Impact of the Adoption of Advanced Information and Communication Technologies on Firm Performance in the Canadian Manufacturing Sector

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Table of Contents

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Abstract

This paper investigates the evolution of the industrial structure in the Canadian manufacturing sector and its relationship to technological change by examining the take-up of advanced technologies and how it is related to the stochastic growth process in the plant population. Its framework is grounded in the view that growth is a stochastic process that involves learning. Experimentation with new technologies rewards some firms with superior growth and profitability. Examining how growth is associated with the choice of different technology strategies indicates which of these is being rewarded.

The evolution of this process is studied by examining the relationship between the uptake of advanced technologies and the performance of plants in the manufacturing sector. This is done by using cross-sectional data on advanced technology use and by combining it with longitudinal panel data on plant performance. In particular, the paper examines the relationship between the use of information and communications technology (ICT) and the growth in a plant's market share and its relative productivity.

The study finds that a considerable amount of market share is transferred from declining firms to growing firms over a decade. At the same time, the growers increase their productivity relative to the decliners. Those technology users that were using communications technologies or that combined technologies from several different technology classes increased their relative productivity the most. In turn, gains in relative productivity were accompanied by gains in market share. Other factors that were associated with gains in market share were the presence of Research and Development (R&D) facilities and other innovative activities.

Keywords: information and communication technologies, ICT, firm performance

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1. Introduction

This paper investigates the evolution of industrial structure in the Canadian manufacturing sector and its relationship to technological change by examining the take-up of advanced technologies and how it is related to the stochastic growth process in the firm population. Its framework is grounded in the view that growth is a stochastic process that involves learning. Production opportunities are not unique and the growth of individual firms occurs in a world where each explores which advanced technologies out of a set of many technological possibilities might be the most suitable to its circumstances. Firms adopt new, advanced technologies as they learn about their possibilities and experiment with their applicability to their own specific situations. Experimentation rewards some firms with superior growth and profitability.

A range of new advanced technologies is available at any point in time. Not all firms will choose the same set. Nor will a particular set result in equal rewards across all environments. The environment faced by a firm and the history of the firm determine the end results of experimenting with new technologies. What may be 'best practice' is difficult for firms to ascertain ex ante and only evolves as the selection process demonstrates which firms have made the 'correct' decision.

New technologies are adopted slowly into the production process because the amount of learning by experimentation is large. A large number of complementary machines and production processes have to be put in place before new technologies can find useful applications.[1] And finding the correct combination requires considerable trial and error. Mature technologies can be incorporated into the production process with the use of blue prints. When knowledge is readily codifiable and easily transferred from one firm to another, diffusion is rapid. By way of contrast, the introduction of new technologies during the early phases of an industrial transformation is more akin to prototype construction. Plans are used as the foundation for a prototype, but the construct changes over time as experience dictates needed changes. Search takes place through a learning-by-experimentation process.

This paper describes how this process evolves by examining the impact of advanced technology adoption on the performance of plants in the manufacturing sector by using cross-sectional data on advanced technology use and by combining it with longitudinal panel data on plant performance.

It focuses on technologies associated with the information and communications technology (ICT) revolution. The relatively cheap processing power of microchips has brought about a dramatic technological change in the manufacturing sector. On the one hand, these consist of a number of labour-saving technologies where computer assisted machinery has been developed to replace manual labour. For example, computer operated robots provide an efficient and safe alternative to humans for repetitive jobs like spot welding and painting. Automated guided vehicle systems replace costly personal delivery. However, the truly dramatic element of the IT revolution has been the birth of 'soft manufacturing', which Bylinsky (1994) notes, differs from

[1] See Baldwin and Sabourin (2000) for a study of the importance of advanced engineering practices for advanced technology adoption.

traditional manufacturing in that software and computer networks are more important than production machines. Furthermore, Bylinsky argues that the effect of the 'soft-manufacturing' technologies has been to enhance rather than replace the abilities of workers. Flexible manufacturing systems with the agility to provide information quickly to workers and to management allow for a high degree of customization at a much lower cost than in the past. The ICT revolution has allowed plants to deliver customized products in small quantities, allowing them to change product lines quickly to meet changing consumer demands.

The first section of the paper examines certain characteristics of the stochastic process that are relevant to the measures of firm and plant performance that are used in this paper. It enumerates the extent to which plants replace one another by transferring market share from one to another over the ten-year period 1988 to 1997 and the extent to which this has been accompanied by changes in relative productivity and profitability.

The paper then studies the effect of technological change on productivity. It examines the relationship between the use of advanced manufacturing technology—such as programmable controllers, local area networks and computer-aided design and engineering equipment—and plant performance. This allows us to discern whether the technological choices are associated with growth. Not all plants have adopted new computer-based advanced technologies. We examine the relationship between changes in plant market share and relative productivity over the time period and the advanced technologies that plants manage to successfully implement by 1998—showing whether plants using advanced technologies, in effect, are selected for survival and growth by the search and culling process that is associated with competition.

The economic performance data used in the study come from a longitudinal file developed from the Annual Survey of Manufactures, which includes data on employment (production and non-production), labour productivity (value added per worker), wages and salaries, manufacturing and total shipments, and manufacturing and total value added for Canadian manufacturing plants during the period 1988 to 1997.[2] The economic performance data were linked to data on advanced technology use at the plant level derived from the 1998 Survey of Advanced Technology in Canadian Manufacturing. In what follows, we will be using plants as the unit of analysis.

[2] Total value added differs from manufacturing value added because of non-manufacturing activities of manufacturing establishments that are intrinsic to the manufacturing operations of the firm.

2. *The Growth Process*

Growth and decline takes place as some plants wrest market share away from others. The amount of change in the manufacturing sector is large. Over the period 1988-1997, some 47% of market share is transferred from those losing market share to those gaining market share within a 4-digit industry, on average. Growing continuers account for 26 percentage points of the gain in market share, while entrants account for the other 21 percentage points. Decline in market share, on the other hand, comes from declining continuers (17 percentage points) and exits (30 percentage points).

This turnover is made up of a large number of small changes, with many new firms that seize small amounts of market share and many incumbents who grow slightly at the expense of others. At the same time, there are a large number of exits, most of which are quite small, and many incumbents who also decline. In the short run, much of this change is reversed—but in the longer run, over periods of a decade, the changes lead to substantial shifts in the relative rankings or position of industry participants.

The extent to which plant growth and decline leads to changes in relative rankings is presented in Table 1. Plant market shares at the 4-digit level are calculated for 1988 and for 1997 and then all establishments are assigned to quartiles in both the start year (1988) and the end year (1997) of the period, based on the rankings of their market share. Table 1 provides the movement of continuing establishments up and down the market-share hierarchy.[3] It gives the percentage of continuing plants, who started in a given quartile in 1988, that had moved up or down a quartile or two, or stayed in the same quartile.

Throughout the decade, there has been substantial change in relative status. For example, of those continuing plants that were in the second quartile in 1988, 23% fell to the bottom quartile in 1997; 17% moved up to the third quartile; while 57% remained in the same quartile.

Table 1. Market Share Transition Matrix for Continuers (1988-1997)

Market Share Quartiles (1988)	Market Share Quartiles (1997)			
	Q1	Q2	Q3	Q4
	percentage of establishments			
Q1	82	15	3	0
Q2	23	57	17	2
Q3	2	22	60	16
Q4	2	2	13	83

There is somewhat greater inertia in the plants that started in the bottom or top quartile—partially because their movement possibilities are truncated, either in an upwards direction for the top quartile or downwards for the bottom quartile. Over eighty percent of the plants in these two groups remained in the same quartile group. Close to a fifth moved to the adjoining category.

[3] In Table 1, the quartiles are calculated using all establishments, but the shares are calculated only for continuers.

Success in terms of the growth in market share is accomplished in various ways. Plants may either improve their relative cost structure or may be able to produce higher quality products for which consumers are willing to pay higher prices. In either case, we would expect this to be reflected in higher levels of labour productivity relative to the industry mean. Indeed, the gain in market-share is accompanied by a growth in relative labour productivity. If we divide continuing plants into two equal groups based on market-share changes, we find that the relative labour productivity of gainers is equal to that of decliners at the start of the period (Table 2). Initial productivity in the continuing group is, therefore, not a good predictor of subsequent market share performance. However, over the period, those gaining market share simultaneously manage to increase their relative productivity. By 1997, their relative productivity is 22% above that of the declining group. By the end of the period, the market has rewarded those who have managed to improve their efficiency or the quality of their product and concomitantly their labour productivity with an increase in market share.

Table 2. Mean Relative Labour Productivity for High-Market-Share Gainers/Decliners and Low-Market-Share Gainers/Decliners

Market Share Change (1988 to 1997)	Relative Labour Productivity (RLP)		Δ RLP
	1988	1997	1988 to 1997
Two category scheme			
• Low gainers or decliners (median and below change)	1.002	0.867	-0.135
• High gainers (above median change)	0.998	1.078	0.080

The amount of change in relative labour productivity can be investigated using the same type of transition matrix that was applied to market-share changes. Labour productivity is defined here as total value added divided by total employment. It is calculated for each plant relative to its industry's labour productivity. Changes in relative labour productivity will occur as a plant becomes more efficient or if it increases its use of capital and other inputs relative to other plants in the industry.

