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The effect of changing technology use on plant performance in the Canadian manufacturing sector

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Abstract

This paper investigates how changes in technology use of individual plants in the Canadian manufacturing sector are related to two measures of performance—productivity growth and market-share growth. The paper describes whether plants are adopting new advanced technologies and if they do so, whether they enjoy superior performance in these two areas. It makes use of panel data on advanced technology use from Statistics Canada's 1993 and 1998 advanced manufacturing surveys that are combined with longitudinal data on plant performance.

Growth in technology use during the period is significantly associated with relative productivity growth. In turn, growth in relative labour productivity is translated into growth in market share. Plants that improve their production efficiencies or produce higher quality products are able to realize gains in market share. Growth in the use of advanced technologies also had a positive impact on a plant's growth in market share, probably through its impact on product innovation. The market rewards those businesses that managed to improve their efficiency or the quality of their product and concomitantly their labour productivity with an increase in market share.

The paper also investigates other plant characteristics that are related to productivity and market-share growth. R&D is related to market-share growth. The use of information and communications networks for ordering goods and services is associated with higher productivity growth.

Keywords: productivity growth, advanced technology, market-share growth, panel data

Executive Summary

A study of individual firms provides important clues as to the nature of the growth process for the overall economy. The economy is just the sum of its individual components—many of which are private businesses. The economic performance of the macro economy depends upon the health and dynamism of these individual businesses.

Previous Statistics Canada studies have therefore concentrated on the connection between growth and innovation by studying specific populations of firms—small and medium-sized businesses or new entrants (Baldwin et al., 1994, Baldwin, 1996, Baldwin and Johnson, 1999). In each of these cases, we have reported that firms that adopted a more innovative strategy were the fastest growing.

Innovation has many dimensions. One key aspect is the technology strategy of the firm. Firms that introduce new important product innovations often also turn to new advanced technologies to support the introduction of the innovation.

The use of advanced technologies in Canadian manufacturing has been examined using several surveys (see Baldwin, Rama and Sabourin, 1999). These surveys describe whether advanced technologies are being used. They do not tell us whether the use of these advanced technologies has been associated with superior economic performance. That is the purpose of this paper.

In order to examine this issue, this paper investigates the extent to which the adoption of advanced technologies between 1993 and 1998 by manufacturing plants was associated with superior growth and productivity performance over this period. To do so, it links the 1993 Survey of Innovation and Advanced Technology and the 1998 Survey of Advanced Technology in Canadian Manufacturing so that technology profiles of plants can be compared over time. These two surveys not only allow us to profile the technology use of each plant but also to examine whether plants perform R&D, are foreign-owned and the emphasis that they place on several competencies—from human resources to implementing new technology. In addition, the plants in each survey are linked to the Annual Survey of Manufactures. This allows us to track the size of each plant that is surveyed, its labour productivity and to thereby measure whether plants are gaining market share or becoming relatively more productive.

This paper complements the macro literature that stresses the importance of ICT (information and communications technologies). But it is much broader in scope than the typical paper in this literature that focuses just on computers, software and communications gear. In this paper, we examine a much wider range of advanced technology investments—such things as robots, flexible-manufacturing systems, and automated retrieval systems. The amount of investment that is part of the electronic chip revolution is larger than just computer investment—especially in the manufacturing sector.

In this paper, we ask three questions.

1) How much dynamic change is taking place within manufacturing?

We examine this issue by measuring the extent to which plants change their relative position both with respect to their size (measured by market share) and productivity (measured by relative productivity). We find that large amounts of market share are shifted from declining firms to growing firms—on average, 15% per industry over the period studied. Simultaneously, plants that increase their market share also increase their productivity relative to those losing market share. At the beginning of the period, plants that subsequently increase their market share are 16% less productive than those about to lose market share. By the end of the period, they have become 17% more productive. The competitive system rewards those who become relatively more productive with increases in market share.

2) How is the adoption of advanced technology related to productivity improvements in manufacturing plants?

To answer this question, we develop and estimate a dynamic structural model that postulates that technology choice affects productivity growth that, in turn, affects market-share growth.

We find that increases in the use of advanced technology between 1993 and 1998 lead to greater productivity growth over the period. Initial technology intensity has a positive but insignificant effect in the sample used for this paper. Finally, reinforcing this finding, giving more emphasis to a technology strategy, in general, positively affects productivity growth.

Some of the impact of advanced technology comes from its effect on increased capital intensity. But that does not obviate the fact that increases in the use of advanced technologies drive the capital accumulation process. Other work for Canada (Armstrong et al., 2002) has shown that ICT investments accounted for a growing portion of capital during the mid to late 1990s. The micro data in this paper show why. Plants that were investing heavily in these technologies were growing more rapidly than those that were not doing so.

The fact that it is capital accumulation that partly drives this process does not downplay the difficulty that firms face in deciding upon the appropriate capital goods and making the right investment decisions. A wide range of assets is available to each firm. Only some firms manage to incorporate them successfully into their production process. And those that do so increase their relative productivity and gain market share.

This paper also sheds light on how new information and communications technologies contribute to success. Information and communications equipment can be used for various purposes—to keep databases for analysis, to engage in financial transactions, to sell products over the internet, and to facilitate the ordering process. Plants that were using their electronic communications networks to improve the efficiency of the ordering process were more likely to have improved their productivity. This accords with our previous findings (Baldwin, 1996) that an emphasis on just-in-time inventory practices could be found in those firms that were more successful.

3) How is the adoption of advanced technologies related to firm growth?

Productivity growth over the period and gains in market share over the same period are related. Those firms with greater relative productivity growth generally experienced increases in their market share.

In addition, growth in the use of advanced technologies had a direct positive impact on a plant's growth in market share, probably through its impact on product innovation. Therefore, additions to technology have both a direct and an indirect effect on market-share growth through their effect on productivity growth. By the end of the period, the market rewarded those who managed to improve their efficiency or the quality of their product and concomitantly their labour productivity with an increase in market share.

Complementary investments outside of advanced technologies were also shown to be important. R&D is found to be an important factor behind the growth of a plant's market share. An R&D strategy is a complementary factor that contributes to the development of new products, just as does an advanced innovation strategy. The fact that R&D is found to have an influence on market-share but not relative productivity growth emphasizes the fact that it is more on the product side than the process side that the effect of this activity is felt.

This paper concludes with several caveats. In particular, we note that innovative firms, if they are to be successful, have to develop superior competencies in a wide range of areas. And while we have focused on the importance of having more than just a technological bent in this paper, we cannot pretend to have fully covered all aspects of firms' competencies. Use of advanced technologies that is measured in this paper is probably related to a host of other competencies. Nevertheless, given that a large number of factors matter in the growth process, the fact that we found any relationship between success and the adoption of advanced technologies suggests that this is an important area. And the fact that this finding has now been replicated in a number of different studies, using different surveys, in a number of different ways (Baldwin, 1996; Baldwin and Johnson, 1998; Baldwin, Diverty, and Sabourin, 1995; Baldwin and Sabourin, 2002; Baldwin, Sabourin and Smith, 2002) strengthens the argument that a technology-based innovation strategy is one of the key factors behind growth.

1. Introduction

This paper investigates how changes in technology use of individual plants in the Canadian manufacturing sector are related to their performance.

Structural change occurs in an industry when plants gain and lose market share. This turnover has been found to be closely related to changes in relative productivity (Baldwin, Diverty and Sabourin, 1995; Baldwin and Sabourin, 2001). In this paper, we ask how market share and productivity changes are related to technological change─that is, the adoption of new advanced manufacturing technologies.

New technologies tend to be adopted slowly into the production process. And plants do not adopt new technology at the same rate. Even though a range of new advanced technologies is available at any point in time, not all plants will choose the same set. Nor will the same set of technologies necessarily result in the same rewards across plants. Plants have different technological trajectories (Nelson and Winter, 1982). That is, the environment faced by a plant and the history of that plant dictate the patterns of technological adoption and the success of the plant.

