Advanced Technology Use in Canadian Manufacturing Establishments

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ABSTRACT

This paper investigates the characteristics of Canadian manufacturing plants that are related to the use of advanced technologies. The data used are taken from the 1989 Survey of Manufacturing Technology and are linked to administrative data taken from the Census of Manufacturers. Technology use is defined first as incidence (whether a technology is used) and second as intensity (the number of technologies used). These variables (incidence and intensity) are then related to a number of characteristics that represent the competencies of the plant reporting technology use--its size, the size of its owning enterprise, the recent growth of the plant, the number of industries in which its owning enterprise operates, its age, and nationality. The results are then compared to several recent U.S. studies.

Keywords: Technology Use, Research and Development, Diversification, Foreign Ownership.

SUMMARY

Advanced technologies are an integral part of the production process. It is, therefore, important to understand the factors that are associated with differences in technology use at the plant level.

This paper uses micro-data to examine the relationship between the use of technologies at the plant level and the characteristics of these plants.

Information on technology use is derived from a survey that investigates the use of 22 advanced manufacturing technologies. Technology use is defined alternately in this study as 1) the use of any one of the advanced technologies; 2) the use of any one technology from a functional group--design and engineering, fabrication and assembly, automated material handling, communications and inspection, manufacturing information systems, and integration and control; and 3) the number of advanced technologies from all of these groups that are in use.

The variables that are used to explain technology use proxy general competencies of the firm. These variables are plant size, plant growth, age of the plant, size of the enterprise that owns the plant, diversity of owning enterprise, nationality of owning enterprise, and both the region and industry in which the plant is located.

Certain characteristics--recent plant growth, plant size, and age--are used to represent the general competencies of the plant to absorb technologies. These variables proxy the receptor capability of establishments to absorb technologies. Plant size and growth variables are proxies that represent the many competencies that result in growth. Foreign-ownership is a specific characteristic that is related to the ability of multinational firms to transfer scientific knowledge from one country to another. Finally, R&D activities are included to represent a plant's disposition to lead in technological activities.

The multivariate results show that two characteristics are most strongly related to technology use. Plant size and plant growth are closely related to both the incidence and the intensity of technology use. Both of these variables proxy the many competencies that are related to success and suggest that technological competence is closely related to success. These results parallel similar studies that have been done for the United States.

Other variables are also related to technology use. Foreign-ownership is almost always positively related to technology use. Enterprise size is not related closely to whether a plant uses at least one of the advanced technologies. It is related to the number of technologies used. Finally, a plant's R&D capabilities are closely related to whether it is technologically advanced.

Introduction

Previous work has shown that technology adoption is a key strategy related to success. Baldwin et al. (1994) find success in small and medium-sized enterprises to be associated with the adoption of an innovation strategy that often is technology-based. Baldwin, Diverty, and Sabourin (1995) report that manufacturing establishments using advanced technologies outperform establishments that do not use advanced technologies. Technology-using plants gain market share at the expense of non-users and enjoy a significant and growing labour productivity advantage. They also pay increasingly higher wages compared to their non-using counterparts in the manufacturing sector.

The demonstrated link between technology adoption and success makes it important to understand which factors distinguish users from non-users of advanced manufacturing technologies. This paper asks which plants are more likely to adopt one or more advanced technologies. The first section investigates the determinants of the incidence of adoption—the factors that are related to the decision to use an advanced technology. The second section investigates the factors that influence the adoptive intensity of the establishment—how many technologies a plant uses. The set of explanatory variables includes both plant characteristics and activities. Characteristics are indicative of a plant's capacity to adopt advanced technologies, while activities are indicative, not only of receptor capability, but also of the disposition of a plant's management to use advanced technology.

Data

Information about the use of 22 advanced manufacturing technologies, at the establishment (plant) level, is available from the Survey of Manufacturing Technology (SMT), conducted by Statistics Canada in March 1989. The survey (Statistics Canada, 1991) asked establishments in the manufacturing sector to indicate their use, planned use, or non-use of 22 separate advanced technologies.[1] Computer-aided design and engineering, flexible manufacturing systems, programmable controllers, robots, computer integrated manufacturing, and artificial intelligence systems are just some of the technologies included in the survey.

For the purpose this paper, the 22 technologies are classified into six functional groups, corresponding to the point in the production process where each is used. The functional groups are design and engineering, fabrication and assembly, automated material handling, inspection and communications, manufacturing information systems and integration and control. A listing of the 22 technologies classified by functional group is provided in Table 1. The majority of these new technologies are the result of applying computers to various facets of the production process.

