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Innovation Capabilities: Technology Use, Productivity Growth and Business Performance: Evidence from Canadian Technology Surveys

by John R. Baldwin and Guy Gellatly

Micro-economic Analysis Division
18th Floor, R.H. Coats Building, 100 Tunney's Pasture Driveway
Ottawa, K1A 0T6

Telephone: 1 800 263-1136

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Keywords: Technology, productivity

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Abstract

This paper summarizes the results of several research studies conducted by the Micro-economic Analysis Division of Statistics Canada that investigate the impact of advanced technology use on business performance. These studies combine establishment-level survey data on advanced technology practices with longitudinal data that measure changes in relative performance. Together, these studies provide strong evidence that technology strategies have considerable bearing on competitive outcomes after other correlates of plant performance are taken into account. Advanced communications technologies warrant special emphasis, as the use of these technologies has been shown to be closely associated with changes in relative productivity.

Executive summary

Dramatic changes in the composition of investment have taken place in the Canadian economy over the last 40 years as investment has shifted toward advanced information and communications technologies (ICT). The growth rates of ICT capital services have consistently eclipsed those associated with other forms of investment—non-ICT machinery and equipment (M&E), engineering structures, building structures, land and inventories. From 1961 to 2002, ICT M&E grew faster than non-ICT M&E. And the difference between the two increased over time. ICT M&E grew 27% faster than non-ICT M&E from 1961 to 1973, 171% faster from 1973 to 1979, 456% faster from 1979 to 1989, and some 552% faster from 1989 to 2002. As a result, ICT capital came to increasingly dominate the overall contribution to output growth that came from increases in capital. From 1963 to 1971, ICT M&E accounted for just 5% of capital's contribution to growth; by contrast, its contribution to capital's contribution increased to 40% from 1989 to 2002 (Baldwin and Gu 2007).

Using detailed data from technology surveys, a set of studies was conducted to evaluate whether technological differences among rival producers have led some firms to outperform others, after other correlates of performance are taken into account. These studies provide more insight into the different types of advanced technologies being used than do many macro-level studies, as the latter tend to focus narrowly on specific commodities, like computers. The technology surveys that support the research discussed herein collected detailed information on a broad range of technology investments—ranging from new information and communications technologies to a host of other advanced production technologies, such as robots, flexible manufacturing systems and automated retrieval systems. With this detail available, these Statistics Canada studies also evaluate whether particular technologies, such as advanced communications technology, are more closely associated with success than others, and therefore could be said to provide the basis on which other advanced technologies and technology strategies are built.

All of the papers described in this review found a robust link between advanced technology use and plant performance, this being after controlling for other firm characteristics such as capital intensity, whether the firm is performing research and development and the general emphasis given to innovation. This indicates that technology strategy is an important separate facet of innovation that affects a firm's performance and substantiates the macro evidence that has linked the productivity resurgence in the 1990s to the ICT revolution. The studies indicate that plants that adopted advanced technologies improved their productivity relative to their compatriots who did not adopt the technologies, which in turn was associated with increases in market share of advanced technology adopters. These microeconomic studies also suggest that technologies well beyond simple computers and software were responsible for productivity growth—robots, material systems and other advanced production technologies all had an impact. Finally, the research suggests that communications technologies played a key role in understanding performance differentials among rival producers. These technologies, in particular, were closely linked to superior performance.

Chapter 1. Introduction

There is substantial interest among industrial economists in the extent to which changes in the relative performance of rival producers reflect underlying differences in their use of advanced technologies. Much of this interest stems from the desire to better understand the competitive dynamics associated with the dissemination and integration of information and communications technologies (ICT): technologies that have revolutionized systems of production in virtually all economic sectors. In Canada, considerable information on the use of advanced technology exists. Statistics Canada has conducted three major surveys on advanced technology use in the manufacturing sector: the 1989 *Survey of Manufacturing Technology* (SMT), the 1993 *Survey of Innovation and Advanced Technology* (SIAT) and the 1998 *Survey of Advanced Technology in Canadian Manufacturing* (SATM). The Agency has also conducted one industry-specific technology survey, the 1998 *Survey of Advanced Technology in the Canadian Food Processing Industry* (SATFP). These surveys yielded rich descriptive profiles of technology use, and together they offer an evolving portrait of technological change in Canadian manufacturing.[1]

These surveys have been instrumental in the development of a research program at Statistics Canada that investigates the relationship between technology use and firm performance. To support this program, data from technology surveys have been linked to a longitudinal database of manufacturing establishments, developed and maintained at the Agency to facilitate microeconomic research on productivity and industrial restructuring. This longitudinal file, derived from the *Annual Survey of Manufactures* (ASM), contains detailed data on plants' sales, value added, wages and employment. It has allowed analysts to evaluate how plant-specific technology strategies are associated with shifts in relative productivity, relative wages and market share within industries as more successful firms displace less successful firms. This paper provides readers with a summary of this research. It concentrates on a set of papers conducted by analysts at Statistics Canada that features detailed investigations of the link between advanced technology use and business performance.