The transition matrix for the relative labour productivity of continuing plants between the years 1988 and 1997 is provided in Table 3. Ranking establishments according to their relative labour productivity in each of 1988 and 1997, and assigning them to quartiles in each of the two years, the transition matrix provides the percentage of establishments that had bettered their relative position, stayed the same, or declined. Relative labour productivity is calculated for the 4-digit industry in which it is located for both years.

As evidenced by Table 3, there is a large amount of shifting of relative position. For continuers, half of the plants shifted up from the lowest quartile and half shifted downward out of the top quartile. Half of the plants initially in the top and bottom quartiles remained there by the end of the period. For those in the middle two quartiles, the movement was even greater, with only a third still in the same quartile in which they had started.

Table 3. Relative Labour Productivity Transition Matrix for Continuers (1988-1997)

Relative Labour Productivity Quartiles (1988)	Relative Labour Productivity Quartiles (1997)			
	Q1	Q2	Q3	Q4
	percentage of establishments			
Q1	49	23	18	10
Q2	28	33	24	15
Q3	15	29	31	25
Q4	9	12	28	51

While the preceding discussion has focused on the continuing population of establishments, the role that entrants and exits play should not be ignored. Figure 1 depicts the percentage of new plants that fall into each of the market-share quartiles and productivity quartiles in 1997. Figure 2 does the same for the closed plants using the 1988 quartiles.

We find that new establishments are roughly equally distributed across relative productivity quartiles by the end of the period, although to a slightly lesser extent for the highest quartile (Figure 1). A similar, although less pronounced, pattern emerges when market share is considered. More than 40% of establishments born in the 1988-1997 period, and that are still alive by the end of the period, are in the top two quartiles by 1997. In fact, 17% of entrants actually find themselves in the highest quartile group. In other words, surviving entrants, when examined over a ten-year period, do not remain at the bottom end of the size distribution. [4]

Exits of the 1988 population that disappear by 1997 also come from all quartiles of the 1988 size distribution (Figure 2), though the smallest are most likely to exit. The percentage of each 1988 market-share quartile that exit by 1997 varies from 63% in the quartile with the smallest establishments to 34% for the plants in the largest quartile. Exiting plants are slightly more likely to be found in the quartile that is less productive. Some 55% of establishments in the lowest productivity quartile had exited compared to 38% of those in the highest quartile.

3. Success, Innovation and Advanced Technology Use

There are many factors behind the growth of firms and plants—from overall management capabilities, to marketing, human resources, and operational capabilities. A substantial part of a firm's capital consists of these internal competencies. One branch of the business literature has focused on the extent to which there is a set of core competencies (Prahalad and Hamel, 1990). Another argues that one of the key areas for success is the dynamic capabilities of a firm that enable it to learn (Teece et al., 1997). Dosi and Marengo (1994) emphasize that there are a variety of ways that firms can learn and that this learning is tied to different sources of technological capabilities. These capabilities extend beyond just R&D performance to encompass those activities that enable a firm to ingest new information and to act quickly and effectively on it. In turn, advantages in this area are postulated to be associated with different levels of performance.

[4] For additional Canadian evidence on the importance of entrants in this process, see Baldwin and Gorecki (1991), Baldwin (1995, chapter 9), Baldwin (1996a).

Figure 1. Productivity and Market Share Distributions for Entrants

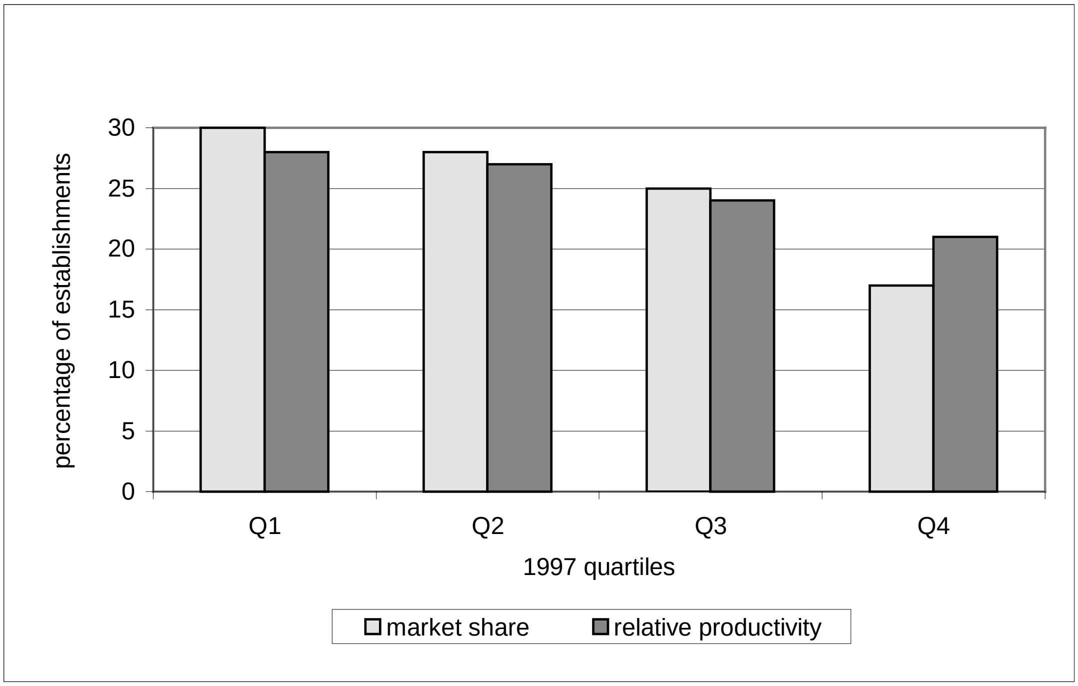
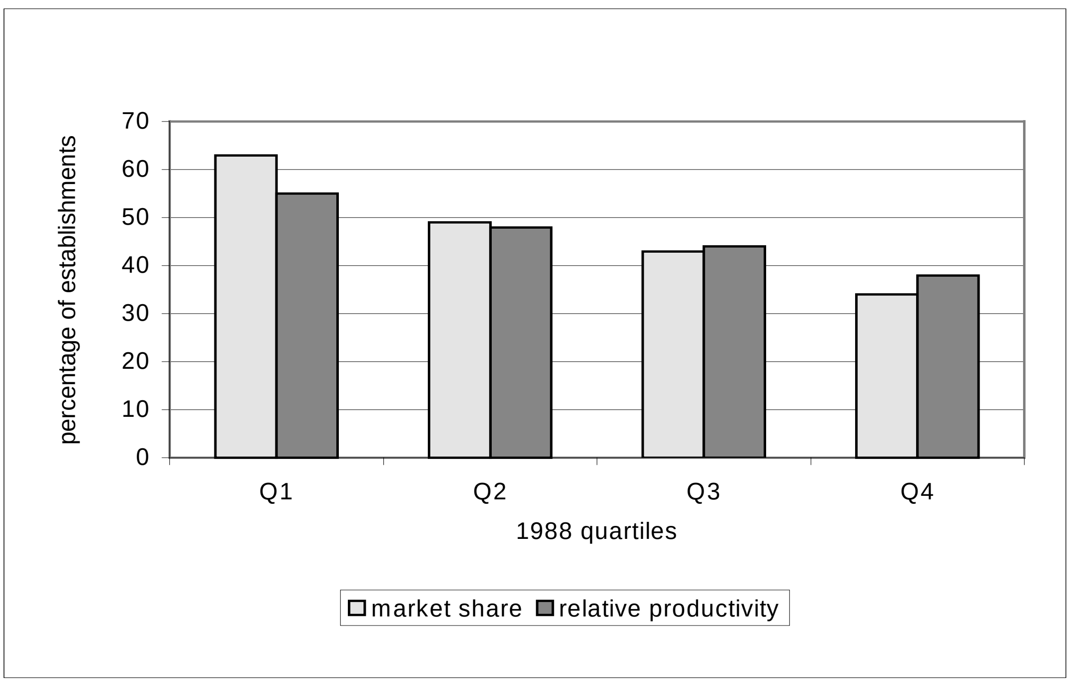


Figure 2. Productivity and Market Share Distributions for Exits



In three earlier studies (Baldwin, Chandler et al., 1994; Johnson, Baldwin and Hinchley, 1997; Baldwin, Diverty and Sabourin, 1995), we have investigated the difference in the competencies found in growing and declining firms to see whether a key difference between the two lies in the nature of their innovation regime. These three studies use three different surveys as sources and find similar results in each case.

While growing firms have to do many things better in order to succeed, there is one factor that appears to discriminate best between the more-successful and the less-successful. Innovation is consistently a factor associated with successful growing firms (Baldwin, 1997; Baldwin and Johnson, 1998).