This paper describes whether plants are adopting new advanced technologies and if they do so, whether they enjoy superior economic performance. It makes use of panel data on advanced technology use at two points in time combined with longitudinal data on plant performance. Productivity growth and market-share growth are the two performance measures used in this study.

Advanced technology use may have several impacts on a plant. It may improve the productivity or the efficiency of a plant and allow it to charge lower prices for the products that it produces. In turn, lower prices should be reflected in higher market shares. Or new technologies may facilitate product innovation or improve the quality of the product. This too should increase market share.

In this paper, we examine whether those manufacturing plants that increase the rate of adoption of various forms of advanced technology saw their labour productivity increase faster than those who had not increased their rate of adoption of advanced technologies. Labour productivity can increase either because of improvements in efficiency or increases in capital intensity. The adoption of advanced technologies is expected to affect both. New advanced technologies are seen to produce more with less. They probably also increase capital requirements.

Because the productivity literature places so much emphasis on the differences in the two causes of changes in labour productivity, we try to take into account the impact of changing capital intensity in this study. But we argue that for our purposes, the distinction between pure efficiency effects and capital deepening is not as useful as the distinction that is drawn in the traditional productivity literature would suggest.

We are interested in investigating whether the adoption of advanced technologies is related to a firm's growth. The growth strategy of most plants involves capital deepening. Large plants differ from small plants in that they employ more capital per worker than small plants do. Growth requires that plants master the process whereby capital is substituted for labour. This is not easy to do. Plants that grow large master this process, while plants that lose market share do not. The capital deepening process then is something that requires special skills. It is of as much interest to us to know that the adoption of new technologies is part of the capital deepening process as it is to learn that it leads to pure efficiency gains.

The paper is structured as follows. The first part discusses the methodology and data to be used. The second part of the paper examines the growth process in Canadian manufacturing. Specifically, the extent to which plants grow or decline in terms of their productivity, and subsequently gain or lose market share, is explored. The third section investigates the relationship between technological change and market-share and productivity growth. It examines the relationship between plant performance and the use of advanced manufacturing technologies, such as programmable controllers, local area networks and computer-aided design and engineering equipment.

2. Methodology and data sources

Advanced technology use has been found in previous studies to be associated with the productivity growth of individual plants. Based on data taken from a survey on technology use that is then linked to longitudinal performance data from the Census of Manufactures, we found that productivity growth over a period was positively and significantly related to end-period technology use. Baldwin, Diverty and Sabourin (1995) and Baldwin and Sabourin (2001) report that plants using advanced technologies at a particular point in time (1989 and 1998, respectively) experienced superior performance during the period prior to the measurement of the technology use (the 1980s and the 1990s, respectively).

To study the effect of the use of advanced technologies, these studies have used the formulation:

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

where $\Delta PERF_{t-\tau,t}$ is the change in a plant's performance over the period t-τ to t and $Tech_t$ is a measure of advanced technology use at the end of the period in year t, and X_t is a set of plant characteristics at time 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, $Tech_{t-\tau}$, plus any changes in advanced technology use during the period, $\Delta Tech_{t-\tau, t}$, equation 1 can be rewritten as:

2) $\Delta PERF_{t-\tau,t} = f(Tech_{t-\tau} + \Delta Tech_{t-\tau,t} , X_t)$[1]

The finding of earlier studies that performance is related to end-period technology use means that it is positively related to a combination of opening-period technology use and changes over the time period. In this paper, we use panel data to separate out the effect of opening-period

1 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 $\Delta Tech_{t-\tau, t}$.

technology use and changes in technology use on performance. The advantage of the panel data is that they allow us to decompose end-period technology effects into start-period and growth effects. Panel data allow us to examine the changes that have occurred not just in the performance of plants but also in the changes that have occurred in advanced technology use.

Two measures of a plant's performance relative to an industry norm will be used here—relative labour productivity growth and growth in market share. Relative labour productivity of a plant is defined as the labour productivity of a plant relative to the average labour productivity of its industry. Market share is defined as the sales of a plant over the sales of all plants in the same four-digit industry.

Performance during a particular time period should be a function of start-period technology use because there is a learning process involved with the introduction and use of advanced technology. Productivity growth should also be related to growth in technology during the period.

In order to examine the relationship between the performance of producers and their technological competencies, we compare the performance of plants to their technological profile during the mid-nineties. The advanced technology data come from a longitudinal panel taken from the 1993 Survey of Innovation and Advanced Technology and the 1998 Survey of Advanced Technology in Canadian Manufacturing. To this was linked longitudinal data measuring economic performance, available from Statistics Canada's Annual Survey of Manufactures. This database contains annual 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.[2]

The 1998 technology survey was 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 had been stratified by industry and size. The overall response rate to the survey was 98%.

The 1998 technology survey was designed in such a way as to provide a longitudinal panel for a set of establishments that could be linked to the 1993 Survey of Innovation and Advanced Technology. The panel was not created by taking two independent samples in 1993 and 1998 and then trying to find plants that were there in each year.[3] This often leads to unrepresentative samples. Instead, the 1998 sample was derived from the 1993 sample in such a way as to produce a random and representative sample that could be used to infer the characteristics of the true continuing population. All results presented in this paper are establishment weighted to reflect population results, rather than sample results.

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2 Total value added differs from manufacturing value added in that it also contains value added from non-manufacturing activities of manufacturing establishments that are intrinsic to the manufacturing operations of the plant.

3 This was the method used by McGuckin et al., 1998 in their study of the effect of changes in technology use on the performance of U.S. manufacturing plants.

The panel data taken from the 1993 and 1998 technology surveys are linked to longitudinal data for the years 1993 to 1997 taken from the Annual Survey (Census) of Manufactures, which covers almost the universe of manufacturing plants in Canada.[4] This linked dataset provides us with information about changes in the use of advanced technology and related characteristics for a sample of establishments that were alive in both periods. In a previous paper (Baldwin and Sabourin, 2001), we used a data base that linked the 1998 technology survey to longitudinal data on plants spanning the period 1988 to 1997 and examined how performance over this period was related to the technologies that had been put in place in 1998. The database used here is superior in that it allows us to examine how performance is related both to changes in technology use and initial period technology use, but it has certain offsetting disadvantages. The database using the 1998 cross-section on technology use contains over 2,000 observations; the panel used here contains only about 400 observations. This is mainly due to survey design constraints that were imposed in the 1998 survey when developing the panel used in this survey. The smaller number of observations for the longitudinal panel means it will be harder to obtain significant relationships here than in the cross-section.

3. The growth process

Before we ask how technology use is related to performance, it is important to delineate the dynamic change that is taking place in the underlying population. If there were no changes taking place in relative productivity or in market share, changes in relative performance are unlikely to be related to technology adoption.

Some plants increase their relative productivity while others fall behind. In addition, growth and decline takes place as some plants gain market share and others lose it. Over long periods, the amount of movement in both relative productivity and market share is substantial. And the two are related. Plants that improve their production efficiencies or produce higher quality products are able to realize gains in market share.

The extent to which plant growth and decline leads to changes in relative rankings based on market share over our period of study is presented in Table 1. Establishment market shares are measured by the total shipments produced by an establishment relative to that of its industry, calculated at the 4-digit level for both the start year (1993) and end year (1997). Based on their market-share rankings, establishments are assigned to quartiles in each of these two years. The movement of continuing establishments up and down the market-share hierarchy for the continuing population of plants is provided in the first part of Table 1.[5] It gives the percentage of continuing plants that had stayed in the same quartile in which they had started, that had moved up one or more quartiles, or had moved down a quartile or two. Similar information, only this time using our constructed panel dataset, is provided in the second half of the table. The two

4 For this paper, we only used data from 1993-1997 from the Census of Manufactures. We are, therefore, comparing performance change between 1993 and 1997 to technology in 1998. The 1998 survey was taken in the early part of that year.

5 In Table 1, the quartiles are calculated using all establishments, but the shares being shifted are calculated only for continuers.

populations provide almost identical results. The weighted panel data that are used in this analysis are representative of the population of continuers.