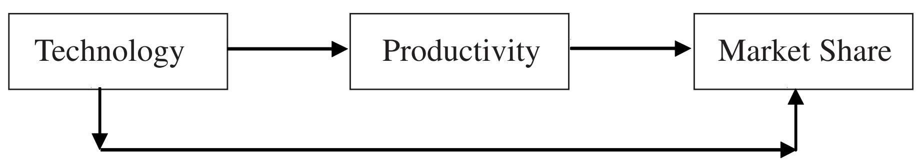
Competition engenders change as more efficient firms supplant the less efficient. The amount of firm turnover that results from competition is large. Baldwin and Brown (2004) demonstrate that, over a decade, almost 40% of jobs in the Canadian manufacturing sector are renewed as plants that close down and downsize are supplanted by new plants and growing plants. Using a 20-year time frame, over 65% of jobs are renewed.

Equally important are changes in the relative productivity of manufacturing plants that accompany and drive firm turnover. The pace of technological progress is quite different across firms and these differences are manifest in dramatic shifts in relative productivity over time (Baldwin and Sabourin 2004). These changes in performance come from different sources—capital deepening, the use of specific types of advanced capital, and changes in organization and innovation.

Changes in relative efficiency underlie firm turnover and changes in market share. Firms that improve their productivity relative to their peers are able to develop advantages, either with respect to the prices that they charge or the quality of their product, and expand their market share. More importantly, the process that leads more productive firms to supplant the less productive accounts for more than 50% of aggregate productivity growth (Baldwin and Gu 2006a, 2006b).

Understanding how the use of advanced technologies contributes to this process is the focus of the set of studies discussed herein. Each of these studies is predicated on a conceptual model in which firm performance is posited to depend on technological choice, as depicted below.

The performance effects of advanced technology use



Producers are seen to make choices on the set of advanced technologies that they will use. For a given producer, these technological choices can be expected to bring about changes in its labour productivity (relative to rivals) through the impact that these new technologies have on production efficiency and capital intensity. In turn, these shifts in relative productivity can be expected to effect changes in market share through their impact on relative prices or on the quality of products offered. Technology choices are thus expected to influence market share indirectly through their impact on relative productivity, but can also affect market share directly, by giving rise to associated product innovations that improve market share.

Implicit in this stylized framework is the recognition that changes in the relative performance of rivals may also depend on a host of other factors, many of which will have little to do with technology decisions. It is worth stressing, however, that complementary research from Canadian business surveys has found that specialized competencies related to innovation are strongly correlated with performance differentials across firms.[2] All of these studies show that differences in the emphasis that firms give to innovation strategies in general are strongly associated with competitive outcomes, after other correlates of business performance are taken into account.

The set of papers described here moves from the general emphasis given to innovation to focus on specific innovation policies. To do so, it focuses on one very tangible manifestation of a firm's innovation strategy—its choice of specific advanced technologies—and the associated benefits that these choices confer on the adopting business.

These studies also ask whether communications technologies warrant special emphasis as the core technology input on which many of the overall benefits depend. They ask whether the use of communications technologies, both separately and in conjunction with other advanced technologies, is more strongly associated with changes in relative productivity and market share than other advanced technologies.

The organization of this summary paper is as follows. Chapter 2 comments on the research design and main findings of each of these studies, and outlines their contribution to the research program. It then emphasizes a central theme to emerge from these studies—the link between communications technologies and changes in relative performance. Chapter 3 concludes and offers some preliminary suggestions for future research.

Endnotes

1. See Baldwin and Sabourin (1995), Sabourin and Beckstead (1999) and Baldwin, Sabourin and West (1999).
2. For extensive discussions, see Baldwin and Gellatly (2003, 2006) and Baldwin and Hanel (2003).