[1] The survey is based on a sample of establishments in the Canadian manufacturing sector. 4200 establishments were surveyed, and 3952 of these (94%) completed the survey in full.

The 4200 establishments sampled represent primarily large manufacturing plants. To better represent the distribution of large and small plants in the Canadian manufacturing sector, the 4200 observations are weighted using the 1989 probability weights attached to the 1989 survey. Thus, the results presented here apply to an estimated population of some 40,000 manufacturing establishments.

Table 1
Advanced Manufacturing Technologies by Functional Group

Functional Group	Technology
Design and Engineering	Computer-aided design and engineering (CAD/CAE)
	CAD output to control manufacturing machines (CAD/CAM)
	Digital representation of CAD output
Fabrication and Assembly	Flexible manufacturing cells/systems (FMC/FMS)
	Numerically Controlled (NC) Machines
	Computer Numerically Controlled (CNC) Machines
	Materials Working Lasers
	Pick & Place Robots
	Other Robots
Automated Material Handling Systems	Automated Storage/Retrieval Systems (AR/RS)
	Automated Guided Vehicle Systems (AGVS)
Inspection and Communications	Automatic Inspection Equipment - Inputs
	Automatic Inspection Equipment - Final Products
	Local Area Networks (LAN) for Technical Data
	Local Area Networks (LAN) for Factory Use
	Inter-Company Computer Network (ICCN)
	Programmable Controllers
	Computers used for control in factories
Manufacturing Information Systems	Materials Requirement Planning (MRP)
	Manufacturing Resource Planning (MRP II)
Integration and Control	Computer Integrated Manufacturing (CIM)
	Supervisory Control & Data Acquisition (SCADA)
	Artificial Intelligence/Expert Systems (AI)

Conceptual Model

At any point in time, a firm's success will depend upon both the strategies it adopts and its inherent abilities. Strategies encompass the overall organization plan that is adopted to meet the firm's goals. Strategies involve decisions about various factors: quality control, financing, the product-delivery plan, the inputs to be employed, and the use of technology. The effectiveness of these strategies in turn depends upon the competencies that have been developed by a firm in these areas.

The competency set of a firm includes the capabilities of the production or engineering group, the inventions coming from the research facility, the imaginativeness of the marketing group, and the resourcefulness of the finance department. These competencies are rarely built over-night; rather, they depend on the success of past strategies. History matters for business enterprises. Firms are complex organizational structures where finding the correct recipe involves experimentation and time. Organizational competencies in one area, like production engineering, have to be complemented with the correct mix of supporting research, management, technical support, and design.

When the correct mix of strategies is found, a firm is rewarded in the next period by expansion in market share, and growth in productivity and profitability. Failure results in contraction and exit. This process results in successful firms displacing unsuccessful firms. The amount of displacement of one group by another is large. Baldwin (1995) reports that about 36% of market share is transferred from declining to expanding firms over the course of a decade in the average 4-digit manufacturing industry.

Growth has feedback effects. Establishments that are increasing in size obtain additional advantages related to economies of scale or economies of scope. Growth also facilitates cumulative learning (Klepper, 1982). Where cumulative learning serves to reduce unit costs, successful growth facilitates more growth because of the competencies that are developed in the firm. Time paths matter because of the effect of cumulative knowledge (see Nelson and Winter, 1982).

Strategic technological policy at any time depends on the competencies of the firm. Competencies that are related to past success will be closely associated with a firm's size, its multinational nature, and its age. These characteristics serve to discriminate between firms in terms of accumulated knowledge that facilitates the adoption of specific technologies in the future. Competencies also depend upon present activities such as technology strategies. These competencies modify and build on competencies that have led to success in the past. Competencies can be changed in the short run, but their effectiveness today depends primarily upon previously established competencies. An example is research and development activity. It adds to the innovative capability of an enterprise, but its effectiveness depends upon skills that have been developed over many years.

The competency set, made up of plant characteristics and activities, determines the success or failure of an establishment. A firm's capabilities ultimately determine the product set, the profitability and the productivity of a firm.

Empirical Model

Technology adoption is posited to be a function of a set of characteristics that are proxies for imbedded competencies in the firm and a set of strategies embodying present activities that facilitate the acquisition of advanced technologies.

The empirical estimates in this paper use two types of dependent variables to investigate the determinants of the *incidence* and the *intensity* of technology usage. A dichotomous dummy variable is used to measure the determinants of the *incidence* of adoption. This variable equals one if a plant uses at least one of the 22 advanced manufacturing technologies and zero otherwise. A discrete variable between zero and 22, representing the number of advanced technologies incorporated in an establishment's production process, is used to measure the *intensity* of technology adoption.