In the first study, based on the *Survey of Growth Companies* (SGC), the generally successful population of small and medium-sized firms (all firms in the study had positive growth over a five-year period) is divided into the more-successful and the less-successful firms and the characteristics of each are compared. This grouping is done using an overall measure of firm performance that is an average of three performance measures—market share growth, labour productivity growth and profitability growth of a firm relative to other firms in an industry. The key characteristic that distinguished the two groups was the degree of innovation taking place in a firm (Baldwin, 1996b). The more-successful firms tended to place greater emphasis on R&D capability and R&D spending. They were more likely to give greater importance to developing new technology. In the production area, they gave more significance to using new materials, and implementing aggressive new strategies like process control and just-in-time inventory control. Differences in the emphasis that the two groups gave to R&D strategies were accompanied by differences in the intensity of R&D activities. More-successful firms were more likely to have an R&D unit. They were more likely to use R&D tax credits. They were also more likely to report that they used patents to protect their innovations.

The second study, based on the *Survey of Operating and Financial Practices* (SOFP) of entrants (Johnson, Baldwin and Hinchley, 1997) provides an overview of the competencies developed by new firms that survive into their teen years. It too is linked to data on sales and financial structure that provide measures of performance for each survivor. As was found in the case of the study of growing small and medium-sized enterprises, success was closely related to innovation. Faster growing entrants were twice as likely to report an innovation. Faster growing entrants were more likely to invest in R&D and technology. They were also more likely to introduce new products. They were more likely to be targeting new foreign markets (Baldwin and Johnson, 1999). But faster growing firms were also more likely to be giving more emphasis to training, recruiting skilled employees and providing incentive compensation programs (Baldwin, 2000).

The findings of the SGC and SOFP as to the importance that firms gave to innovative strategies and activities, are confirmed by another study that uses data at the plant level on the use of advanced technologies. Advanced technology use is a form of innovation. The 1989 *Survey of Advanced Technology* outlines the extent to which plants in the manufacturing sector use advanced technologies in the different functional areas that each firm must master—in fabrication and assembly, in inspection and communications, in integration and control, and in design and engineering. Data from this survey on 1989 technology use are linked to the performance of plants during the 1980s. Performance is measured using information on a plant's sales, labour productivity and wage rates. Advanced technology-using plants are then compared to plants not using advanced technologies as of 1988 in order to study whether the market share, the productivity and the wage rate had grown relatively faster in the former group (Baldwin, Diverty and Sabourin, 1995).

Advanced technology-using plants increased their market share relative to plants that were not using advanced technologies. Growth in market share was higher for users of advanced technologies in the fabrication and assembly area than for most of the other functional areas. It was also relatively high for plants that were complex technology users, that is, for plants that combined advanced technologies from several of the functional groups (design, fabrication, communications, and integration and control).

Plants that managed to successfully incorporate advanced technologies into their production process by 1989 also saw their labour productivity increase relative to non-technology users during the previous decade when the adoption of advanced technologies was occurring. Those that used communications technologies or that integrated advanced technologies from several areas experienced the highest productivity growth rates. Accompanying this increase in relative labour productivity was a growth in the relative wage paid to production workers.

In summary, all three studies found that firms that managed to grow more quickly also *developed* certain innovative competencies that distinguished them from firms that grew less quickly. Differences in technological competencies had the same effect. That innovative and technological competencies are linked is not surprising. Some 53% of respondents to the 1993 *Survey of Innovation and Advanced Technology* who had indicated that they introduced the advanced technologies did so in conjunction with the introduction of a product or process innovation.

These conclusions, based on Canadian empirical evidence, are confirmed by research that covers the experience of other countries. Stoneman and Kwon (1996), Rischel and Burns (1997), Ten Raa and Wolff (1999), and Van Meijl (1995) find a positive relationship between advanced technology use and superior firm performance.

On the basis of these studies, there is a strong presumption that advanced technology users in Canadian manufacturing as of 1999 should have had superior performance during the 1990s. In order to investigate whether the same type of relationship, between market performance and advanced technology use, existed in Canada during the 1990s, we will examine the connection between advanced technology use and the growth of plant market share or the growth in productivity in this period. Growth is defined as the change in market share over the period 1988 to 1997—a period of ten years prior to the survey date of 1998. In order to correct for industry effects, growth was defined in terms of market share, as calculated at the 4-digit 1980 SIC industry level. Similarly, plant productivity is calculated relative to its 4-digit industry average. Productivity is defined as labour productivity[5] and will be affected by changes in capital intensity and technological advances.

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[5] Defined as census total value added for manufacturing operations divided by total employment of both salaried and production workers.

In what follows, we compare the performance of plants throughout the nineties to their technological profile at the end of the period. We have seen that differences in the productivity performance of growers and decliners do not exist at the beginning of the study period but emerge over the period studied. This accords with a world in which firms experiment with alternate advanced technologies and the market rewards those who have chosen the correct technologies and managed to get them to work in the appropriate fashion. At the end of any period, productivity differences are evident between those who have managed to gain market share and those losing market share. For this reason, this study examines the differences in advanced technology use at the end of the period and the changes that have occurred in market share and changes in relative labour productivity over the previous time period.

This procedure will show whether advanced technology use is associated with improved performance. It cannot ascertain how changes in technology use affect performance. It is, of course, likely that changes in advanced technology use at the margin matter—though to ascertain how important the latter are, we need a longitudinal database that compares changes of advanced technology use over time. The latter is the subject of a separate study (Baldwin and Sabourin, 2002).

In this paper, we experimented with performance measures calculated over two different periods of time. The first covered a seven-year span from 1990-1997. The second covered the ten-year span from 1988 to 1997. Both yielded qualitatively the same results—but the results were more significant over the longer time period and are reported here. This bolsters our trust in the hypothesis that change occurs slowly—that the effects of using advanced technologies do not emerge immediately. Lags in the effect of the use of new advanced technologies exist because new machines have to be integrated into the production process. New techniques and business practices are often required if the new technologies are to be more successful. For example, concurrent engineering practices are needed if design and engineering advanced technologies are to be used successfully in plants.[6] Introducing advanced business practices involves organizational changes and takes time to implement.

4. Data Source for Advanced Technology Use

We focus in this paper on the adoption of a set of advanced technologies that are based on microelectronic computer technology. Computer-based technologies have penetrated all parts of the production process—from the design and materials planning stage, through the fabrication and assembly process, to the inspection and materials handling stage. They are also a key part of the communications process. While computers have stimulated the development of individual components, they are also key to integration and control of the various parts of the manufacturing process.

[6] The relationship between these practices and technology has been explored more fully in a recent study of technology use in the food-processing sector (Baldwin, Sabourin and West, 1999).

The effect of computers does not arise just from the ubiquitous stand-alone desktop. It is true that certain aspects of design and engineering depend on the stand-alone computer—but software is equally important here. Moreover, chips and computers are being increasingly imbedded into machines. Just as the electric motor moved from being a separate appendage located beside machines to being included in the machine, computers are now also an integral part of machinery such as robots and flexible manufacturing systems.

In this study, we make use of the results of the *1998 Survey of Advanced Technology in Canadian Manufacturing* conducted by Statistics Canada to measure the extent to which advanced technologies have been integrated into the production process. The survey is based on a frame of Canadian manufacturing establishments drawn from Statistics Canada's Business Register. The sample was randomly drawn from a manufacturing establishment population that was stratified by industry and size. Excluded from the target population were food processing establishments and plants with fewer than 10 employees (Sabourin and Beckstead, 1999). The overall response rate to the survey was 98%.

In addition to questions on which technologies were being used, the survey asked respondents questions about general firm and establishment characteristics, whether research and development was being conducted, whether several advanced business practices were being used, the skill requirements needed for advanced technologies, as well as questions about the benefits and obstacles to the adoption of advanced technologies.

Twenty-six advanced technologies were listed on the survey—technologies that are applied in a wide range of functional areas. These range from computer-aided design that is used in design and engineering, to robots that are used in fabrication and assembly, to computer networks that are used as part of the communications and control function. For the purposes of this study, the advanced technologies covered in the survey are aggregated into three information and communication technology (ICT) groups—(i) software, (ii) network communications, and (iii) hardware technologies. In our earlier study (Baldwin, Diverty and Sabourin, 1995), we found that plants using communications technologies did particularly well over the 1980s. In a recent study, Ten Raa and Wolff (1999) also found a positive relationship between ICT use and productivity growth. Van Meijl (1995) argues that this is mostly due to externalities associated with ICT adoption.

The ICT groups, their constituent advanced technologies, and their adoption rates are provided in Table 4. Eight advanced technologies belong to the software group—computer-aided design and engineering (CAD/CAE); CAD output to control manufacturing machines (CAD/CAM); modelling or simulation technologies; manufacturing resource planning (MRP); computer integrated manufacturing; supervisory control and data acquisition (SCADA); use of inspection data for manufacturing control; and knowledge-based software.

Five advanced technologies belong to the network communications group—electronic exchange of CAD files; local area network (LAN) for engineering or production; company-wide computer networks; inter-company computer networks; and digital, remote controlled process plant control.