Chapter 2. Technology use and business performance

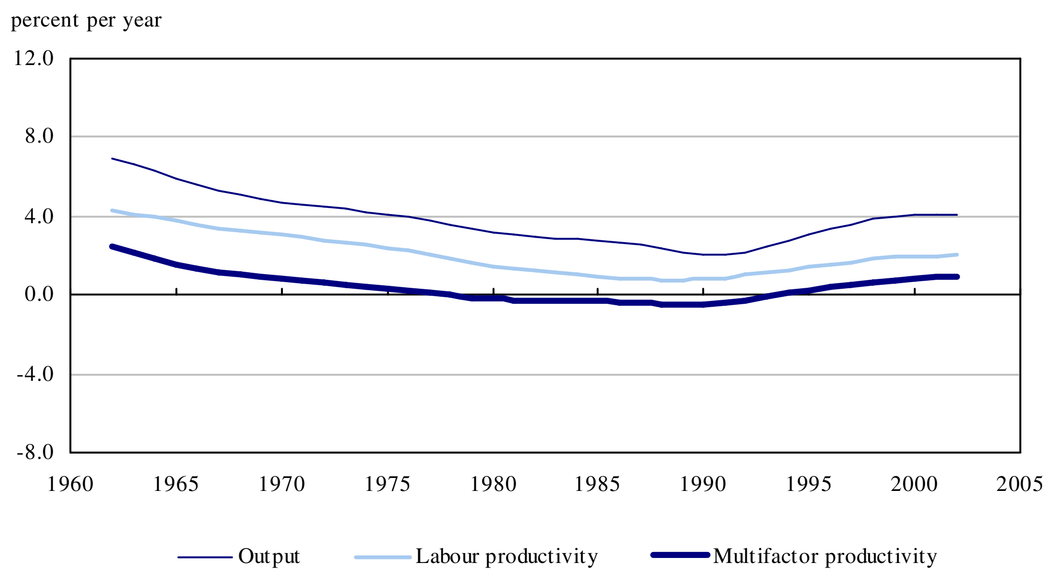
Dramatic changes in the composition of investment have taken place in the Canadian economy over the last 40 years as investment has shifted toward advanced information and communications technologies (ICT). The growth rates of ICT capital services have consistently eclipsed those associated with other forms of investment—non-ICT manufacturing and engineering (M&E), engineering structures, building structures, land and inventories. From 1961 to 2002, ICT M&E grew faster than non-ICT M&E. And the difference between the two increased over time. ICT M&E grew 27% faster than non-ICT M&E from 1961 to 1973, 171% faster from 1973 to 1979, 456% from 1979 to 1989, and some 557% faster from 1989 to 2002. As a result, ICT capital came to increasingly dominate the overall contribution to output growth that came from increases in capital. From 1963 to 1971, ICT M&E accounted for just 5% of capital's contribution to growth; by contrast, this increased to 40% from 1989 to 2002 (Baldwin and Gu 2007).

These changes in production technology are seen by many to have been associated with marked improvements in Canada's aggregate labour productivity growth rates during the 1990s (Armstrong et al. 2002, Jorgenson 2004). After strong productivity growth in the early 1960s and 1970s, productivity growth for the Canadian business sector slowed. Labour productivity growth declined from 3.5% before 1973 to 0.9% from 1979 to 1989. Since 1989, at the same time that ICT investment came to dominate total investment, labour productivity growth rates increased, averaging 1.5% from 1989 to 2003 (see Figure 1).

While macroeconomic research on capital investment and productivity has emphasized the growing importance of ICT by highlighting the extent to which overall growth has moved closely in step with aggregate ICT investment, complementary microeconomic research conducted at Statistics Canada has concentrated on investigating the relationship between advanced technology use and business performance at the firm or plant level. As part of a research agenda that has examined the economic impacts of new technology, these studies aim to refine our understanding of the importance of ICT use, as well as other types of advanced production technology. By focusing on the level of the firm, they provide corroboration to macroeconomic studies by demonstrating that it is indeed new advanced ICT technologies that are driving the growth process.

Using detailed data from technology surveys, these microeconomic studies evaluate whether technological differences among rival producers have led some firms to outperform others, after other correlates of performance have been taken into account. They also provide more insight into the different types of advanced technologies being used than do many macro-level studies, because the latter tend to focus narrowly on specific commodities like computers. The technology surveys that support the research discussed herein collected detailed information on a broad range of technology investments—ranging from new information and communications technologies to a host of other advanced production technologies, such as robots, flexible manufacturing systems and automated retrieval systems. With this detail available, these Statistics Canada studies also evaluate whether particular technologies, such as advanced communications technology, are more closely associated with success than others, and therefore can be said to provide the basis on which other advanced technologies and technology strategies are built. We discuss these studies, in turn, below.

Figure 1
Productivity trend growth: Rebound in the 1990s



Source: Statistics Canada, Canadian Productivity Accounts.