Over the four-year period studied here, there was substantial change in relative status.[6] A quarter or more of the plants that started the period in one of the middle two quartiles, had moved out of that quartile by the end of the period.[7] There is greater inertia for the plants that started in the bottom or top quartile, primarily because their movement possibilities are truncated, either in an upwards direction for the top quartile or downwards for the bottom quartile. Between eighty and ninety percent of these plants remained in the same quartile group. Less than twenty percent moved to another category.

Looked at a different way, about 15 percent of market share in an average four-digit SIC was transferred from continuers who lost market share to continuers who gained market share over the period.

Table 1. Market-share transition matrix for continuers and panel (1993-1997)

Market-share quartiles (1993)	Market-share quartiles (1997)			
	Q1	Q2	Q3	Q4
	Percentage of establishments			
Continuers (93-97)				
Q1	85	13	1	0
Q2	14	71	15	1
Q3	1	15	72	12
Q4	0	1	12	87
Panel (93-97)				
Q1	83	17	0	0
Q2	2	73	25	0
Q3	0	9	68	23
Q4	0	1	8	91

Even greater movement is found for relative productivity. Relative productivity of a plant is the productivity of that plant divided by the weighted average productivity of all plants in the industry. To track the movement of continuers through the use of a productivity transition matrix, we ranked establishments according to their relative labour productivity in both 1993 and 1997, and then assigned them to quartiles in each of these two years. Table 2 provides the percentage of establishments that had bettered their relative position, stayed the same, or declined.

Shifts in productivity rankings over a four-year period are substantial. For continuers, only six out of ten plants initially in the top and bottom quartiles remained there by the end of the period.[8] For those in the middle two quartiles, the movement was even greater, with less than half still in the same quartile in which they had started. This indicates either that there is a substantial change in relative efficiency or that plants change their relative capital intensity quite dramatically.

6 For evidence covering a longer period from 1988 to 1997, see Baldwin and Sabourin (2001).
7 Over the 1988-97 period, this increases to over 40% shifting out of the middle two quintiles.
8 For the period 1988-97, only 50% stayed in the bottom and top quintile.

Table 2. Relative labour productivity transition matrix for continuers and panel (1993-1997)

Relative labour productivity quartiles (1993)	Relative labour productivity quartiles (1997)			
	Q1	Q2	Q3	Q4
	Percentage of establishments			
Continuers (93-97)				
Q1	58	25	11	6
Q2	25	44	21	10
Q3	11	22	42	25
Q4	7	9	25	59
Panel (93-97)				
Q1	58	19	19	4
Q2	32	40	21	8
Q3	11	9	48	33
Q4	10	7	19	63

While there is inertia in the system—that is, the most productive plants remain relatively more productive over time—there is nevertheless a substantial change taking place in relative productivity.

To this point, we have examined changes in market share and changes in productivity independently of one another. Changes in relative productivity and changes in market share should be related. Success in terms of the growth in market share is accomplished in various ways. Plants may attract customers either through lower prices or by offering higher quality products. Higher levels of labour productivity permit a plant to offer either or both. In either case, we would expect changes in a plant's relative productivity to be associated with increases in market share on average.

To illustrate how the gain in market-share is accompanied by a growth in relative labour productivity, we divide continuing plants into two equal groups based on the size of their market-share changes over the period (growers versus decliners). Two questions are examined. The first is whether differences in labour productivity at the beginning of the period provide any signals as to who is likely to do better over the period? The second is whether plants that improve their relative productivity also gain market share.

Table 3. Mean relative labour productivity by growth in market share

Market-share change (1988 to 1997)	Relative labour productivity (RLP)		ΔRLP
	1993	1997	1988 to 1997
Low growth	1.09	0.91	-0.18
High growth	0.92	1. 06	0.16

We find that the relative labour productivity of growers is less than that of decliners at the start of the period (Table 3). Opening-period success with regards to relative productivity is not a good indicator of growth in market share over a subsequent period. But, by the end of the period, those gaining market share simultaneously manage to increase their relative productivity. By

1997, their relative productivity is above that of the declining group. The market has rewarded those who have managed to improve their labour productivity with an increase in market share.

This is a phenomenon that has been repeatedly found in studies of the Canadian manufacturing sector. Baldwin (1995) examined changes between 1970 and 1979 in the relative productivity of plants that continued between 1970 and 1979. The mean ratio of the productivity of gainers to losers in 1970 was 0.98. In 1979, it was 1.34. Baldwin (1996) examined similar changes over three periods—1973-1979, 1979-1985 and 1985-1990. The relative productivity of market-share gainers to losers was always less than one at the beginning of each period (0.99, 0.98 and 0.95, respectively) and it was considerably higher by the end of the period (1.26, 1.33 and 1.28, respectively). Baldwin and Sabourin (2001) examined changes from 1988 to 1997 and found that the relative productivity of gainers to losers increased by some 28 percentage points over this period.

There is an alternate way of examining how the changes in market share and relative productivity are related. In Table 4, we divide the population of plants into two groups—into those with positive growth in relative productivity and those with negative growth. Then we calculate the growth in market share of each group. Categorizing continuing establishments as growers or decliners, according to their change in productivity throughout the period of study, we find that the productivity-growers group increased their market share throughout the period by 17 percent in the population as a whole, while the productivity-decliners group saw their market share eroded by about 9 percent (Table 4). Thus, plants that increased their relative productivity during the period also managed to gain market share. By the end of the period, the market 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 4. Market-share growth by productivity growth

Relative labour productivity growth (1993-1997)	Market share (MS)		Δ MS (%)	N count
	1993	1997	1993 to 1997	
Continuers (93-97)[9]				
• *Growers (Δ RLP > 0)*	0.012	0.014	17	7710
• *Decliners (Δ RLP < 0)*	0.011	0.010	-9	9910
Panel (93-97)				
• *Growers (Δ RLP > 0)*	0.037	0.041	10	182
• *Decliners (Δ RLP < 0)*	0.030	0.027	-10	208

9 Excludes food processing establishments and establishments with fewer than 10 employees.

4. *Technologies*

In this study, we ask how changes in market performance are related to the level of advanced technology use and changes therein. Data on the latter were derived from two Statistics Canada surveys—the 1993 Survey of Innovation and Advanced Technology and the 1998 Survey of Advanced Technology in Canadian Manufacturing.

The technology surveys covered twenty-six advanced technologies—technologies that are applied in a wide range of functional areas—design and engineering; processing, fabrication, and assembly; network communications; integration and control; automated materials handling; and inspection.[10] The technologies 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, to computer integrated manufacturing systems that are used in integration and control, to automated retrieval systems used in automated materials handling, to automated inspection systems used in the inspection functional area.

Advanced technology use increased between 1993 and 1998 (Table 5). Network communication technologies experienced the highest growth (29 percentage points). Integration and control and fabrication both experienced strong growth with 25 and 20 percentage points, respectively.

These results show that the relative growth rates in the late 1990s correspond closely to the relative performance or success of the different technologies in the 1980s. In an earlier study (Baldwin, Diverty and Sabourin, 1995), we found that plants using communications technologies did particularly well over the 1980s and it is therefore not surprising that advanced technology use increased most in this functional area. Integration and control, which was also associated with more success in the earlier decade, experienced the second highest growth rate in the mid 1990s.

Table 5. Technology use by functional group—1993-1998

Technologies	Use		
	% of establishments		
	1993	1998	1993-1998
Design and engineering	37	51	14
Processing, fabrication, and assembly	24	44	20
Network communications	18	47	29
Integration and control	24	49	25
Automated materials handling	4	5	1
Inspection	10	13	3

10 A slightly larger number of technologies were investigated in the 1998 than in the 1993 survey. Only the common technologies are used here; 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. For further discussion of the overlap sample, see Baldwin, Rama and Sabourin, (1999).