Table 4. Adoption of Advanced Information and Communications Technologies, 1998 (percentage of establishments using the technology)

IC Technology	Specific Technology	In Use	Standard Error
Software	• Any	65	1.3
	• Computer-aided design and engineering (CAD/CAE)	44	1.4
	• CAD output to control manufacturing machines (CAD/CAM)	36	1.4
	• Modelling or simulation technologies	17	1.1
	• Manufacturing Resource Planning (MRP)	21	1.0
	• Computer integrated manufacturing	18	1.1
	• Supervisory control and data acquisition (SCADA)	16	0.9
	• Use of inspection data for manufacturing control	26	1.2
	• Knowledge-based software	18	1.1
Communications	• Any	59	1.4
	• Electronic exchange of CAD files	34	1.4
	• Local area network (LAN) for engineering or production	36	1.3
	• Company-wide computer networks	35	1.3
	• Inter-company computer networks	29	1.2
	• Digital, remote controlled process plant control	5	0.5
Hardware	• Any	57	1.4
	• Flexible manufacturing systems	15	1.0
	• Programmable logic controllers	37	1.4
	• Robots with sensing	8	0.7
	• Robots without sensing	7	0.6
	• Rapid prototyping systems	5	0.6
	• Part identification for manufacturing automation	18	1.0
	• Automated storage/retrieval system	5	0.6
	• Automated vision-based inspection/testing systems	11	0.8
	• Other inspection/testing automated sensor-based systems	13	0.9
	• Computers used for control on the factory floor	31	1.3

There are ten advanced technologies in the hardware class—flexible manufacturing systems; programmable logic controllers; robots with and without sensing capabilities; rapid prototyping systems; part identification for manufacturing automation; automated storage/retrieval systems; automated vision-based systems used for inspection/testing; other automated sensor-based systems used for inspection/testing; and computers used for control on the factory floor.

Three of the twenty-six specific advanced technologies—lasers for materials processing; high speed machining; and near-net shaped technologies—have been excluded from the analysis.

Similar rates of adoption are found for each of the three ICT groups. Sixty-five percent of manufacturing establishments use at least one of the eight software technologies listed on the survey; 59% use at least one of the five network communications technologies; while 57% use at least one of the 10 hardware-based technologies.

Computer-aided design technologies dominate the software category. Close to half the plants have adopted at least one computer-aided design and engineering technology (CAD/CAE), with about a third using at least one CAD/CAM machine.

Plants use a variety of network communications advanced technologies—local area networks, company-wide networks and inter-company networks. The use of programmable logic controllers and factory control computers in the hardware group is reported most frequently. For our comparisons of technology use and plant performance, advanced technology use will be measured in several different ways in this study. We use: (i) incidence of use (the use of at least one advanced technology); (ii) intensity of use (the number of advanced technologies adopted); and (iii) measures of complexity of use (whether advanced technologies are being combined from more than one category). Plants adopt, on average, two advanced software technologies, and about one and a half network communications and hardware technologies each (Table 5).

Table 5. Incidence and Intensity of Adoption of ICTs (1998)
(Standard Errors provided in brackets)

ICTs	In Use	Number of Technologies	Number of Technologies in Group
	(% of establishments)		
Software	65 (1.3)	1.97 (0.05)	8
Hardware	57 (1.4)	1.49 (0.05)	10
Communications	59 (1.4)	1.40 (0.04)	5
All	76 (1.2)	4.85 (0.12)	23

5. Performance and ICT Use

At issue is the extent to which plants that exhibit different levels of success are found to use advanced technologies more or less intensively. We approach this question first with bivariate analysis that compares different measures of performance to advanced technology use and then with multivariate analysis that regresses performance measures on advanced technology use and a number of other plant characteristics.

For both purposes, we relate performance over a period (1988-1997) to advanced technology use at the end of the period (1998).

1) $\Delta PERF_{t-\tau,t} = f(Tech_t)$

where $\Delta PERF_{t-\tau,t}$ is the change in a plant's performance measured in various dimensions (relative productivity, market share, employment share, relative wage rates, relative profitability) over the period $t-\tau$ to t and $Tech_t$ is a measure of advanced technology use at the end of the period in year t.

Since advanced technology use at the end of the period is just the sum of advanced technology use at the beginning of the period $Tech_{t-\tau}$ and the change in advanced technology use over the period, $\Delta Tech_{t-\tau, t}$, equation number 1 can be written as:

2) $\Delta PERF_{t-\tau,t} = f(Tech_{t-\tau} + \Delta Tech_{t-\tau, t})$[7]

Economic performance is expected to be related to technology use at the start of the period and changes in advanced technology use over the period.

Performance over any period is posited to be a function of advanced technology use at the beginning of the period because there is a learning process involved with the introduction and use of advanced technology. Changes in labour productivity resulting from advanced technology adoption are, therefore, expected to occur slowly as plant managers learn how to use them in the most effective fashion. Since benefits or gains from the adoption of advanced technology are not realized immediately, there is a lagged effect of advanced technology use on performance. In addition, we expect that increases in advanced technology use during the period will affect relative performance over the period. While all benefits from the adoption of additional technologies will not be felt immediately, some will be.

Relative labour productivity is calculated as total value added divided by total employment for the establishment divided by the same measure calculated at the 4-digit industry level. Growth in relative labour productivity is calculated as the difference between end-period relative labour productivity and start-period relative labour productivity.

Labour productivity is affected by many factors—by technical change in a plant, by its changing capital intensity, by organizational changes—all of which factor into a firm's success. Since all of these factors and, in particular, capital accumulation are associated with firm growth, we make use of this measure.

While some might prefer to see a total factor productivity measure rather than a labour productivity measure used for this analysis, because the former is widely perceived to better measure technical progress, it should be noted that the two measures are closely related. When the production function approximates a Cobb-Douglas, growth in labour productivity is equal to multifactor productivity growth plus the growth in the capital/labour ratio times capital's share (Baldwin, Beckstead et al., 2001). As a result, empirical studies often find similar results using the two measures (Salter, 1966). The final argument in favour of using labour productivity is that measures of it are inherently more accurate than measures of total factor productivity.

Growth in market share is measured here as the total shipments produced by an establishment relative to total shipments at the 4-digit industry level. Growth is measured as the difference between end- and start-period market shares.

Growth in relative profitability is calculated here in a similar fashion, only that profitability at the establishment level is calculated as the value of shipments less wages, salaries and materials all divided by the value of shipments.

[7] The estimated coefficient from such an equation will be a weighted average of the coefficients that are attached to each of $Tech_{t-\tau}$ and $\Delta Tech_{t-\tau, t}$

Table 6. Relationship Between Performance Growth (1988-1997) and Advanced Technology Adoption (1998)

Advanced Technology Adoption	Performance Growth[8] (1988-1997)					
	Relative Labour Productivity (I)		Market Share (II)		Relative Profitability (III)	
	low	high	low	high	low	high
	Percentage of establishments using technologies					
ICT use						
• Software	63	73	63	74	64	71
• Hardware	54	66	55	65	54	65
• Communications	58	69	57	71	59	68
• Any	75	83	74	85	75	83
Multiple use						
• 5 or more	42	55	40	58	43	53
• 10 or more	18	23	17	26	17	24
Combination use						
• Software and hardware	46	59	46	59	47	58
• Software and communications	50	63	51	64	52	61
• Hardware and communications	43	56	44	55	44	55
• All three	39	54	40	53	41	52
	Number of advanced technologies adopted					
Numbers of ICT						
• Software	1.9	2.3	1.8	2.5	2.0	2.3
• Hardware	1.4	1.8	1.4	1.9	1.4	1.9
• Communications	1.4	1.7	1.4	1.8	1.4	1.7
• All	4.7	5.9	4.7	6.1	4.8	5.8

Note: All differences reported in this table are statistically significant at the 5% level. In fact, most are statistically significant at the 1% level.