The link between technology adoption and business performance was first examined by Baldwin, Diverty and Sabourin (1995). The authors combined data from the 1989 *Survey of Manufacturing Technology* (SMT) with data from the *Annual Survey of Manufactures* (ASM) longitudinal file to create a study panel of approximately 4,200 continuing establishments—a subset of relatively large producers that operated from 1981 to 1989. The SMT collected data on the use of 22 advanced technologies, which the authors (hereafter BDS) classified into 10 functional categories. These included seven separate groups—Design and engineering, Fabrication and assembly, Automated materials handling systems, Inspection and communications, Automated control devices, Manufacturing and information systems, and Integration and control—along with three categories that focused on specific technology combinations. BDS then analysed changes over the period 1981 to 1989 in market share, relative productivity and relative wage rates between technology users and non-users, based on their technology profiles in 1989.

The tabulations reported in BDS (1995) offered some initial evidence that advanced technology strategies are correlated with performance outcomes. Among each of the functional technologies examined, technology users were shown to acquire market share from non-users. Plants with comprehensive technology strategies—those that reported integrating different technologies from multiple functional groups—experienced the highest rate of market-share growth. BDS then evaluated whether the positive association between technology and performance reflected underlying differences in industrial structure by recalculating their estimates for two-digit industries. In most manufacturing industries, technology users gained market share at the expense of non-users.

BDS also evaluated the link between technology use and other measures of performance, notably changes in relative labour productivity and relative wage rates. For the vast majority of functional technologies under study, technology users started off in 1981 with higher productivity levels than non-users, and they saw their productivity advantage over non-users increase over the decade. In particular, plants that reported using inspections and communications technology enjoyed relatively large advantages over non-users—both in terms of productivity levels and growth rates. Similar results were also apparent when examining wage rates.

The descriptive tabulations in BDS (1995) set the stage for more complex multivariate studies on the performance effects of technology use. Baldwin and Sabourin (2001) combined survey data on technology use from the 1998 *Survey of Advanced Technology in Canadian Manufacturing* (SATM) with longitudinal data on labour productivity and market share for the 1988 to 1997 period. Like BDS (1995), this paper focused explicitly on technologies that were associated with the computer-chip revolution. SATM collected data on 26 technologies, which were classified as either hardware, software or communications technologies. Multivariate regressions were then used to evaluate the impact of technology strategy on changes in relative productivity and market share from 1988 to 1997.

Baldwin and Sabourin (2001) utilized a two-equation framework, examining in turn the correlates of productivity growth and market-share growth. The first equation posited that changes in plant-level productivity are a function of technology use and a set of other factors, among them initial size, initial productivity, changes in capital intensity, research and development (R&D) and innovation activities, and other business practices.

The inclusion of a set of innovation-related characteristics in the analysis was intended to test whether it was technology use as opposed to other innovation-related competencies that was driving productivity gains. Other Statistics Canada studies (Baldwin and Gellatly 2003) have shown that more successful firms are differentiated from less successful firms across a large number of innovation dimensions. Since these innovation capabilities are highly correlated with one another, the inclusion of only a single characteristic—whether it be technology use or R&D intensity—risks attributing an inappropriately large impact to the single variable included in the analysis.

Several mutually exclusive binary variables were constructed to measure the technological characteristics of manufacturing plants. These ranged from the exclusive use of software technologies, hardware technologies or network technologies, to the use of various technology combinations. Their regression analysis suggested that improvements in relative productivity are linked to the use of network communications technologies, and the simultaneous use of technologies from all three groups (hardware, software or communications), after controlling for other factors. Plants that adopted combined technology strategies experienced the largest productivity gains.

A number of these other control variables warrant emphasis. First, the link between technology use and productivity growth was apparent, even after controlling for changes in capital intensity—which were also found to exert a significant impact on productivity growth. Accordingly, the performance-enhancing effects of technology go beyond what can essentially be viewed as capital deepening. Capital-deepening estimates are generally derived from aggregate measures of all capital in a firm—with all forms of investment being given equal weight. The fact that specific technologies are significant, even with the capital-deepening variable included, suggests that some forms of capital may be more important than others—in particular, that network communications technologies were at the core of the technological revolution that the electronic chip brought about in the early 1990s.

Second, changes in relative productivity at the plant level were shown to be heavily influenced by mean reversion, as plants with higher productivity in the initial period were more likely, other things being equal, to experience slower rates of productivity growth, and vice versa. Mean reversion is a persistent characteristic of growth distributions, and Baldwin and Sabourin (2001) demonstrate that the link between technology use and productivity growth remains after basic differences in starting position are taken into account.

A third factor warranting mention is the inclusion of the R&D and innovation variables in the regression analysis. These variables were included to address the possible estimation bias that stems from omitted plant-specific fixed effects related to their level of 'innovativeness'—factors that may be correlated with more specific activities such as technology use. Their presence as controls increases our confidence in the positive association that was found between technology use and productivity growth.