For the purposes of this study, the advanced technologies covered in the survey are aggregated into three new groups—(i) software, (ii) network communications, and (iii) hardware technologies. These classifications do not so much use the functional area of the production process in which the technologies are used as the type of technology, where type is broken into communications and all other machinery (here called hardware). In addition, a third category is created that recognizes that many technologies essentially revolve around software. The new technologies make use of electronic chips. These chips need instructions via software. Some technologies consist mainly of machines with software as a facilitating language. Other technologies are primarily software, with a machine (normally a computer) added on.[11]

Table 6. Adoption of advanced technologies, 1998 population (percentage of establishments using the technology)

Technology group	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
Network 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

The technology groups, their constituent advanced technologies, and their adoption rates as of 1998 are outlined in Table 6. 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.

11 This taxonomy was developed with the aid of outside technology experts.

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.

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.

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 advanced network communications 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 this study, advanced technology use will be measured for each member of the ICT group—software, hardware and communications. Each of these areas of technology use experienced growth between 1993 and 1998 (Table 7). The highest rate of growth was in network communications. The next fastest was in hardware. It is the relationship between this growth in technology use and performance that we investigate in the next section.

Table 7. Technology use in panel data set—1993-1998

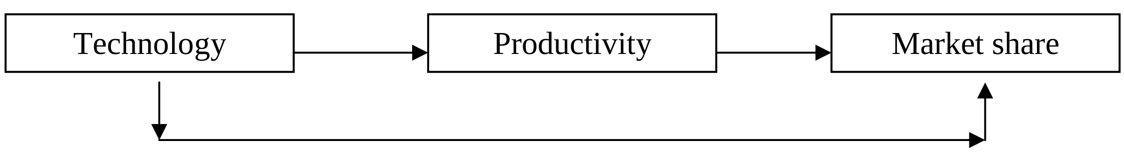
Technologies	Use		
	% of establishments		
	1993	1998	1993-1998
Software	48	67	19
Network communications	25	61	36
Hardware	38	62	24

5. *Multivariate analysis*

5.1 Model

This paper investigates the relationship between technology choice and plant performance. Plant performance is measured here in two ways—first, as growth in relative labour productivity and second, as growth in market share. Both are measured over the period 1993-1997, as the difference between end-period relative productivity (or market share) and start-period relative productivity (or market share). Changes in labour productivity reflect changes in the capital intensity of an establishment, changes in its organizational structure or changes in its technological capabilities—all of which factor into its success.

The framework that instructs the analysis is straightforward (see boxes below). Plants are seen to make choices on technologies that they will use. In turn, the technologies chosen will affect labour productivity through their impact on both efficiency and capital intensity. In turn, productivity will impact on market share through its effect either on relative prices or on the quality of product. Technology choice affects market share indirectly through its impact on productivity but also directly through its effect on product innovation that improves market share.



We start with a linear directional model that runs from technology choice to productivity to market-share growth. Productivity growth is posited to be a function of opening-period technology and additions to technology and other factors such as R&D intensity. Market-share growth in turn is taken to be a function of labour productivity growth, technology use and a set of other plant characteristics. The latter will be discussed in more detail in the next section.

We construct a 2-equation system. The first equation (equation 3) estimates the correlates of productivity growth, while the second equation (equation 4) examines the correlates of market-share growth.

$$3)\ \mathrm{PRODGRTH} = \alpha_0 + \alpha_1{*}\mathrm{TECH\,93} + \alpha_2{*}\mathrm{TECHGROW} + \alpha_3{*}\mathrm{SIZE93} + \alpha_4{*}\mathrm{FOREIGN} + \alpha_5{*}\Delta\mathrm{CAPINT} + \alpha_6{*}\mathrm{LABPROD93} + \alpha_7{*}\mathrm{R\&D} + \alpha_8{*}\mathrm{REGION} + \alpha_9{*}\mathrm{STRAT} + \alpha_{10}{*}\mathrm{NETWORK}$$

$$4)\ \mathrm{SHARGRTH} = \beta_0 + \beta_1{*}\,\mathrm{PRODGRTH} + \beta_2{*}\mathrm{TECH\,93} + \beta_3{*}\mathrm{TECHGROW} + \beta_4{*}\mathrm{FOREIGN} + \beta_5{*}\Delta\mathrm{CAPINT} + \beta_6{*}\mathrm{MKTSHR93} + \beta_7{*}\mathrm{R\&D} + \beta_8{*}\mathrm{REGION}$$

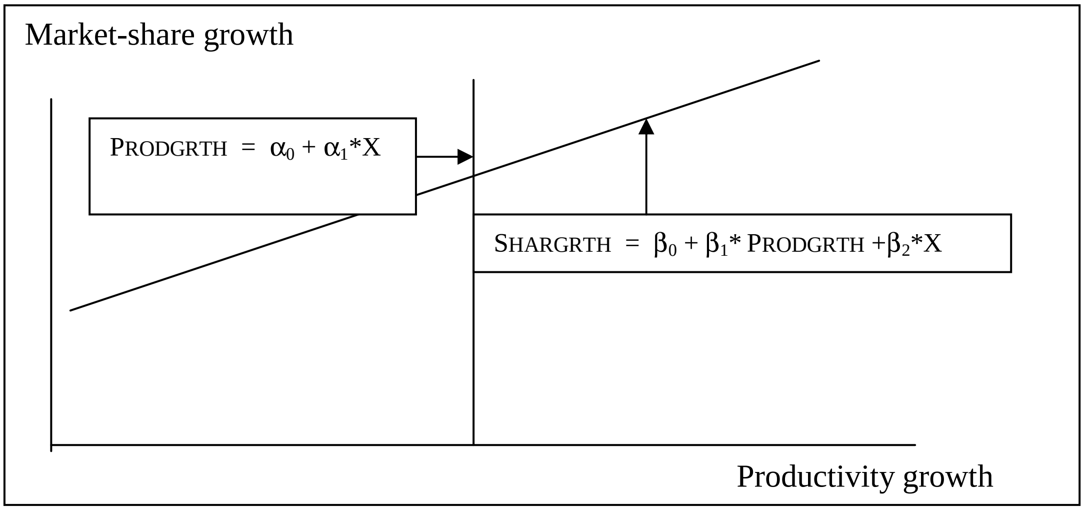
where *PRODGRTH* measures the growth in relative labour productivity of a plant.
SHARGRTH measures the growth in market share of a plant.
TECH93 measures the use of advanced technologies by the plant at the start of the period.

TECHGROW measures the growth in the use of advanced technologies by the plant.
SIZE93 measures opening-period employment size of the plant.
FOREIGN captures whether or not an establishment is foreign owned.
ΔCAPINT captures changes in the capital intensity of a plant through changes in the flow of capital services.
LABPROD93 measures opening-period labour productivity levels.
MKTSHR93 measures opening-period market share.
R&D captures whether or not an establishment is an R&D performer.
STRAT captures the technology and human-resource strategy emphasis
NETWORK is the type of use made of the ICT network by the plant
REGION captures any regional effects.

We recognize that there may be feedback effects but postulate that they occur with a lag. Improvements in market share should eventually feed back to affect technology use and productivity gains. For example, there is evidence to suggest that investment in innovation assets follows cash flow (Himmelberg and Peterson, 1994) and the latter should improve with gains in market share. But we believe that this also occurs with a relatively long lag. Our survey evidence suggests that this is the case. Despite the clear benefits from using network communications technology in the 1980s (see Baldwin, Diverty, and Sabourin, 1995), the percentage of manufacturing establishments that used these technologies rose only to 47% in 1998 from 17% in 1988.

Examples of the slow diffusion of other new technologies abound. The introduction of electric power sources into the industrial system was spread over three to four decades. The 1901 census first began to measure the horsepower of electric motors, and only 7% of total horsepower is listed as coming from electric motors in the manufacturing sector in that year. This increased to 20% in 1911, to 50% by 1921 and to 74% by 1930. While communications technologies have spread far more quickly than did electric motive power, their diffusion still takes place with a lag.

As a result, we estimate the change in productivity equation as a function of technology choice and a set of plant characteristics, and a market-share equation as a function of changing productivity and a set of plant characteristics. The implicit relationship that is the foundation for our maintained hypothesis is depicted below.