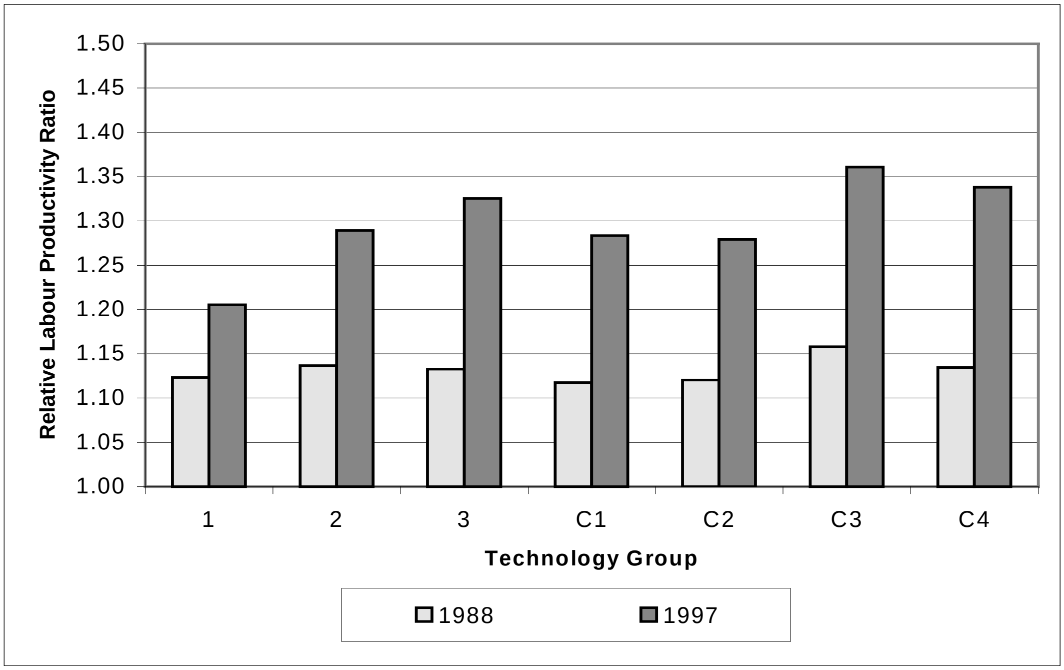
Bivariate results of the relationship of economic performance and advanced technology adoption are provided in Table 6. Three separate measures of performance are used—growth in relative productivity (column I), growth in market share (column II) and growth in relative profitability (column III) over the period 1988-1997. In each case, establishments are divided into two equal sized groups, those with more and those with less growth than the median. Then the differences in advanced technology adoption of the two groups are compared.

Establishments in the top half of the labour productivity growth distribution are found to be more likely to be using at least one advanced technology. This result extends across all ICTs—software, hardware and communications. High productivity growth establishments are also more likely to be using greater numbers of technologies.

Differences also exist between the fastest labour productivity growers in terms of combinations of advanced technologies used. The greatest differences are found for plants that use all three types of ICTs. A significantly higher proportion of high-productivity growers adopts all three types of ICTs than do slow-productivity growers—a difference of 15 percentage points.

[8] Labour productivity is defined as total value added divided by total employees; profitability is defined as total shipments less materials less wages and salaries divided by total shipments—the price/cost margin.

Figure 3. Relative Productivity of Advanced Technology Users and Non-Users: 1988 vs. 1997



Group Number	Technology Group	Group Number	Technology Group
1	Software	C1	Software and hardware
2	Hardware	C2	Software and communications
3	Communications	C3	Hardware and communications
		C4	Software, hardware and communications

Finally, there are differences in the intensity of advanced technology use. Establishments with the highest growth in labour productivity adopt, on average, 5.9 advanced technologies compared to 4.7 for low-growth plants. Similar differences are found across the individual ICT groups.

We also examine how the productivity of advanced technology users relative to non-users has evolved over time using a classification that divides plants into users and non-users based on their status as of 1998. To do so, we calculate the ratio of the mean productivity of advanced technology users to the mean productivity of non-users of advanced technology in 1988 and 1997 and then plot this relationship in Figure 3.[9] This is done for each of the technology groups—software, hardware, communications and then for four sets of combinations—software and hardware (C1), software and communications (C2), hardware and communications (C3) and all three (C4). Advanced technology users have increased their productivity advantage over non-users across all technology measures, particularly when it involves the use of network communications technologies, both by itself and in combination with other types of advanced technologies. The largest rates of increase in relative productivity occur in the network communications group; in hardware and communications; and in the use of all three ICTs. This

[9] The ratio is calculated as the sum of value-added, divided by the sum of employment, of all plants that are technology users within a class, divided by the same ratio for non-technology users.

replicates the findings of our earlier study (Baldwin, Diverty and Sabourin, 1995), which reports that the greatest gains in relative productivity in the 1980s occurred in plants that adopted advanced communications technologies, either singly or in combination with other ICTs.

When plants are divided at the median on the basis of profitability growth (defined as the growth in the price-cost margin)[10] over the 1988-1997 period, we also find significant differences in the incidence of advanced technology use, the numbers of technologies used and the extent to which advanced technologies from software, hardware and communications are used jointly (Table 6, column III). Plants with the highest growth in profitability adopt, on average, 20% more advanced technologies than do low-growth plants. High-profitability-growth plants adopt, on average, 5.8 advanced technologies compared to 4.8 for low-growth plants. These differences extend to incidence of use as well, with hardware and network communications technologies exhibiting the greatest differences.

When growth in market share is used to divide the sample into two parts, similar results are found. The plants that experienced the highest market-share growth also tend to be more likely to adopt more advanced technologies from each of the groups.

6. Differences at the Industry Level

Growth in productivity varies by industry (Baldwin, Beckstead et al., 2001). In order to examine whether the differences that were presented in Table 6 at the national level also pertain to most individual industries, we repeat the bivariate tabulations in Tables 7 and 8 at the 2-digit industry level. Establishments are divided into those with low growth in relative productivity and those with high growth in relative productivity on an industry-by-industry basis using the median value as the dividing point. Productivity growth is calculated as the difference between the end-year relative productivity and the start-year relative productivity of the establishment.

For this exercise, it should be noted that the survey was not designed to provide highly accurate results for the subsectors of industries that are being examined here. Therefore, we can only look for similarities in terms of the differences across industries and we should expect that many of these differences, even if real, are not statistically significant.

Table 7 contains the percentage of plants from each group that use a particular type of advanced technology. For example, in the primary metals industry, 49% of the low-growth plants had adopted at least one advanced hardware technology by 1997, compared to 88% of those in the high-growth category, a difference of close to 40 percentage points. The national relationship that was observed between advanced technology use and productivity growth in hardware is significant in chemicals and petroleum, fabricated metals, furniture and fixtures, primary metals, and printing and publishing, though there are also relatively large positive differences in rubber and plastics, as well as industrial machinery. When it comes to network communications technologies, a greater number of industries exhibit positive differences, but they are often not statistically significant.

[10] Profitability is defined as value of shipments less wages and salaries less materials divided by value of shipments.

Table 7. Growth in Relative Labour Productivity by Technology and by Industry

Industry	Software		Hardware		Communication		Any Advanced Technology		Five or More Technologies	
	Low ΔRLP	High ΔRLP	Low ΔRLP	High ΔRLP	Low ΔRLP	High ΔRLP	Low ΔRLP	High ΔRLP	Low ΔRLP	High ΔRLP
	(percentage of establishments using technologies)									
• Chemicals & Petroleum	60	68	60**	75**	65**	80**	79	86	42***	63***
• Electrical & Electronics	91*	80*	75	64	84	83	91	85	68	74
• Fabricated Metals	75*	91*	51**	75**	64	80	84	95	48	68
• Furniture	44	59	30**	69**	42	53	44	71	22*	49*
• Industrial Machinery	67	88	61	74	69	82	76	88	51	70
• Non-Metallic Minerals	64**	42**	67	52	52	38	75	59	51**	30**
• Other	65	61	47	50	58	51	71	75	38	35
• Paper	85	75	86	84	85	58	97	84	63	59
• Primary metals	59	87	49**	88**	59	87	59	88	58	70
• Printing & Publishing	44*	63*	29**	51**	61	75	65**	84**	20***	44***
• Rubber & Plastics	57**	80**	61	78	58*	80*	72**	94**	40*	62*
• Textiles	47**	66**	50	52	37***	61***	60*	75*	29**	46**
• Transportation	76	80	67	68	68	74	82	81	58	71
• Wood	56	55	63	58	38	52	79	76	35	31
• ALL	63***	73***	54***	66***	58***	69***	75***	83***	42***	55***

Note: *** means that differences are statistically significant at the 1% level; ** significant at the 5% level; and * significant at the 10% level.

Table 8. Growth in Market Share by Technology and by Industry

Industry	Software		Hardware		Communication		Any Advanced Technology		Five or More Technologies	
	Low ΔMS	High ΔMS	Low ΔMS	High ΔMS	Low ΔMS	High ΔMS	Low ΔMS	High ΔMS	Low ΔMS	High ΔMS
	(percentage of establishments using technologies)									
• Chemicals & Petroleum	60	69	61**	74**	67*	79*	79	87	45*	59**
• Electrical & Electronics	87	83	63*	80*	85	82	89	87	70	73
• Fabricated Metals	76	90	54	68	58***	88***	84	95	39***	79***
• Furniture	50	48	42	49	46	45	56	49	28	40
• Industrial Machinery	69**	94**	58*	83*	71	83	75*	94*	48***	83***
• Non-Metallic Minerals	52	58	53	69	36*	57*	62	76	35	48
• Other	54**	75**	41	58	48	63	63**	86**	31	44
• Paper	85	76	100**	74**	77	66	100	82	77*	49*
• Primary metals	69*	94*	64**	95**	69*	94*	69*	95*	56**	94**
• Printing & Publishing	47	62	35	46	60**	80**	67**	85**	24**	44**
• Rubber & Plastics	72	61	71	66	64	70	82	80	46	52
• Textiles	49**	66**	47	57	37***	66***	60**	78**	29**	49**
• Transportation	73	85	64	73	69	74	76*	90*	61	69
• Wood	53	60	62	59	47	40	77	78	33	35
• ALL	63***	74***	55***	65***	57***	71***	74***	85***	40***	58***

Note: *** means that differences are statistically significant at the 1% level; ** significant at the 5% level; and * significant at the 10% level.