Baldwin and Sabourin (2001) then estimate a second equation that evaluates the correlates of market-share growth—primarily focusing on changes in relative productivity as the driving force behind changes in relative market share. But they also posit that market share may depend on technology use along with other factors included in the productivity equation.[3] Hence, the model attempts to evaluate whether differences in technology use have an additional effect on relative market-share growth, beyond those that work through changes in labour productivity and several characteristics that capture the general innovativeness of the firm, such as R&D intensity.

Baldwin and Sabourin (2001) found no evidence of an additional effect of technology use outside of the indirect effect on productivity growth. Differences in technology use were not related to changes in market share, after controlling for plant-level differences in productivity. By contrast, both starting-period labour productivity and changes in labour productivity over the analysis period were positively associated with market-share growth.[4]

The next study to investigate the link between ICT use and productivity growth was based on a 1998 survey of manufacturing establishments in the Canadian food processing industry. Using multivariate regressions, Baldwin, Sabourin and Smith (2003) once again evaluated whether differences in productivity performance were associated with advanced technology use. One major advantage of the 1998 survey rests with the breadth of information collected on different types of production technology—respondents were asked to report on their use of 60 advanced technologies, including ICTs. The authors (hereafter BSS 2003) examined the impact of technology use in different ways. First, they tested whether performance differentials were linked to differences in technological intensity. Their operational measure of intensity was the number of advanced technologies that the plant reported using, ranging from zero to 60. The authors found that differences in technological intensity were strongly associated with changes in relative productivity, after accounting for changes in capital intensity and initial productivity differentials across plants (both significant factors). As in Baldwin and Sabourin (2001), BSS (2003) then found that labour productivity growth is strongly associated with changes in market share. Unlike this earlier study, however, the authors found some evidence that the impact of technology use on market-share growth may exceed that which just works through changes in labour productivity.

BSS (2003) also evaluated the impact of different types of technology on plant performance by grouping the 60 technologies into clusters. Principal component analysis was used to generate a series of independent technology profiles—various combinations of advanced technologies that account for much of the observed variation within the sample. These variables (15 components in all), along with other controls, were regressed on productivity growth to examine how different groups of advanced technology use affect changes in productivity and market share. The authors found that ICTs are strongly associated with productivity growth. The impact of these technologies is often felt in combination with other advanced technologies. Communications technologies, such as local- and wide-area networks, were found to play a central role in these comprehensive technology strategies. As in Baldwin and Sabourin (2001), these effects are apparent, even after changes in capital intensity and initial productivity differences are taken into account.

All of the studies described above—BDS (1995), Baldwin and Sabourin (2001) and BSS (2003)—use information on final-year (i.e., survey year) technology use when evaluating the technological characteristics of plants. These studies rely on the general formulation:

(1) $$\Delta PERF_{t\text{-}\tau,t} = f(TECH_t, \mathbf{X})$$

where $\Delta PERF_{t-\tau,t}$ is the change in a plant's performance over the period $t-\tau$ to t, $TECH_t$ is a measure of advanced technology use at the end of the period in year t, and **X** is a set of plant characteristics evaluated either at $t-\tau$, t, or as changes over the period. The effect of technology use on plant performance thus measures both the effect of opening period ($t-\tau$) technology use and changes in technology use over the period $t-\tau$ to t. There are advantages and disadvantages to this approach.

First, some advantages. These relate to the nature of the process under study—the substitution of new technology for old—and our ability to measure this process. The integration of advanced technologies into business routines may involve large amounts of continuous learning that, in turn, require firms to make substantial investments in developing other complementary skills, such as improving the quality of their workforce. Canadian surveys provide considerable evidence to this effect (see Baldwin and Gellatly 2003, Baldwin and Hanel 2003). In a world in which advanced-technology adoption is challenging and costly, it may be relatively difficult to differentiate users from non-users at early stages of an observation period (particularly if these are years in which the technologies in question are relatively new). Technology users may be plants that go on to develop technology skills and complementary assets over the medium to longer run (which may give rise to concomitant gains in relative performance), while non-users do not. At the onset of a measurement period, there will be fewer differences to differentiate adopters from non-adopters, because adopters are still in the process of developing these skills. Conversely, it may be far easier to differentiate adopters from non-adopters at the end of an observation period, and then ask whether those who have learned how to work with technology have performed better than non-adopters over the period during which this strategic differentiation occurred. If this is true, adopting the approach that was used in these first few studies allows us to look at the characteristics that differentiate those who succeed from those who do not—after the market has sorted the two groups into distinct camps.