While we start with a prior belief that feedback or simultaneous relationships should not be important based on the reasons outlined above, we also estimate an additional set of relationships that include them. In these formulations, productivity growth is made a function of both changes in technology and changes in market share, with the latter being treated as endogenous. And in the market-share equation, the explanatory variable ‘changes in productivity growth’ is treated as endogenous.

If simultaneity exists, normal estimation procedures yield biased coefficients. We note however that taking into account simultaneity when the endogenous variables are poorly predicted can lead to equally serious problems. Replacing an endogenous variable with white noise in a two stage least squares regression or using a poor instrumental variable risks leaving the false impression that the variable in question does not matter.

The second set of equations that were estimated are the same as the first except that now market-share growth (SHARGRTH) is included in the productivity growth equation (#3). Before we estimated these regressions, we performed Hausman tests to examine whether endogeneity existed in the system. The technology variables were not found to be endogenous. The endogeneity of the market-share growth variable in the productivity growth equation was found to be weakly significant (at the 9% level); the productivity-growth variable was not found to be endogenous in the market-share equation. We interpret this as weak evidence for our maintained prior as to the nature of our relationship between technology use, productivity growth and subsequent market-share gain. Nevertheless, we present both sets of results in the following section.

Finally, we should note that the panel data allows us to estimate all our regressions in first difference form thereby removing constant fixed effects from a model where productivity and market share differ across plants because of unknown differences that are constant over time. Use of panel data reduces estimation bias in these circumstances (Hsiao, 1986). Panel data, which has both a cross sectional and a time series dimension, provides greater flexibility than cross-sectional data for investigating behavioural differences across units (Greene, 1997).

But it should be recognized that our formulation in a simple fixed-effects model would normally include only the explanatory variables in first-difference form as well. We do not slavishly follow this model because we use the first difference formulation as a result of our inherent interest in it rather than in the level form of the equation. We are interested in asking how performance varies over time and whether this difference is related to certain plant characteristics. We ask how it is related to changes in technology and certain other plant characteristics. But we also include some variables in level form to test whether the fixed effect varies over time with this characteristic—whether the component of labour productivity or of market share that is unexplained has increased in step with a certain plant characteristic, such as nationality of ownership or size or R&D intensity. We recognize, however, that the coefficients on these variables may be zero if the variable captures a fixed effect that does not change over the period.

5.1.1 Productivity growth

The first equation examines relative productivity growth during the 1993-97 period. Relative productivity growth is postulated to be a function of advanced technology use at the start of the period plus any additions of technology throughout the period.

Technology: We represent advanced technology use with a number of mutually exclusive, and increasingly comprehensive technology variables. Use of one type, and only one type, of the three advanced technology types—software, hardware, or communications—is captured by the first binary technology variable. A second binary variable captures the use of any two of the advanced technology types; while a third variable captures the use of all three.

Previous work (Baldwin and Sabourin, 2001; Baldwin, Diverty and Sabourin, 1995) found that 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 it was also found that the plants combining technologies from different areas were characterized by the best performance. We, therefore, expect productivity growth to be higher where plants added technologies. To capture this, we include a measure of technology growth. This is a zero-one binary variable that takes a value of one if an establishment increased its 'sophistication' of technology use and a value of zero otherwise. Increasing sophistication occurs by definition here if an establishment moved from being: 1) a non-user to a user; 2) a user of one ICT group to a multiple user; 3) a user of two ICT groups to a user of three ICT groups; and 4) initially a user of three ICT groups to where it increased the number of technologies more than most others in the group.[12]

Capital intensity: Productivity growth may be a function of advanced technology use to the extent that use is associated with higher capital intensity. To test for this, the increase in a plant's relative profitability (its profit/sales ratio) is also included since this measure of profitability

12 The difference in the number of additional technologies added by plants between 1993 and 1997 that were classified in the third group in 1993 was examined and it was ascertained that roughly half added 2 or more technologies. Therefore those plants that added 2 or more technologies in this third group were defined as being the more technologically sophisticated.

should be closely correlated with capital intensity. In the long run, profits measure the flow of capital services derived from the capital stock owned by the plant.

Plant size: Plant size was included to capture the greater financial and informational capabilities often associated with larger establishment size. Large plants tend to develop superior capabilities that lead to growth. While a number of other characteristics are included to capture these competencies, they probably do not capture all such effects. Consequently, size is included to do so. Employment data were used to measure size.

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

Region: A set of binary variables were included to test whether the geographic environment matters.

Foreign ownership: Nationality of ownership of a plant is included since multinational firms are seen to play an important role in the global diffusion of technology (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.

Since we are examining market performance over time, characteristics like nationality may change over time. Indeed, a considerable number of our sample underwent a change in control over the period of study as a result of mergers and takeovers (Table 8).

Table 8. Changes in nationality

	1998 control status (% of plants)	
1993 control status	domestic	foreign
Domestic	86.5	13.5
Foreign	25.0	75.0

Rather than utilize the foreign-ownership status of a plant in just one period, we introduced four categories—remains under domestic control over the entire period, remains under foreign control over the period, moves from domestic to foreign control, moves from foreign to domestic control—and defined a binary variable associated with each. These categories allow us to test not only that nationality matters, but also that changes in nationality matter.

Research and development: A binary variable that measures whether the plant reported that it performed R&D, whether on a continuing or only an occasional basis, is also included. This is done because of 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 interested in knowing whether R&D activity affects productivity performance after the technology mix has been taken into account.

As was the case for the nationality status of a plant, four categories were also defined for its R&D activity—whether it did not perform R&D during the entire period, whether it did so during the entire period and whether it changed its activity in this area—either from not performing R&D to doing so or vice-versa. An R&D performer is a producer that reports that it conducted R&D—either in-house, jointly with another firm, or by contracting it out.

There were considerable changes in R&D status over the period as Table 9 demonstrates. A quarter of the plants that indicated that their parent performed R&D in 1993 no longer did so in 1998; while more than half of the plants in 1993 that indicated their parent did not perform R&D did so by the end of the period.

Table 9. Changes in R&D status

1993 R&D status	1998 R&D status (% of plants)	
	R&D performer	R&D non performer
R&D performer	76.8	23.2
R&D non performer	51.8	48.2

Strategies: A comprehensive characterization of a plant requires information on more than just technology use, capital employed, or size. Plants differ substantially in terms of the strategic stance that they adopt and the resulting managerial competencies that are used to improve productivity or market share (Baldwin and Gellatly, 2004). There is evidence that the emphasis that is given to certain activities is related to performance. In Baldwin (1999), we find that firms that emphasize innovation are more likely to grow. Baldwin, Sabourin and Smith (2002) report that a plant’s emphasis on quality control and skill training was related to market-share gain.

To allow for differences in the nature of the strategies being followed by different producers, the 1993 survey investigated the emphasis that was given to a set of three strategies—marketing, production, and human resources. In the area of marketing, plants ranked the emphasis that they gave to the introduction of new products and the penetration of new markets on a five-point Likert scale. In the area of production, plants ranked the importance given to reducing production costs, introducing new technologies, and using new materials. In human resources, plants ranked the importance of flexible systems such as teams and the importance of formal training programs. The percentage of producers scoring above the median (4 or 5 on a five-point scale) in each of these areas is presented in Table 10.

A binary variable was added to our regressions for each one of these strategies when the producer indicated the emphasis that was given to this strategy was either a 4 or 5—above the median value. After experimenting with all strategy variables, we kept only the variables capturing the emphasis given to production and human resources because only they are close to being statistically significant. The emphasis given to developing a new market or entering new markets could not be distinguished from the R&D activity variable, probably because each is so closely related to an innovation strategy.

Table 10. Importance of strategies

Strategy	% scoring 4 or 5
Marketing	
a) Developing new markets	50
b) Entering new markets	54
Production	
c) Reducing manufacturing costs	77
d) Developing new manufacturing technology	50
e) Using new materials	36
Human resources	
f) Using teams (e.g., cross-functional)	47
g) Ongoing technical training	50

Use of electronic networks: ICT use can be directed at different areas. And some uses may be more productive than others. The 1998 survey asked plants to indicate the purpose to which communication networks were being put. The list of purposes was extensive: ordering products, tracking production flow, on-line maintenance, tracking sales and inventory, tracking distribution, sharing technology information, accounting and finance, human-resource purposes, management planning, marketing and customer information, financial transactions, consumer information, production status information, and general reference.