Substituting market-share growth for productivity growth, we find stronger results in Table 8. With the exception of paper and rubber and plastics industries, higher market-share growth is often associated with greater advanced technology adoption rates across all technology groups. About one third of these differences are statistically significant. Differences are positive and have the highest significance for industrial machinery, 'other', and textiles for software technology; chemicals and petroleum, and primary metals for hardware technology; fabricated metals, printing and publishing, and textiles for communication technology. Only in the paper industry are low gains in market share associated with higher adoption rates. This may simply indicate that the advanced technologies chosen for the 1998 Advanced Technology Survey are less applicable to this industry.[11] Use of five or more advanced technologies is associated with significant differences in seven industries—chemicals and petroleum, fabricated metals, industrial machinery, paper, primary metals, printing and publishing, and textiles.

7. Multivariate Analysis

7.1 Model

In this section, we use a multivariate framework to examine the connection between advanced technology use and several measures of the market performance of plants in the manufacturing sector. The performance measures are the growth in relative productivity, the relative average wage rate, relative profitability as well as the growth in market and employment share.

There are two main components to the analysis—an equation that estimates the correlates of productivity growth and one that examines the correlates of market-share growth. The regressions that were estimated were:

1) $$\text{PRODGRTH} = \alpha_0 + \alpha_1{*}\text{TECH} + \alpha_2{*}\text{SIZE88} + \alpha_3{*}\text{FOREIGN} + \alpha_4{*}\Delta\text{CAPINT} + \alpha_5{*}\text{LABPROD88} + \alpha_6{*}\text{R\&D} + \alpha_7{*}\text{INNOV} + \alpha_8{*}\text{BUS} + \alpha_9{*}\text{REGION}$$

2) $$\text{SHARGRTH} = \beta_0 + \beta_1{*}\text{TECH} + \beta_2{*}\text{SIZE88} + \beta_3{*}\text{FOREIGN} + \beta_4{*}\Delta\text{CAPINT} + \beta_5{*}\text{LABPROD88} + \beta_6{*}\Delta\text{LABPROD} + \beta_7{*}\text{MKTSHR88} + \beta_8{*}\text{R\&D} + \beta_9{*}\text{INNOV} + \beta_{10}{*}\text{BUS} + \beta_{11}{*}\text{REGION}$$

where *PRODGRTH* measures the growth in relative labour productivity of a plant.
SHARGRTH measures the growth in market share of a plant.
TECH measures the use of advanced technologies by the establishment.
SIZE88 measures opening-period employment size of the plant.
FOREIGN captures whether or not an establishment is foreign owned.
ΔCAPINT captures the capital intensity of a plant through changes in profitability.
LABPROD88 measures opening-period labour productivity levels.
ΔLABPROD measures changes in relative labour productivity over time.

[11] A special survey (see Baldwin, Sabourin, and West, 1999) was conducted in the food processing sector after it was found that the 1989 generic advanced technology survey needed to be expanded to take into account the special circumstances of the food processing sector.

MKTSHR88 measures opening-period market share.
R&D captures whether or not an establishment is an R&D performer.
INNOV captures various aspects of innovation in a plant.
BUS captures the extent to which advanced business practices exist in a plant.
REGION captures any regional effects.

7.1.1 Productivity Growth

The first equation examines relative productivity growth during the 1988-1997 period. Relative productivity growth is postulated to be a function of advanced technology use at the end of the period since end-period advanced technology use is taken as an indicator that the plant has learned how to work with innovative technological processes. We capture advanced technology use with a number of mutually exclusive, increasingly comprehensive and, therefore, sophisticated technology variables. Use of one type, and only one type, of the three information and communication advanced technologies—software, hardware and communications—is captured by a set of three binary technology variables. Four other variables capture the use of combinations of ICTs—software and hardware; software and communications; hardware and communications; and the most sophisticated of all, the use of all three types.

Previous work (Baldwin, Diverty and Sabourin, 1995) found that, in 1989, the use of just one particular technological group (fabrication, design and engineering, or communications) was sufficient to differentiate plants from one another in terms of performance—but also found that the plants that were combining advanced technologies from different areas were characterized by the best performance. Since we are measuring advanced technology use 10 years later in 1998 and, by the latter year, many more plants had adopted at least one advanced technology, we expect the single technology-use variables to have less effect on plant performance in the 1990s. But we hypothesize that those plants combining advanced technologies from a number of different areas will exhibit the fastest productivity growth over the 1990s.

Productivity growth is also likely to be a function of advanced technology use to the extent that advanced technology use is associated with higher capital intensity. To correct for this, the increase in a plant's relative profitability (its profit/sales ratio) is also included—since the measure of profitability should be closely correlated with capital intensity on average.

Plant size was included to capture the greater financial and informational capabilities often associated with larger establishment size. Large plants tend to invest more in new equipment and capital, which tends to lead to growth. Employment data were used to measure size.

Initial period productivity is included to allow for regression-to-the-mean. Previous work (Baldwin, 1995) and the tables presented in the first section of this paper have reported that plants tend to regress to the mean over the period.

Nationality of ownership of a plant is included since multinational firms are seen to play an important role in the global diffusion of advanced technologies (Caves, 1982). Previous work has found that labour productivity growth in foreign-controlled plants has been greater than in the domestic sector (Baldwin and Dhaliwal, 2001). The advantages of multinational enterprises are typically related to their size, expertise and financial resources. Nationality of control is captured, in this study, by a binary variable that takes a value of one if the establishment is foreign controlled, and a value of zero if the establishment is domestically controlled.

A binary variable that measures whether the plant reported that it performed R&D is also included. This is done for two reasons.

First, because of the evidence from previous studies on the effect of R&D on productivity (Lichtenberg and Siegel, 1991; Hall and Mairesse, 1995; Dilling-Hansen et al., 1999), we are inherently interested in knowing whether R&D activity affects productivity performance after the technology mix has been taken into account.

Second, the inclusion of this variable is meant to reduce the fixed-effects econometric problem. The econometrics literature has spent considerable effort worrying that equations like equation 1 will yield biased estimates of the parameters attached to the independent variables if there are omitted fixed effects at the plant level that are correlated with the included variables. Much of our previous work on the characteristics of firms suggests that this is likely to be a problem. This is because firms divide into those who are innovative and stress a large number of functional areas, such as human resources or marketing capabilities (Baldwin and Johnson, 1996, 1998, 1999), and those who do not. Since advanced technology use is likely to be highly correlated with the plant's degree of innovativeness, a regression that only employs advanced technology use will risk attributing the effect of a large number of activities to just advanced technology use. The correlation between technology use and productivity may simply reflect the fact that superior firms make greater use of new technologies and do a lot of other things as well (see McGuckin et al., 1998).

In order to address this problem, we include three different variables that capture whether a plant is more innovative. The first innovativeness variable captures whether R&D is conducted either in that plant or in an associated plant on an ongoing basis. Previous work demonstrates that firms that conduct R&D on an ongoing as opposed to an occasional basis are more likely to be innovative (Baldwin and Hanel, 2002).

The second is a variable that measures the importance given to a number of strategies that capture aspects of innovation that are different from a plant's R&D focus. On the technology survey, plant managers rated the importance of 'developing new products, entering new markets, using new materials, giving ongoing technical training, and using teams' on a five-point Likert scale from 1 for 'low importance' to 5 for 'high importance'. Variants of these questions have been used previously in the Growth Companies Survey and the Survey of Operating and Financial Practices to distinguish between more and less innovative firms.[12] The questions used here to measure the innovation stance of the firm do so in two ways. First, it captures this phenomenon directly with the question on whether new products have been introduced. Second, it does so indirectly via an examination of human resource, marketing and production strategies. Innovation and a training strategy are closely related (Baldwin, 1999). Focusing on new materials involved innovation. Placing a stress on new markets is an essential part of an

[12] See Baldwin, Chandler et al. (1994) and Johnson, Baldwin and Hinchley (1997).

innovation strategy. The variable included in the estimated regression is the average of the response to the five survey questions listed above.

The third innovation-related variable measures the emphasis that is given to a set of advanced business practices that were found elsewhere to be closely associated with the adoption of advanced technologies (Baldwin, Sabourin, and West, 1999). These practices include "cross-functional design teams, concurrent engineering, continuous improvement (i.e., TQM), benchmarking, plant certification (i.e., ISO 9000), certification of suppliers, just-in-time inventory control, statistical process control, electronic work order management, process simulation, distribution resource planning and quality function deployment". Many of these practices are required to make the best use of of advanced technologies. For example, concurrent engineering complements CAD systems and enables plants to better exploit the capabilities of these new technologies. Use of these practices then allows us to distinguish between those plants that are better managed and those that are not. For the statistical analysis, we make use of a variable that measures the number of these practices that are used in any particular plant.