The type of regression technique employed here depends on the nature of the dependent variable. When measuring the incidence of adoption, a probit regression technique is used. In this particular model (Model 1), the dependent variable measures the probability that the i'th establishment uses at least one technology in its production process. When measuring adoptive intensity, ordinary least squares and negative binomial regression techniques are used. In this model (Model 2), the dependent variable measures the number of technologies being used in the production process within a plant. In both cases, weights based on the original sample survey are used during estimation.

Two types of explanatory variables are used to capture the competencies affecting technological decisions. Characteristic variables, fixed in the short run, represent the capability of the establishment to adopt advanced technologies. The characteristic variables capture the extent to which there are certain cost advantages associated with economies of scale or other advantages that depend upon a plant's past history. These variables include age, employment size, shipment growth, province of location, foreign or domestic ownership, stand-alone or multi-plant enterprise, enterprise size, and the number and type of industries in which the enterprise operates. The second set of variables capture competencies that are only imperfectly embodied in the plant-characteristic variables. These competencies are represented by the plant's research and development activities.

The characteristic variables capture factors that make some plants more receptive than others to advanced manufacturing technologies. The first explanatory variable in this category is plant size, measured by the number of production and non-production workers employed by the plant. Plant size captures the myriad of advantages associated with scale. Large plants are hypothesized to be better able to absorb capital investment expenditures than small plants, because they are able to spread the fixed costs of engineering facilities across more machines, thereby lowering the adoption costs per unit.

Scale is also a proxy for the many competencies that lead to growth since size is directly related to the successes of previous periods. Larger plants are likely to be more complex plants, a factor related to cumulative learning. More complex plants are more likely to perform a wider range of activities, from design and engineering to fabrication. Therefore, they are more likely to use at least one advanced technology somewhere in the plant. To measure plant scale, three size-class dummy variables are specified—separating plants into those with less than 100 employees, those with between 100 and 500 employees, and those with more than 500 employees. Size is measured as of 1980 in order to purge the variable of the consequences of recent growth.

Cost advantages in adopting technologies are also hypothesized for plants owned by enterprises that are large because of their ownership of many plants. A large multi-plant enterprise is better able to share the fixed costs of implementing new technologies, and the information about how to do so, successfully across its plants. This effect is captured here with a variable that represents enterprise employment. To separate the effects of enterprise from establishment size, establishment employment was subtracted from enterprise employment. A set of four dummy variables capture variations in the amount of employment in the enterprise outside of the particular plant in question. The four variables are: a stand-alone plant (residual enterprise employment equals zero), residual enterprise size of 1 to 499 employees, 500 to 999 employees, and 1000 or more employees.

A third plant characteristic is output growth in the 1980s. The output-growth variable is used to separate the scale effects due to recent growth from the scale effects of overall size, which is captured by the employment-size variable. This separates the effect of those who are large but not growing from those who are large because they have recently had strong growth. Plants that are large but have not experienced much recent growth possess an older set of competencies. Growth, on the other hand, is a proxy for the development of recent competencies that are associated with success. These competencies serve to improve a firm's ability to adopt strategies in areas like technology programs. Growth has also been posited to improve a firm's ability to adopt new technologies (Schmookler, 1972). A growing environment facilitates experimentation. It provides room at the margin to adopt new machines and avoids the difficulties associated with the replacement decision in old plants that have to consider sunk costs. In this analysis, growth is measured by a set of three dummy variables that divide all plants into three equal-sized groups by ranking them on the basis of the size of their shipments, measured in dollars, over the period of study (1980-1989). The three equal-sized categories divide plants into those with negative or small growth, medium growth, and large growth. [2]

The nationality of a plant is used to capture other competencies that are hypothesized to be positively associated with a firm's ability to adopt technology. Multinationals are the vehicle through which hard-to-transfer scientific knowledge is moved from one country to another (Caves, 1982). This may be either because of scale economies associated with their larger size or because of an inherent advantage associated with information that is uniquely held by these types of firms. To capture the advantages of foreign-owned plants, a dummy variable is included that equals one if a manufacturing plant located in Canada is foreign-controlled, and zero otherwise.

Age of the plant is included to test whether maturity or usefulness is more closely associated with technology use. On the one hand, older plants have more experience on which to draw and might be expected to have better information about effective uses of technology, as compared to younger plants. On the other hand, younger plants may be better able to adopt advanced technology than older plants whose capital stock may be outdated and less compatible with new technologies being adopted. Three dummy

[2] Change in market share was entered as an alternate variable to test for the effect of growth. While it had a positive effect, it was only weakly significant. Therefore, it is absolute growth rather than relative growth that matters. Market share growth is more important in large markets than small markets.

variables are used to capture age effects—one for plants born before 1970, a second for plants born during the 1970s, and a third for plants born in the 1980s.