The intensity of ICT use in these areas varies widely (Table 11). The greatest use (outside of general reference) is that of marketing/customer information, with some 47% of producers using their communications network for this purpose. At the other end of the spectrum, only 22% indicated that they used their ICT communications system for tracking distribution. In the middle, with about 30%, are such functions as developing consumer information, performing financial transactions, and ordering products.

It is our objective to test whether some uses are more important than others. But these network-use variables (whether a producer makes use of ICT for a particular purpose) are closely related. Plants tend to use electronic communications networks for more than one purpose. However, they combine them in different ways. Since our purpose was to ask what combination was more closely associated with performance, we developed a new set of variables that summarizes how the various uses were combined. This reduces the dimensionality in the original set of network-use variables.

To do this, we performed a principal component analysis on a set of variables that encompassed all the uses outlined above—whether the plant used communications technologies for a particular purpose. Principal component analysis reduces a complex set of interrelated variables to a new set of variables, each of which is orthogonal to one another.

Table 11. Purpose of communications network

	% of producers using
General reference	52
Marketing/customer information	47
Accounting and financing	46
Tracking sales and inventory	38
Sharing technology information	36
Consumer information	34
Financial transactions	34
Ordering products	31
Production status information	30
Management planning	27
Human-resource purposes	26
Tracking production flow	25
Tracking distribution	22
On-line maintenance	12
Other	5

The new variables (PC_i) are related to the use variables (U_i) by the following algebraic transformation.

$$PC_i = \sum_i w_i{*}U_i$$

The weights attached to the original use variable in each principal component indicate how the various original variables (the uses) are combined within that component. Table A1 in Appendix A contains these weights for each of the components—what are referred to as $\text{Comnet}_{i.}$ For example, the first component gives positive weights to most of the uses and may thus be described as the all-encompassing component. On the other hand, the fourth component (Comnet4) has a large positive weight on ordering products, and sharing technology information but gives a large negative weight to using communications technology for consumer information. Producers who do more of the former but do less of the latter will have a higher value of this component—or conversely, those using their networks for consumer information but not for ordering products and sharing technology information will obtain a lower value of this component. Component five weights ICT use for ordering products negatively and ICT use for on-line maintenance, financial transactions positively. Producers that use their communications networks for ordering products but not for financial transactions will have a higher value of this component and those that do less ordering and more financial transactions will have a lower value for this component. The interpretation of the impact of each variable will also depend on the sign of the coefficient of the component in the multivariate analysis, a sign that can take on either positive or negative values.

5.1.2 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 plant an advantage over its competitors. Growth in market share is posited to be a function of the initial market share because of the inexorable tendency towards regression-to-the-mean. Baldwin (1995) outlines the 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.

Growth in market share is also hypothesized to be related to the growth in labour productivity 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 plant—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 additional effect running from advanced technology use on market-share growth over and above its effect on relative labour productivity growth. Technology use not only allows an improvement in relative costs that are reflected in lower prices, but it also improves the flexibility of 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 effect on growth in market share, which is independent of its effect on measured labour productivity.

The other variables—nationality, R&D, plant strategies, and region variables—are essentially the same as were used in the growth in the relative productivity model.

6. Empirical results

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 advanced technologies, does not perform R&D, and is in the Atlantic region.

6.1 OLS results

Earlier work using the entire 1998 survey sample (Baldwin and Sabourin, 2002), reported that productivity and market-share growth were related to end-of-period technology use. For comparative purposes, we ask whether our reduced panel data set, which contains a technology-change variable, yields the same results. To do so, we estimated the relative productivity growth and market-share growth equations as before to see whether our panel sample produces the same result as the full sample. We use a slightly reduced set of explanatory variables and the same econometric technique (OLS) as used in our earlier work.

6.1.1 Growth in productivity

Results of the OLS regressions that model relative productivity growth as a function of advanced technology use are presented in Table 12. Growth in capital intensity is included in the first model (Model 1) but not in the second (Model 2) in order to observe the effect of this variable.

Table 12. OLS relative labour productivity growth regressions

	Model 1	Model 2
Intercept	0.120	0.259***
Advanced technology use (1998)		
One ICT group only	-0.031	0.148
Two ICT groups	0.024	0.092
All three ICT groups	0.126***	0.220***
Plant size		
Employment –1993	6e-7	9e-5
Nationality of control (1998)		
Foreign	0.016	-0.040
Capital intensity		
Profitability change 1993-1997	1.846***	---
Initial labour productivity		
Relative labour productivity – 1993	-0.114	-0.281***
R&D (1998)		
R&D performer	-0.109**	-0.107
Region (1998)		
Quebec	-0.030	-0.134
Ontario	-0.026	-0.082
Prairies	-0.020	-0.037
British Columbia	-0.091	-0.197*
Summary Statistics		
N	390	390
F (degrees of freedom)	(12, 377) = 16.78	(11, 378) = 1.93
R^2	0.48	0.12

Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

All three technology variables are positively related to productivity growth when capital intensity is not included in the model specification. But only the coefficient on the use of all three technology variables is significantly different from zero. This is also the case when change in capital intensity is included as an explanatory variable. The earlier article also found that it was generally the case that only all three technologies taken together were significant. We conclude from this that the sample panel data set generally captures the connection between technology use and productivity growth that was revealed by the full cross-sectional data set for 1998.

As before, the coefficient on the starting-period productivity variable is negative and highly significant when changes in capital intensity are not included. 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.

Table 13. OLS Market-share growth regressions

	Model 1
Intercept	-0.005
Advanced technology use (1998)	
One ICT group only	-0.002
Two ICT groups	0.001
All three ICT groups	0.001
Plant size	
Employment – 1993	-1e-5
Nationality of control (1998)	
Foreign	-0.001
Capital intensity	
Profitability change 1993-1997	0.009
Initial labour productivity	
Relative labour productivity – 1993	0.001
Relative labour productivity growth	
Labour productivity growth 1993-97	0.004*
Initial market share	
Market share 1993	-0.038
R&D (1998)	
R&D performer	0.004**
Region (1998)	
Quebec	0.005
Ontario	0.005
Prairies	0.002
British Columbia	0.004
Summary Statistics	
N	390
F(degrees of freedom)	(14, 375) = 1.34
R^2	0.12

Note: *** significant at 1% level; ** significant at 5% level;
* significant at 10% level.

Finally, regional location does not have a consistently significant effect on labour productivity growth. This also is similar to our previous results. Although regional location generally does not have a statistically significant effect on labour productivity growth, 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).

6.1.2 Growth in market share

Growth in market share is strongly related to the growth in labour productivity over the period (Table 13) when using the reduced panel. These results are similar to those produced by the full dataset. Similar to the original results, the coefficient on R&D is positive and significant. Finally, after the effects of relative productivity growth on market share are taken into account, growth in market share is not related to end-of-period advanced technology use. Nor was it previously.

It is noteworthy that none of the other variables is significant. The market-share equation has a much lower R^2 than the relative productivity equation. Market-share changes are not easily explained. They are the result of an idiosyncratic process. Plants may adopt new technologies in order to improve relative productivity and gain market share. But the growth process is on the whole stochastic, depending not only on production success but also on the whims of consumer demand. We are more successful in separating out the correlates of changing productivity than we are in mustering a strong set of candidates that are related to a plant's success in capturing market share.

6.2 Simultaneous and selection corrected estimates

In the first estimation stage, we focused on a robust estimation procedure that made use of ordinary least squares. In this section, we adjust these estimates to take into account two potential problems with the estimates presented above. We also add additional explanatory variables.