In addition, binary variables were included to test whether the geographic environment matters.

7.1.2 Market Share Growth

The second equation examines the correlates of growth in market share. Growth in market share is postulated to depend on factors that give a firm an advantage over its competitors. Growth in market share is posited to be a function of both the advantages in labour productivity experienced at the beginning of the period and its growth over the period. In our formulation, growth in relative labour productivity is a proxy for a host of factors that are related to technical efficiency, changes in capital intensity, and other competencies in a firm—from management capabilities to human resource strategies such as training.

Although we already have included advanced technology use in the labour-productivity equation, we also include advanced technology use in the market-share equation to test whether there is an effect of advanced technology on market-share growth that is separate from its effect on the growth in relative labour productivity. Advanced technology use not only allows relative cost gains that are reflected in lower prices, but it also improves the flexibility in the production process and the quality of products produced (Baldwin, Sabourin and Rafiquzzaman, 1996; Baldwin, Sabourin, and West, 1999). As such, it might be expected to have an independent effect on growth in market share independent of its effect on measured labour productivity.

The other variables were essentially the same as were used in the growth in the relative productivity model, except that we included opening-period market share so as to allow for regression-to-the-mean. Baldwin (1995) outlines the inexorable changes that have occurred in the Canadian manufacturing sector in the 1970s in most industries as small plants gained market share and large plants lost market share. The data in Table 3 demonstrate that the same process was taking place during the late 1980s and early 1990s.

7.1.3 Wage Rate, Employment and Profitability Growth

We also estimate three additional models—one examining the correlates of growth in the relative average wage rate over time; another investigating the correlates of the growth in relative firm profitability; and a third one examining the correlates of the growth in employment share over time. These three variables—the relative wage rate, employment share and relative profitability—jointly determine value added at the plant level.[13] Our purpose in investigating the relationship between advanced technology use and each of these variables is to determine whether advanced technology use has more of an influence on one than another. Many of the same independent variables are used in these models as in the productivity growth model.

The wage rate of a plant is measured relative to the industry wage rate. It is calculated as the ratio of wages and salaries to total employment for the establishment divided by the same for the 4-digit industry. Growth of the relative wage rate is then calculated as the difference between the end- and start-year relative wage rates. Relative profitability growth is calculated in a similar fashion, only that profitability at the establishment level is calculated as the value added less wages and salaries divided by value of shipments—a type of price-cost margin. Employment share of an establishment is also calculated relative to the industry of that establishment. Growth in employment share, like the other performance measures, is calculated as the difference between the end-period employment share and the beginning-period employment share.

7.2 Empirical Results

The results of the OLS regression that models several different measures of market performance as a function of advanced technology use are presented in Table 9. Since the data are taken from a survey that randomly sampled the population, weighted estimates are provided. All regressions are estimated against an excluded plant that is Canadian-owned, has not adopted ICTs, does not perform R&D, and is in the Atlantic region.

7.2.1 Growth in Productivity

Growth in relative labour productivity is positively and significantly related to advanced technology use (column 1, Table 9). Plants that have managed to adopt advanced technology by the end of the period have higher productivity growth over the period than those that did not. But it is a particular type of technology use that is associated with the growth in relative labour productivity. Establishments that had adopted only network communications technology were significantly more likely to have higher productivity growth than those that did not. But the real gains came from the joint adoption of all three types of technology—software, hardware, and network communications. These results are significant at the 1% level if capital intensity is not included as an explanatory variable (column 2); and at 5% if it is included (column 1). Regressions were also run (but not reported here) using numbers of advanced technologies adopted, instead of incidence of adoption, as the independent variables. Similar results were found. Plants that made greater use of advanced technologies in the late 1990s experienced

[13] Value added is equal to $wL + rK$ where w is the wage rate, L is employment, r is the profit rate and K is capital.

relatively faster productivity growth during the previous decade. This relationship is particularly strong for plants that adopted network communications technologies.

Significantly higher growth in labour productivity is found to be associated with foreign-controlled establishments. This finding occurs despite the inclusion of size, R&D performance and technology usage. It is sometimes suggested that it is these variables that primarily determine the labour productivity advantages of foreign-controlled plants. But their inclusion here, along with the significant coefficient attached to foreign-controlled plants, indicate that there are still other unmeasured characteristics that give multinationals a productivity advantage.

The coefficient attached to plant size is positive but not significant. The difference in productivity growth between large and small plants in Canada during the early 1990s accords with previous studies dealing with the 1970s and 1980s (Baldwin, 1998; Baldwin and Dhaliwal, 2001). If nationality of ownership is omitted from the regression, however, the coefficient on plant size becomes significant at the 5% level. This suggests a strong link between size and nationality of ownership as it relates to productivity growth. Foreign-controlled establishments tend to be larger than domestic-controlled establishments. But after controlling for nationality of ownership differences, no size advantages are found.

The coefficient on the starting-period productivity variable is negative and highly significant. There is regression-to-the-mean in relative productivity. Plants that started the period with a high relative labour productivity saw their relative labour productivity decline. Equivalently, those plants that were below average in terms of relative labour productivity at the start of the period saw their productivity increase relative to their compatriots.

There is a large, significant effect of the growth in capital intensity on the growth in relative labour productivity. Because there is some overlap in the definitions of labour productivity and profitability, we remove this variable from the estimation to see whether doing so affects the estimated parameters associated with the advanced technology variables (Table 9, column 2). It does not.

Neither R&D performance, nor the other variables (business strategy and business practices) are significant determinants of a plant's relative productivity growth. This suggests that the fixed effects that these variables capture do not bias the estimated impact of technology on productivity growth.

Finally, regional location does not have a consistently significant effect on labour productivity growth—though it should be noted that the omitted region (the Atlantic Provinces) has a slightly superior performance to the other regions. This is consistent with a regression-to-the-mean effect, since this region lags behind the other regions in labour productivity (Zietsma and Sabourin, 2001).[14]

[14] There were no differences in these equations across industries.

7.2.2 Growth in Market Share

Labour productivity at the start of the period and growth in relative labour productivity over the period are both positive and highly significant factors contributing to market share growth (columns 3 and 4, Table 9).

Table 9. OLS Regressions for Productivity and Market Share Growth from 1988 to 1997 (establishment weighted)

	Δ Relative Productivity		Δ Market Share	
	Column 1	Column 2	Column 3	Column 4
Intercept	0.270***	.394***	-0.002	-0.0003
Advanced Technology Use				
Software Only	-0.006	-0.015	-0.0003	-0.0001
Hardware Only	-0.013	0.045	0.004	0.004
Network Communications Only	0.144*	0.165*	0.002	0.003
Software + Hardware Only	0.018	-0.030	-0.001	-0.001
Software + Communications Only	0.021	0.017	0.0004	0.001
Hardware + Communications Only	0.022	0.091	-0.0009	-0.0004
All three	0.098**	0.169***	0.0004	0.0008
Business Practices				
Practices	0.002	-0.001	9e-5	0.0001
Plant Size				
Employment Size-1988	3e-5	4e-5	-4e-6	-4e-6
Nationality of Control				
Foreign	0.296***	0.398***	0.003	0.003**
Capital Intensity				
Profitability change 1988-1997	1.410***	---	-0.003	-0.003
Initial Labour Productivity				
Relative Labour Productivity – 1988	-0.442***	-0.616***	0.002**	---
Labour Productivity Growth				
Relative Labour Productivity Growth	---	---	0.005***	0.004***
Initial Condition				
Market Share – 1988	---	---	-0.035	-0.029
R&D				
Ongoing R&D performer	-0.035	-0.017	0.002**	0.002*
Business Strategy				
Firm's business strategy	0.003	0.003	0.0001*	0.0001*
Region				
Quebec	-0.076	-0.078	-0.0005	-0.0005
Ontario	-0.034	-0.066	-0.001	-0.001
Prairies	-0.113*	-0.133	0.0002	0.0002
British Columbia	-0.069	-0.122	-0.001	-0.0008
Summary Statistics				
N	2362	2367	2362	2362
F(degrees of freedom)	(18, 2343)	(17, 2349)	(20, 2341)	(19, 2342)
	18.94	12.81	4.30	4.65
R^2	0.52	0.33	0.03	0.03

*** statistically significant at the 1% level; ** at the 5% level; * at the 10% level.

Table 10. OLS Regressions for Wage Rate, Profitability and Employment Growth from 1988 to 1997 (establishment weighted)