There is an assumption in this approach that the identities of users and non-users are reasonably stable over time. This issue is acknowledged in BDS (1995: 17), who note that some "(e)stablishments who were non-users in (the end year) were very likely to have been non-users earlier; but establishments that were users of advanced technologies in (the end year) were not necessarily users earlier in the decade." This (as the authors note) can hamper interpretation. The main limitation of these end-period classifications is that they cannot disentangle the effects of *changing technology use* on plant performance from those associated with pre-existing (i.e., initial-period) differences. And this restricts our ability to fully delineate the extent to which the impact of technology use is changing over time.

Since advanced technology use at the end of the observation period (time t) 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) $$\Delta PERF_{t-\tau,t} = f(TECH_{t-\tau} + \Delta TECH_{t-\tau,t}, \mathbf{X})$$

The impact of these marginal changes in technology use, $\Delta TECH_{t-\tau,t}$, was evaluated in Baldwin and Sabourin (2004). A significant extension of earlier Statistics Canada studies on technology use and business performance, this paper measured changes in technology use by constructing a longitudinal panel of manufacturing establishments—by linking data from the 1993 *Survey of Innovation and Advanced Technology* (SIAT) with data from the 1998 *Survey of Advanced Technology in Canadian Manufacturing* (SATM). These data were then combined with data from the ASM longitudinal file in order to obtain measures of relative productivity and market share.

The development of a longitudinal link between the 1993 and 1998 technology surveys was a key aspect of the overall research program. As Baldwin and Sabourin note (2004: 10) "(t)he 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", but by designing "(t)he 1998 technology survey…in such a way as to provide a longitudinal panel for a set of establishment that could be linked to the 1993" SIAT. This strategy allowed Baldwin and Sabourin to decompose the technological profiles of these longitudinal plants into start-period effects (based on their technology profile in 1993) and growth effects (based on differences in their technological profiles between 1993 and 1998). The most notable limitation of this research design was that it resulted in a much smaller analysis sample than those utilized in earlier studies. While the 1998 survey collected data on approximately 2,000 plants (all of which can be used for cross-sectional analysis), only about one fifth of these observations were used in developing the longitudinal link between the 1998 and 1993 surveys. The sample weights for this longitudinal subset, however, were designed to produce longitudinal estimates that are representative of the full manufacturing population.

The authors once again rely on a two-equation framework to estimate the correlates of productivity and market-share growth. Both equations have a similar structure to those in Baldwin and Sabourin (2001), except in terms of their treatment of technology. As before, the focus rests on the set of 26 ICTs evaluated in Baldwin and Sabourin (2001), which are classified as either hardware, software or network communications. Technology use was operationalized in two ways. First, Baldwin and Sabourin utilized binary indicators of intensity, corresponding to the number of different technology categories (software, hardware or network communications technology) in use. Total technology use at the end of the observation period (1998) is then decomposed into a measure of technology use in the initial year of observation (1993) and a measure of technology growth over the course of the period.

Second, the authors examined the uses to which network-communications technologies were being put, asking whether certain applications had larger productivity-enhancing effects than others. Here principal components were used to characterize different technology applications.

Prior to a discussion of results, some comments on methodology are required. This study dealt more rigorously with econometric issues than did its predecessors. The productivity growth and market-share equations were evaluated first, using single-equation models, and second, via a simultaneous-equation system. The latter approach was designed to account for potential bias in the single equation estimates that can arise because of simultaneity and/or selection issues.

The simultaneity problem stems from possible feedback effects on the productivity-growth equation from the market-share equation. Baldwin and Sabourin (2004: 29) noted that the productivity equation "may have an omitted variable problem if market-share changes feed immediately…into productivity gains. And if this variable is included, it may also be the case that it is simultaneously determined." The authors utilized a Hausman test and did not find strong evidence of simultaneity between the market-share and productivity equations. The second potential problem—selection bias—stems from the fact that the analysis sample covers only a subset of the plants operating in 1993—those that survived to 1998. Accordingly, the authors used a Heckman two-stage procedure to correct for selection bias.

Results for both single-equation and simultaneous-equation models were presented. In each case, productivity growth was not related to initial-period technology use, but was positively associated with changes in technology over the observation period. The parameter estimate on technology growth was qualitatively larger in the simultaneous model.

Both models yielded evidence that the productivity-enhancing effects of network communications are related to how these technologies are being applied in the plant. One of the principal component variables included in productivity equation is significant (common to both models). It suggests that plants that use network communications for ordering products often realize larger productivity gains.

It is worth stressing that these productivity-enhancing effects of technology use occur after controlling for changes in capital intensity (also positively associated with productivity growth). In addition, plants that reported more emphasis on developing technology also experienced larger productivity growth after changes in capital structure were taken into account.

