thus the provision of extensive computer training of school students would probably do much to ensure that students make a successful transition into the working world.

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 1970's, 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 to revamp radically 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, represent another possibility. In the United States, the National Assessment of Vocational Education found that in the early 1980's 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.[22] 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.[23]

More specifically, what skills should vocational education 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 1960's and

[22] National Assessment of Vocational Education (1989).

1970's, 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. 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 which 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.

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 general public. 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 can practice fully. [24] 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

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[23] For a thought-provoking review of recommendations for change in the American vocational education system, see Boesel and McFarland (1994).

recognized Associate Degrees in a wide variety of fields, in a sense has a more structured certification system.

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 that were described in Section 4.1.

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: the standards, if enough input is received from industry, 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 which make recruiting young workers such an uncertain process. Furthermore, national standards would reduce provincial barriers to movement of workers. Although this might seem like a hidden subsidy for the more industrialized provinces, which could now recruit from the other provinces with surer knowledge of the training background of workers from the less industrialized provinces, 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 on their own to set standards because such

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[24] See Kinzer (1993).

standards represent a “public good” -- the creation of standards will benefit all employers, not just those which 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 were recognized nationally. The idea of national standards in occupational licensing has long been practiced 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. (See Commission of the European Communities, 1993, Chapter 2.) 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 which will do best in attracting multinational firms to their shores will include those which can provide these prospective employers with a well administered, easily understood, and *consistent* system for credentialling workers. A national system of licensing or certificates would move a long way in that direction.

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 nation-wide 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 re-take 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. (See Dore and Sako, 1989.)

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, the collection and dissemination of information on graduation rates, employment rates, and perhaps earnings, for students in secondary and postsecondary vocational programs and apprenticeships is in order. 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.

6.2 Policies for Older Workers: Re-Training

It is older workers, whose education and training have become partly obsolete due to computer-related innovations in the workplace, who may be most threatened by technological change. A number of policies may help to inoculate older workers against technologically induced unemployment. First, government should encourage businesses to retrain such workers through tax credits for training. Second, a re-licensing system similar to Japan's would also ensure that older workers maintained and upgraded their skills on a regular basis. Such a policy would reduce the chances that older workers will be laid off as new technologies emerge. Re-licensing would also likely increase firms' willingness to hire older workers who become unemployed. Experience-rated unemployment insurance premiums are a third possibility. This policy, used in the United States, calls for firms which have laid off a smaller than average proportion of their workers in the past to pay less than average into the fund which 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 the survey conducted by the Economic Council of Canada (1987) suggests that in the mid 1980's Canadian firms were already preferentially using re-training or transfers rather than layoffs to deal with redundancies.

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 the United States in 1986 39% of students enrolled in public vocational institutions were age 30 or older, and 34% of students in all two-year public institutions were 30 or older. These figures compare to just 14% 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) has found 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 (1990) 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 1980's, come to similar conclusions 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 (1990) is that small firms in Canada are much more likely to participate in government programs to retrain displaced workers.

One reform which 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 which provide longer, more thorough training, and which confer upon the worker a well recognized certificate or degree at the end of the program.

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

Evidence suggests that training of workers is essential in the global marketplace. As documented in Section 3.3, 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. Section 4.3 reviewed theoretical evidence suggesting that the way in which firms organize their workforce can significantly impact the firm's 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 of 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. American evidence also suggests that a package of worker incentives such as profit sharing can increase productivity growth substantially.

6.4 The Case for Cooperation among Community Colleges, Universities, Business and Government

The evidence marshaled above makes clear that new technologies have tended to increase skill requirements, and that a lack of sufficiently trained and educated workers is frequently cited in surveys of firms as 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 the other firms can poach the worker from the firm which has provided the training by paying a higher wage. [25]

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 prove infeasible, regardless of the wage gains which 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.

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, of 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 due to both liquidity constraints among workers and the unwillingness of firms to pay for general training of workers. Japan represents a good example of a country where government plays a predominant role in training. Dore

[25] Becker argues that if training provides skills which are useful only at the given firm, then sharing of the costs between worker and firm makes sense. Realistically, almost any training program will provide at least some general skills, which creates the above dilemma: a firm which subsidizes training is likely to lose its workers after they have finished their training.

and Sako (1989, page 143) estimate that in Japan during the period 1984-1986, government paid for approximately three times as much training as did firms.

Firms can reduce the second problem above, of informational asymmetries, by providing constant feedback to educators about the changing skill requirements on their shop floors.[26] 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 directed to firms for training might generate huge subsidies for activities that in fact had nothing to do with training.[27]

The idea of cooperation between the private sector and government in order 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.

[26] A study of American postsecondary vocational education confirms that the best postsecondary programs, as judged by employers, were more likely to have maintained direct links with local employers and professionals. See Depietro et al. (1989).

[27] More broadly, a common complaint in the literature which evaluates 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 American research.

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.[28] This finding suggests that increasing educational standards must go hand in hand with any attempt to implement informal or formal apprenticeships for young workers.

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 1980's, 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 unwillingness of 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. The differential uptake rate may

[28] See U.S. Office of Technology Assessment (1995) for details on the School to Work Opportunities Act.

reflect liquidity constraints or lack of information on the part of smaller firms, rather than a lack of willingness by small firms to train. Leigh (1990) reports the results of a survey of Canadian firms which found that smaller firms which accepted government training subsidies were much more likely to report that they would not have been able to provide the training without government support than were larger firms.

Government subsidies for training are not the only fertile ground for cooperation between government and business. 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.

Finally, in recognition of the constant evolution of skill requirements, both universities and community colleges should institute or expand a series of mid-career 'refresher' courses for workers who have previously received degrees or certificates. Postsecondary institutions could also become involved in the re-licensing of workers in certain occupations, as was recommended above. For such courses to be useful, industry should be involved in drafting an updated syllabus for these refresher courses in each field on a regular basis.

7. Conclusion

The notion of a technological revolution which has led to mass unemployment and plummeting wages is inconsistent with 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 cope with firms' changing needs. Plants which implement new technologies do not seem to reduce employment by large amounts, perhaps because they gain market share thanks to the ensuing gain in productivity. Indeed, it may be that job losses from innovation result mainly at the firms which *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 is relevant, because it may help 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 the way in which firms train workers, and provide incentives to workers, can influence the firm's level of productivity. It follows that improved training along with improved incentives such as profit sharing, could actually increase the rate of technical change in Canadian industry.

Government has a key role to play in this process to ensure that the ongoing stream of technological changes within firms each year 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. A key to success in this endeavour is cooperation between postsecondary institutions, as purveyors of training and education, provincial and federal government, as subsidizers of education and the setters of standards in certificate in degree programs, and business, which plays a crucial role in guiding the country's training efforts toward the areas of greatest need.

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