We address two possible problems in sequential order—simultaneity and selection. There may be bias in our estimates of the coefficients in Table 13 if there are feedback effects between productivity and market share. In the productivity equation, we may have an omitted variable problem if market-share changes feed immediately (over the five-year period used here) into productivity gains. And if this variable is included, it may also be the case that it is simultaneously determined. Both problems lead to potential bias in the productivity equation. Simultaneous bias may also be a problem in the market-share change equation. Despite the fact that a Hausman test revealed that the potential problem arising from simultaneity was not statistically very significant, the simultaneous equation problem was addressed by employing a two-stage-least-squares procedure.

The second problem that was addressed is one of sample selection. The panel that is used for estimation excludes a particular group of plants—those that exited the 1993 cross-sectional survey data set. These include those plants who exited and those that were not sampled in 1998. This sample selection problem can also lead to biased estimators. For this study, our population is all establishments alive in 1993. But our sample has been drawn from the population of continuing establishments, that is, those establishments that were alive in 1993 and had survived until 1997. We need to adjust for those establishments that had exited the population during that four-year period. The logit equation is included in Table B1 of Appendix B. It shows that plants were more likely to exit the sample if they used fewer technologies, and if they were younger. Since the selection criteria is related to the variables of interest (technology use), correcting for the selection problem may affect the estimates of the technology effect.

To correct for sample selection, we use the Heckman two-step procedure. In the first step, we use a logit model to estimate the likelihood that a unit will be located in the non-truncated part of the population. In the second step, we include the Mills ratio in the main equation. However, the Heckman corrections are not reported here as they do not have a meaningful impact on our estimates.[13]

For purposes of comparison with our earlier findings, the single equation estimates for productivity growth and market-share growth, that now include the new explanatory variables, are reported in Table 14 (columns 1 and 2) along with a set of simultaneous equation estimates (columns 3 and 4). In this formulation, we include both the opening period technology use and growth in technology use. Opening period technology use is not significant in the productivity growth equation; but technology growth is significant. This occurs in both the single equation and the simultaneous equation estimation procedure. Moving from the single equation system to the simultaneous equation system strengthens the effect of technology growth in the productivity-growth equation, where the coefficient triples in size. Technology growth is also significant in the market-share equation.

Plant strategies matter for productivity growth. Plants that emphasize the strategy of developing new technologies have significantly faster productivity growth. On the other hand, plants that emphasize training have lower productivity growth, although this result is only significant for the single equation results. This result, about the effect of training, is consistent with a number of other studies that find that the emphasis given to training is related neither to a firm’s likelihood of innovating (Baldwin, Hanel and Sabourin, 2002), nor to its productivity performance, nor its market-share performance (Baldwin et al., 1994; Baldwin, 1996).

Plants that use ICT networks for particular purposes do better in terms of their growth of relative productivity. The negative sign on component 5 (Comnet 5) indicates that plants that use these networks for ordering products have shown faster productivity growth.

The three foreign control variables all have positive coefficients but none are significant in the relative productivity growth equations at the conventional levels of significance. Since we know the level of significance in our sample is less than in the larger cross-sectional sample, we interpret our finding here to be supportive of a foreign-firm effect that we have found elsewhere. Interestingly, moving from domestic to foreign control increases productivity, particularly in the simultaneous equation estimates. In the market-share equation, moving from being foreign-owned to Canadian-owned leads to a loss of market share.[14]

Conducting R&D affects market-share growth. In particular, those plants whose parent firm conducted R&D throughout the period gained market share compared to those that had no R&D facilities continuously available to them.

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13 This may have occurred because the selection criteria involve both exits and those continuing plants that were not sampled in the second stage of the development of the longitudinal panel. While the former are a distinct group, the latter were chosen to be representative of the entire population of continuers and therefore do not provide much in the way of bias.

14 The parameters on these variables consistently fall between 10% and 20% in terms of probability values.

Table 14. Productivity and market-share growth OLS regressions

	Single equation system		Simultaneous system	
	Productivity growth	Market-share growth	Productivity growth	Market-share growth
Intercept	-0.045	0.003	0.144	0.003
Market-share growth				
Growth (93-97)	1.604	---	-42.388	---
Initial market share				
Market share –1993	---	-0.078	---	-0.077
Productivity growth				
Growth (93-97)	---	0.005***	---	0.007***
Initial productivity				
Productivity – 1993	-0.105	---	-0.075	---
Advanced technology use (1993)				
One ICT group only	0.045	0.0003	0.087	0.0002
Two ICT groups	-0.014	-0.002	-0.057	-0.003
All three ICT groups	0.014	-0.002	-0.024	-0.004
Technology growth				
Growth (93-98)	0.070*	0.003*	0.211*	0.002*
Initial plant size				
Employment –1993	9e-5	---	-0.0006	---
Nationality of control				
Always foreign	0.070	-0.0003	0.020	-0.0001
Foreign (93) – Canadian (98)	0.091	-0.004*	-0.014	-0.004
Canadian (93) – Foreign (98)	0.062	0.002	0.202	0.003
Capital intensity				
Change in profitability (93-97)	1.883***	---	2.558***	---
R&D performer				
Always R&D doer	---	0.005***	---	0.005***
Doer (93) – Not doer(98)	---	0.0001	---	-0.0001
Not doer(93) – Doer (98)	---	0.002	---	0.002
Plant strategies				
New technologies	0.086*	---	0.168*	---
Training	-0.088*	---	-0.153	---
Network purpose				
Comnet1	-0.011	---	0.011	---
Comnet2	0.010	---	0.011	---
Comnet3	-0.022	---	0.001	---
Comnet4	0.013	---	-0.053	---
Comnet5	-0.076**	---	-0.116*	---
Region (1993)				
Quebec	0.008	-0.004*	-0.161	-0.004
Ontario	0.046	-0.003	-0.107	-0.003
Prairies	0.079	-0.004*	-0.122	-0.004*
British Columbia	-0.020	-0.005**	-0.251	-0.005**
Summary Statistics				
N	390	390	390	390
F(degrees of freedom)	F(22,367)=12.91	F(16,373)=2.1	F(22,367)=3.52	F(16,373)=1.87
R^2	0.50	0.11	0.35	0.10

Note: *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

In the market-share equation, labour productivity growth continues to be the dominant influence. In the productivity-growth equation, market share has a negative and not a positive effect. The latter finding is compatible with the argument that most growing plants are in the early stages of their life cycle. Slower growing plants are in the later stages of their life cycle. The former group generally is not increasing their labour productivity. The latter are in the stage where process innovations prevail and plants substantially reduce their labour force and increase their productivity. Other evidence of this phenomenon is provided in Baldwin and Dhaliwal (2001).

7. Conclusion

Growth and decline of establishments in the Canadian manufacturing sector is substantial. Throughout the nineties, there has been substantial turnover of market share among manufacturing plants. Accompanying these shifts, plants have also changed their relative productivity.

Advanced technology use emerges from the multivariate analysis as having a close relationship to growth in relative labour productivity. Growth in technology use during the period exhibited a positive and significant effect on relative productivity growth. Establishments that started the period with many technologies also were more likely to experience positive productivity growth but this effect is not statistically significant when technology growth is included.

The reduction in the significance of the initial technology use variable when technology growth is included should probably not be interpreted as evidence that it is only growth and not initial technology use that matters. We know that the sample used here is not as large as for the earlier work; and we know that the effect of technology without the growth variables is less than it was in the earlier work that lacked data on changes in technology. Moreover, we know that our technology use competency variable is very significant in the productivity growth equation. Technology competencies do not change quickly. They take long periods to develop. It is this evidence that suggest strongly to us that it is both initial conditions and change on the technology side that affect productivity growth.

In turn, growth in relative labour productivity is translated into growth in market share. Plants that improve their production efficiencies or produce higher quality products were able to realize gains in market share. Growth in the use of advanced technologies also had a positive impact on a plant’s growth in market share, probably through its impact on product innovation. By the end of the period, the market rewarded those who managed to improve their efficiency or the quality of their product and concomitantly their labour productivity with an increase in market share.