In terms of the market-share equations, changes in market share were again positively related to changes in labour productivity—both in the single-equation and simultaneous-equation models.

As in BSS (2001), both models provided evidence that changes in the intensity with which plants used advanced technology had an additional impact on market share, beyond those that worked through changes in labour productivity. Continuous R&D effort was another factor that was shown to be strongly correlated with changes in market share.

The four studies described above—BDS (1995), Baldwin and Sabourin (2001), BSS (2003) and Baldwin and Sabourin (2004)—form the analytical core of Statistics Canada's research on technology use and business performance. One other study warrants mention. Baldwin and Gu (2004) examined how tariff reductions affect the export behaviour of Canadian manufacturing plants. As part of their analysis, they used data on exports from the ASM longitudinal file, in conjunction with data on technology from the 1993 SIAT, to examine how entry into export markets influences the intensity of advanced technology use. Their results suggest that exporting behaviour is linked to an increase in technological intensity. Prior to entering export markets, plants that go on to export and those that do not do so exhibited similar technology profiles. In the post-entry period, however, exporters make significantly more use of advanced technologies than do non-exporters.[5] The authors thus argue that "plants become more intense users of advanced technologies in order to remain competitive in export markets." (Baldwin and Gu 2004: 25).

All of the papers described in this review found a robust link between advanced technology use and plant performance, thereby substantiating the macro evidence that linked the productivity resurgence in the 1990s to the ICT revolution. But these microeconomic studies also suggest that technologies well beyond simple computers and software were responsible for productivity growth—robots, material systems and other advanced production technologies all had an impact. Finally, this research suggests that communications technologies played a key role in understanding performance differentials among rival producers. These technologies, in particular, were closely linked to superior performance. We comment on this issue below.

In the initial study, BDS (1995: 30) concluded that "(i)t is clear that the inspection and communications group…is where computer-based technologies have made the greatest impact." Users of these technologies were shown to enjoy large advantages over non-users across a range of performance metrics, including changes in relative productivity, market share and employment share. The productivity differential between plants that reported using inspections and communications technologies and those that did not warrants emphasis. In 1989, the final year of the observation period, the labour productivity average of technology-using plants was 1.7 times that of non-users, the result of a widening productivity gap between these two groups during the 1980s.

Efforts to disentangle the performance effects of different types of ICTs in Baldwin and Sabourin (2001) brought the importance of communications technology into clearer view. Their regression analysis demonstrated that improvements in relative productivity were linked to the use of network-communications technologies, effects that were not apparent for either hardware or software technologies when these different ICT groups were evaluated individually. The analysis of food-processing industries in BSS (2003: iv) helped corroborate the view that "certain types of technology…have more impact on (productivity) growth than others". In particular, the use of communications technologies, such as local- and wide-area networks and inter-company computer networks, was associated with higher productivity growth throughout the 1990s. The impact of network technologies was again evident in Baldwin and Sabourin (2004: 33), as "(p)lants that were using their electronic communications networks to improve the efficiency of the ordering process were more likely to have improved their productivity."

These research studies also found that communications technologies play a pivotal role in fostering plant-specific technological complementarities, the effects of which are particularly beneficial to producers. Communications technologies were shown to be an integral part of more comprehensive strategies in which different types of advanced manufacturing technologies are combined with one another. Baldwin and Sabourin (2001: 23) note that the "real (productivity) gains came from the joint adoption of all three (ICT) types of technology—software, hardware and network communications."

Endnotes

3. The regression equation also included initial market share to control for mean reversion.
4. The paper also examined the impact of technology use on other performance measures—including changes in relative wages, relative profitability and employment. The strongest finding here was that comprehensive technology use (plants that adopt advanced hardware, software and communications technologies) was related to wage and profitability growth.
5. Baldwin and Gu (2004) employed a highly creative methodology to differentiate between pre- and post-entry effects, as the technology data in their study was limited to a single year (1993). See (2004: 16–17) for a detailed discussion of this aspect of their research design.

Chapter 3. Conclusions and directions

This note has described a series of Statistics Canada research papers, all of which focus on the relationship between advanced technology use and business performance. These studies were conducted by combining establishment-level survey data on technology use with longitudinal data on plant performance. They form the core of a research program at Statistics Canada that investigates the impact of technological change on competitive restructuring.

By making use of several different databases and alternate techniques, the studies taken together provide robust evidence of a close link between productivity growth and the use of advanced technologies. Technology strategies have considerable bearing on productivity differentials across plants, after other correlates of plant performance are taken into account. Advanced communications technologies warrant special emphasis, as the use of these technologies was shown to be closely associated with changes in productivity.