	Δ Relative Wage Rate	Δ Relative Profitability	Δ Employment Share
Intercept	0.545***	0.543***	0.0008
Advanced technology Use			
Software Only	0.0002	0.139	-0.0002
Hardware Only	0.014	0.263**	0.003
Network Communications Only	0.084**	0.225	0.004
Software + Hardware Only	0.053	-0.037	0.001
Software + Communications Only	0.091***	0.082	0.0005
Hardware + Communications Only	0.064	0.203	-0.002
All three	0.128***	0.237**	0.001
Business Practices			
Practices	-0.003	0.002	-5e-5
Plant Size			
Employment Size-1988	4e-5***	6e-5**	---
Nationality of Control			
Foreign	0.083***	0.263***	0.0004
Capital Intensity			
Profitability change (1988-97)	0.037	---	-0.002
Initial Value			
Relative Wage – 1988	-0.580***	---	---
Profitability –1988	---	-0.889***	---
Employment Share – 1988	---	---	-0.033
R&D			
R&D ongoing performer	-0.036*	0.051	0.002***
Business Strategy			
Firm's business strategy	-0.001	-0.0002	9e-5
Region			
Quebec	-0.070	0.023	-0.001
Ontario	-0.030	-0.181**	-0.001
Prairies	-0.093	-0.076	0.0004
British Columbia	0.014	-0.273**	-0.001
Summary Statistics			
N	2362	2362	2362
F(degrees of freedom)	(18, 2343)	(17, 2344)	(17, 2344)
	16.58	50.21	2.55
R^2	0.33	0.45	0.01

*** statistically significant at the 1% level; ** at the 5% level; * at the 10% level.

But after the effects of relative productivity growth on market share are taken into account, growth in market share is not related to advanced technology use. It is related to whether a plant benefits from the performance of R&D and to whether a set of technology-related business strategies are being pursued. If the innovation-related variables (R&D, business practices and business strategies) are removed—in an unreported regression—then the most sophisticated use of technology variable (the use of all three technologies) becomes significant, as does the use of software and communications technologies by themselves. Establishments that adopt all three types of ICTs are significantly more likely to increase their market share but only when the other innovative variables are removed from the regression. In addition, establishments that adopt communications technologies are also more likely to increase their market share. This accords with our earlier finding that communications technology use at the end of the 1980s was most closely associated with superior performance during that decade (Baldwin, Diverty, and Sabourin, 1995).

What conclusions can be drawn from this? In previous work, we have found that some firms adopt a very different innovation profile than others do (Baldwin and Johnson, 1996, 1998, 1999). They perform R&D; they stress a number of advanced management practices; *and* they are comprehensive advanced technology users. For this, they are rewarded with growth in market share. Comprehensive technology use matters, but as part of a package of activities.

As with relative labour productivity, there is a regression-to-the-mean process at work in changes in market share. Plants that are larger in 1988 generally lost market share. However this result is not statistically significant. Foreign-controlled plants are gaining market share.

There are no significant regional effects. This result implies that there have been very few changes in the relative importance of plants within industries at the regional level—that the geographic distribution of employment has been relatively constant.[15]

7.2.3 Growth in Wage Rate, Profitability and Employment

Turning to the equations for the relative wage rate, employment share and relative profitability (Table 10), we see that comprehensive technology use is significantly related to relative wage rate and relative profitability. Moreover, being foreign controlled has a positive effect on relative profitability and on the relative wage rate, but it does not affect growth in employment share. In the case of relative wage and relative profitability growth, there is regression-to-the-mean. Employment share also is characterized by regression-to-the-mean, but this effect is not significant.

The R&D variable is only significantly related to the relative wage rate, and the sign of this effect is negative. Plants that have access to R&D do not pay particularly high wages relative to their competitors. As before, neither of the two other firm-effect variables (either business practices or business strategies) is significant. Once more, we argue that this probably means that the technology variable is not just capturing a firm fixed effect that is associated with these plants being generally more innovative.

In summary, advanced technology use emerges from the multivariate analysis as having a close relationship to the growth in relative labour productivity—and it is positively associated with higher relative wage rate growth, and relative profitability growth.

Plants that manage to incorporate advanced technologies, to do so more intensively, and to combine advanced technologies across more functional groups also grew in terms of relative labour productivity. In turn, growth in relative labour productivity is translated into growth in market share.

[15] For more on changing regional distributions, see Baldwin and Brown (2001).

It should be noted that advanced technology use not only had an indirect effect on growth in market share via relative productivity growth, it also had a direct effect, albeit in conjunction with innovation in general. This is probably because advanced technologies, along with a general inclination to innovate, increase the flexibility of firms and hence their ability to respond quickly to customer needs, thereby enhancing their market shares.

8. Conclusion

Our understanding of the amount and type of dynamics in the firm population has improved as a result of the development of longitudinal databases that allow us to measure the entry of new firms, and the exit of old ones, and how incumbents change market position as the result of growth and decline. While these databases allow us to measure some aspects of the effects of competition, they do not easily allow us to understand the underlying factors that are generating the change. For this, we need more detail on the underlying characteristics of firms and their plants. This paper has used data on one such characteristic—the incidence of use of advanced technologies—as well as the extent to which plants were pursuing a general strategy of innovation.

One question that is often posed is the extent to which ICTs have an effect on the amount of change that is occurring. This paper has addressed this question by examining whether plants with different growth paths made different use of advanced technologies. Examining differences in success across plants reveals which set of advanced technologies are more appropriate than others. All plants have the same technological capabilities open to them at any point in time. But only a subset of the population chooses to adopt ICTs. By examining which plants and which technologies were more closely associated with success than others, we isolate which of the technological paths were revealed by the competitive process to be the more successful.

We find that the adoption of many of the ICTs was associated with greater growth in labour productivity and market share during the period 1988 to 1997.[16] This finding replicates the results of an earlier paper that examined the relationship between plant performance in the 1980s and advanced technology use (Baldwin, Diverty and Sabourin, 1995). This confirms our view that the adoption of ICTs is one of the keys to growth. And this growth is associated with improvements in labour productivity.

We have also found that communications technologies play a special role in growth. ICTs are built around the capabilities of computers. The computer-assisted machines not only allow for precision cutting, shaping and forming; computer technologies permit the acquisition of large amounts of information that in turn permit monitoring, evaluation, and rapid adaptation to changing circumstances. The capabilities of the new technologies have been referred to as bringing about the soft-manufacturing revolution (Bylinsky, 1994). The new advanced technologies permit the advantages of machines to be effectively combined with human cognitive capabilities. And it is in this area where advanced technology adoption appears from the evidence adduced here to have had the greatest impact.

[16] Weaker effects are also found for ICT adoption on relative wage rate growth and relative profitability growth.

Several caveats to the results summarized above are, however, necessary. Our results do not show that simply purchasing advanced technologies necessarily leads to success. We have shown that plants that successfully implement ICTs (those who report that they possess such equipment) do better than others. But implementation requires a number of skills. It requires a human-resource strategy to develop the necessary worker skills (Baldwin, 1999, 2000). It requires that firms overcome financing problems associated with acquiring the new and untried technologies (Baldwin and Lin, 2001). Innovation, even on the technical side, is often accompanied by the development of best practices in quality control and engineering (Baldwin and Sabourin, 2000).

In this paper, we have focused on only one characteristic of manufacturing plants—their technological sophistication. But we recognize that plants rarely distinguish themselves from others in only one dimension. Baldwin and Johnson (1996, 1998) demonstrate that innovative and non-innovative firms differ in a number of dimensions simultaneously—in terms of the emphasis placed on marketing, human resources, financing, and technological developments. Technology is just one part of the puzzle that creates a successful firm. That said, it is a key piece, as this paper has shown. Plants that adopt advanced technologies become more productive and grow more quickly. That they have to master a number of skills to be successful does not subtract from the central importance of mastering a way to successfully introduce ICTs into the business operations of manufacturing plants.

Appendix A

In order to examine growth over time, we use only those establishments for which economic performance data are available over a ten-year period. The period of study is the ten-year period 1988 to 1997 inclusive. Of the 3,699 establishments in the original sample, 2,113 are present throughout the ten-year period.

Since reduced samples of continuing establishments such as those used here are sometimes not representative of the population as a whole, it is useful to examine the differences between the sample that we have used and the population to understand where differences arise. Size and industry distributions of the sample used are provided in Table A.1 for the total population of manufacturing establishments and for the 'continuers' population in 1997, for all establishments with at least 10 or more employees. With essentially the same industry composition as the total population, the 'continuers' in our sample are generally representative of the population of establishments, at least in terms of industry composition, and to a slightly lesser extent for size.

Table A.1. Size and Industry Distribution of Continuers and Total Manufacturing Population (Establishment Weighted)

Characteristics	Total Population (10 or more employees)	Continuers Population (10 or more employees)
	(percentage of establishments)	
Size		
• Small (10-99 employees)	83	72
• Medium (100-249 employees)	11	19
• Large (250 plus employees)	6	9
Industry (2-digit)		
• Chemicals & Petroleum	5	5
• Electrical & Electronics	6	5
• Fabricated Metals	20	18
• Furniture	5	6
• Industrial Machinery	7	7
• Non-Metallic Minerals	4	5
• Paper	3	4
• Primary metals	2	2
• Printing & Publishing	10	9
• Rubber & Plastics	6	6
• Textiles	10	10
• Tobacco & Beverages	1	1
• Transportation	6	5
• Wood	10	11
• Other	7	7
All	100	100

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