Some of the impact of advanced technology comes from its affect on increased capital intensity. But that does not obviate the fact that it is increases in advanced technologies that drives the capital accumulation process. Other work for Canada (Armstrong et al., 2002) has shown that ICT investments accounted for a growing portion of capital during the mid to late 1990s. The micro data in this paper show why. Plants that were investing heavily in these technologies were growing more rapidly than those who were not doing so.

The fact that it is capital accumulation that partly drives this process does not downplay the difficulty that firms face in deciding upon the appropriate capital goods and making the right investment decisions. A wide range of assets is available to each firm. Only some firms manage to incorporate them successfully into their production process. And those that do so increase their relative productivity and gain market share.

This paper also sheds light on which areas of new information and communications technologies are most related to success. Information and communications equipment can be used for various purposes—to keep databases for analysis, to engage in financial transactions, to sell products over the internet and to facilitate the ordering process. Plants that were using their electronic communications networks to improve the efficiency of the ordering process were more likely to have improved their productivity. This accords with our previous findings (Baldwin, 1996) that an emphasis on just-in-time inventory practices could be found in those firms that were more successful.

While this paper complements the macro literature that stresses the importance of ICT (information and communications technologies), it is much broader in scope than the typical paper in this literature that focuses just on computers, software and communications gear. In this paper, we have examined a much wider range of advanced technology investments—such things as robots, flexible-manufacturing systems, and automated retrieval systems. The technological trajectory that accompanied the adoption of electrical power into the factory eventually saw the electric motor move from a stand-alone machine to being incorporated directly into machines it powered. The same is happening with computers that have been incorporated directly into systems. The amount of investment that is part of the electronic chip revolution is larger than just computer investment—especially in the manufacturing sector.

Complementary investments outside of advanced technologies are required. This is driven home by the fact that R&D is also found to be an important factor behind the growth of a plant's market share. An R&D strategy is a complementary factor that contributes to the development of new products, just as does an advanced innovation strategy. The fact that R&D is found to have more of an influence on market-share growth than productivity growth emphasizes the fact that it is more on the product side than on the process side that this activity is felt (Baldwin and Hanel, 2003).

Despite our having found that a broad technological focus is associated with success, we caution the reader to conclude that it is the particular types of advanced technologies that we describe herein that generate all the growth that has occurred. High performance firms are generally the more compleat firms in any population (Baldwin and Gellatly, 2003). Baldwin (1996) as well as Baldwin and Johnson, (1998, 1999) report that firms gaining market share or improving their relative productivity generally give greater emphasis to a host of competencies—from management skills, to technological and innovation capabilities, to finding the funds necessary to make investments in advanced technologies, and to developing human resources in order to enhance their pool of skilled workers.

This paper finds evidence of the importance of an overall comprehensive strategy as well, though our investigation here has been somewhat more restricted than in previous papers. When we include a variable that captures the overall emphasis on technological progressiveness, this variable substantially reduces the significance of our technology variables that measure the relationship between specific advanced technologies and market performance. While a substantial effort was expended on developing the list of advanced technologies in conjunction with the help of an expert panel, we cannot claim that even our extended list of specific types of technologies is exhaustive. But we do feel that our research has found that a general emphasis on the use of advanced technologies is one of the keys to success.

We note that much of the change that we have investigated, whether it is in productivity growth or market-share changes is idiosyncratic. We have found that it is difficult to explain the growth process at the plant level. The correlation coefficients for the market-share growth equation are generally small. The same is true of the relative productivity growth equations when capital intensity is excluded. Growth is very much a stochastic process that results from firms' experimenting with different strategies. Some firms move ahead after adopting the strategy that is most suitable for the particular environment in which they find themselves. This finding qualifies the central findings of this paper. While technology adaptation is related to success, it is not the only factor that is driving market performance. There are a large number of other factors that matter.

That does not mean we should discard the finding that an advanced technology strategy is associated with superior performance. Given that a large number of factors matter in the growth process, the fact that we found any relationship between success and the adoption of advanced technologies suggests that this is an important area. And the fact that this finding has now been replicated in a number of different studies, using different surveys, in a number of different ways (Baldwin, 1996; Baldwin and Johnson, 1998; Baldwin, Diverty, and Sabourin, 1995; Baldwin, Sabourin and Smith, 2002) strengthens the argument that a technology-based innovation strategy is an important factor behind growth.

Finally, we should stress that industrial structure matters in a broad sense. Canada is a small open economy where multinationals participate actively in the manufacturing sector. Previous work has found that they have higher productivity than domestic plants (Baldwin and Dhaliwal, 2001). Here we also find that they tend to be more productive, but the degree of statistical significance is not high after all the technology and R&D variables are included—though some of this may have resulted from the small size of the sample used for the multivariate analyse. We conclude that it is this technological emphasis that accounts for most of the difference between foreign and domestic plants. This accords with findings from Baldwin, Hanel and Sabourin (2002) who report that foreign firms are generally more innovative than domestic firms, but that in a multivariate regression, this difference is substantially reduced once differences in R&D performance and other technological competencies are taken into account.

Appendix A: Principal component analysis for communication network purpose

Table A1. Eigenvectors for communication network purpose principal components

Communication network purpose	***COMNET1***	***COMNET2***	***COMNET3***	***COMNET4***	***COMNET5***
Ordering products	0.243	0.073	-0.060	0.541	-0.587
Tracking production flow	0.296	-0.278	0.118	-0.135	-0.060
On-line maintenance	0.208	-0.110	0.723	0.100	0.344
Tracking sales and inventory	0.326	-0.235	-0.197	-0.078	-0.181
Tracking distribution	0.284	-0.170	-0.059	-0.273	-0.197
Sharing technology information	0.218	0.397	0.252	0.391	-0.112
Accounting and financing	0.307	-0.136	-0.290	0.159	0.161
Human-resources purpose	0.275	-0.068	0.033	-0.005	0.216
Management planning system	0.300	-0.121	0.045	-0.131	0.036
Marketing/customer information	0.249	0.406	-0.036	-0.120	-0.019
Financial transactions	0.237	0.069	-0.485	0.282	0.564
Consumer information	0.167	0.566	-0.081	-0.525	-0.070
Production status information	0.300	-0.233	0.069	-0.183	-0.170
General reference	0.281	0.286	0.136	0.011	0.150
	COMNET6	***COMNET7***	***COMNET8***	***COMNET9***	***COMNET10***
Ordering products	0.183	0.428	-0.173	-0.134	0.115
Tracking production flow	-0.388	0.072	0.214	-0.096	0.258
On-line maintenance	0.046	0.379	-0.198	0.226	-0.007
Tracking sales and inventory	-0.067	-0.092	-0.066	0.005	-0.191
Tracking distribution	0.313	0.044	0.160	0.647	-0.260
Sharing technology information	-0.208	-0.344	0.558	0.154	-0.165
Accounting and financing	-0.035	-0.151	-0.262	0.095	-0.304
Human-resources purpose	0.619	-0.181	0.349	-0.296	0.262
Management planning system	0.215	-0.014	-0.005	-0.428	-0.130
Marketing/customer information	0.101	-0.315	-0.411	0.291	0.583
Financial transactions	-0.175	0.331	0.157	0.123	0.153
Consumer information	-0.052	0.467	0.158	-0.127	-0.125
Production status information	-0.426	-0.093	0.006	-0.095	0.269
General reference	-0.112	-0.220	-0.367	-0.272	-0.399

Appendix B: The exit process

Table B1. Logit exit model (establishment weighted)

	Logit exit model
	Likelihood of survival
Intercept	-2.045***
Initial productivity	
Productivity – 1993	-0.348**
Advanced technology use (1993)	
One ICT group only	-0.390
Two ICT groups	-0.763***
All three ICT groups	-0.459
Initial plant size	
Employment –1993	-0.0001
Plant age	
Age2	0.321
Age3	0.679***
Competition	
Compet2	0.237
Compet3	0.187
R&D performer	
Performer (93)	0.109
Region (1993)	
Quebec	0.271
Ontario	0.579*
Prairies	0.709**
British Columbia	0.081
Summary Statistics	
Number of obs	1946
χ^2	37.9

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