These studies do not suggest that technology adoption is a trivial or costless process, a strategy to which rival producers can quickly turn in order to improve their relative productivity and wrest market share away from competitors. On the contrary, these survey data suggest that technology adoption involves a continual process of learning, one that requires substantial investments in developing the skills required to support new production methods. Related Statistics Canada studies (Baldwin, Sabourin and Rafiquzzaman 1996; Baldwin and Lin, 2002) have found that intensive users of technology often report facing more barriers than do non-intensive users— probably because they have chosen a strategic path that requires more problems to be solved. But producers that select the correct mix of technologies, and are able to overcome the difficulties associated with the adoption process, are often rewarded with improvements in productivity relative to their peers, along with gains in market share.

These studies help lay the groundwork for future research on the economic impacts of information and communications technologies (ICT) use. They have focused on technology adoption from the late 1980s to the late 1990s, early and emerging stages of what Bylinsky and Moore (1994) termed the soft manufacturing revolution. These years were witness to vast amounts of technological restructuring in the Canadian manufacturing sector, as many producers sought to exploit the benefits of advanced technology. The technology surveys that supported the studies described herein were conducted during periods in which the manufacturing population divided into plants that were actively incorporating new ICTs into their production routines and plants that were not doing so. Even in 1998 (the reference year for the *Survey of Advanced Technology in Canadian Manufacturing*), non-users of each general class of ICT (i.e., of hardware, software and network communications, respectively) still accounted for sizable shares of the manufacturing population (see Baldwin and Sabourin 2004). Some 10 years hence, basic distinctions between adopters and non-adopters (a central facet of this research program) may prove to be less illuminating, if the latter are becoming less common. However, substantial improvements in the efficiency of ICTs, which have resulted from the advent of broadband communications, effectively bring new issues to light. Below we offer some preliminary thoughts on possible directions that new research on ICT use and productivity could take.

A first task is to evaluate the extent to which the use of new broadband technologies statistically discriminates between more- and less-successful businesses. Here the focus may rest more on understanding the impact of changing technological quality amongst users. For example, we know from earlier research that the adoption of communications technology is strongly associated with superior performance. Less is known about the effects of changes in technological quality. To what extent do users of new communications technologies realize performance gains at the margin when they switch from older to newer, more efficient communications systems? That is to say, what are the treatment effects associated with major technological innovations embodied in ICT products and services? It is to state the obvious to note that questions like these demand a great deal from data. Their assessment requires the development of longitudinal panels that feature highly detailed survey information on the changing characteristics of individual plants, as well as adequate data on plant performance on either side of these technology transitions.

Another challenge is simply to better understand how these new technologies are being applied to the production process. Here the goals are to learn more about (1) how these technologies are changing the organizational structure of the firm, and (2) which applications of technology are more associated with success. Both speak directly to what is, at root, the core issue: where are the productivity gains associated with advances in communications technology coming from?

Related industry-level research has begun to examine—in a slightly different vein—the issue of *where* within the production chain the value-added benefits of new technology lie. New Statistics Canada research on technology use, following the classification standards that are used in the System of National Accounts, distinguishes between traditional ICT investments and expenditures on intermediate technology inputs that are readily consumed or transformed in production routines (Beckstead, Burrows and Gellatly 2007). Baldwin and Gu (2007) use this information to evaluate the relationship between offshoring and changes in productivity performance. Their analysis, which uses industry-level data on manufacturing and services, finds that offshoring increases productivity and that increases in offshoring are driven, in part, by the level of intermediate ICT use within industries. These increases, by contrast, are less correlated with differences in ICT investment. This again raises basic questions about how and which ICT technologies are being used to improve business performance.

An additional issue that needs to be addressed when designing the future research agenda pertains to research strategy. The studies reported on here have moved from using short surveys that investigate only a small number of technologies to very complex surveys that collect information on a large number of technologies and many other firm characteristics. They employ techniques that vary from linking longitudinal data on performance to a single technology survey, to developing a linked set of technology surveys that allow for the testing of treatment effects. They employ multivariate techniques—ranging from single-equation least squares regressions to simultaneous equation systems—that are designed to take into account simultaneity and selection effects. The fact that our general results were quite robust to these alternate approaches gives us confidence in the general thrust of the findings presented herein. It also suggests that, for very general findings, additional complexity may not be warranted. And this has implications for further research. Some issues may be quite appropriately dealt with by linking data from a single technology survey to longitudinal data on performance. Other, more complex issues may require developing linked surveys that can track firm- or plant-level changes in technology practices over time. But researchers who suggest that the latter are required need to carefully consider whether the benefits that come from demanding linked longitudinal surveys justify the associated costs.

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