The level of diversification of a plant's parent enterprise is hypothesized to affect its ability to adapt to new technologies. Diversification is measured here as the number of industries, measured at the 4-digit SIC level, in which the establishment's parent has production facilities. This study controls for diversification by including a set of four dummy variables for enterprises with plants in one, two, three, or four or more 4-digit industries.

As was the case with the age variable, the direction of the effect hypothesized to accompany greater diversification is uncertain. On the other hand, diversification may lead to the adoption of fewer technologies. A number of studies have found that diversification sometimes leads to the loss of management control (Royal Commission in Corporate Concentration, 1978 and Lecraw, 1984). On the other hand, a diversified firm has greater first-hand experience in adapting to many different situations. An enterprise that specializes in production for just one industry has fewer contact points where it can continually "fine tune" its production processes than an enterprise that owns plants in more than one industry. The latter has a varied set of contact points at which it can experiment with different uses of technologies. Knowledge gained at one plant can be transferred within the firm. Where such transfers are difficult to accomplish via the market, diversification allows the internal transmission to accomplish this procedure less expensively and this reduces the knowledge costs associated with technology acquisition. If this is important, then diversification might be expected to be associated with a greater probability of technology use.

Technology incidence and intensity are also hypothesized to be affected by the particular industry, or industries, in which the plant is located. Some sectors are more innovative than others. Those who produce more innovations are also likely to have the competencies that allow greater adoption of advanced technologies. To control for this, a dummy variable that classifies industries as more innovative and less innovative is included. The classification used here is derived from Robson et al. (1988) who, after investigating differences in innovative tendencies of 2-digit industries, classified 2-digit industries into three groups. The first two groups, which are here defined as the innovative industries, produce the majority of innovations. Many of these innovations are used in the less innovative set of industries. The more innovative industries consist of electrical and electronic products, chemicals and chemical products, machinery, refined petroleum and coal, transportation equipment, rubber products, non-metallic mineral products, plastics, fabricated metals and primary metals. The less innovative industries are textiles, paper, wood, clothing, leather, beverages, food, furniture and fixtures, and printing and publishing.

Finally, dummy variables are included to control for regional differences in the competencies of plants. The five regions are the Maritimes, Quebec, Ontario, the Prairies, and British Columbia.

The activity variable in the empirical analysis focuses on research and development. R&D activities not only indicate a receptor capability for technology, but also convey a plant's disposition towards advanced technology use. R&D activities are divided into three categories—representing plants that contract out their research and development, plants that do it within their enterprise, and plants that do not perform any R&D activities.

Empirical Results—Technology Incidence

Results for Model 1 are presented initially including only plant characteristics (Table 2), and then including both plant characteristics and R&D activities (Table 3). The estimates in both tables are probit regression equations in which the dependent variable is the probability that a particular plant uses at least one technology. Since the explanatory variables are all zero-one binary variables, the coefficients attached to each variable represent the probability that a plan will have at least one technology where the condition represented by that variable holds, i.e., where a plant is foreign-owned. Comparison of the size of the coefficients then permits a determination of the relative importance of each characteristic.

Results are first presented for the use of any technology--irrespective of its location in the production process (column 1). Subsequently, the results are presented for technology use in each of the six functional groups (columns 2-7). The baseline or omitted plant is small, born before 1970, domestically owned, has negative or small shipment growth, produces for four or more industries, is a stand alone plant, is located in the Maritimes, is not considered innovative, and, where applicable(Table 3), does not do any R&D.

For the incidence of at least one technology (column 1 of Table 2), the employment size of the plant is the most important determinant of use. The probability that a plant uses technology increases monotonically in the number of employees. Large establishments are more likely to use technology than small ones. Receptor capacity associated with economies of scale or cumulative learning is the most important consideration in the technological capacity of plants.

The likelihood of using at least one technology also increases significantly with the size of a plant's growth in shipments. Plants whose shipments have grown the most over the period of study are the most likely to adopt an advanced technology.

Table 2: Determinants of the Use of at Least One Technology—Plant Characteristics

	At Least One Technology		Design and Engineering		Fabrication and Assembly		Automated Material Handling		Inspection and Communications		Information Systems		Integration and Control	
Intercept	-0.596	***	-1.852	***	-1.233	***	-2.200	***	-1.422	***	-1.548	***	-2.004	***
Plant employment 100-499	0.619	***	0.658	***	0.679	***	0.209	**	0.654	***	0.692	***	0.284	***
Plant employment 500 or more	0.892	***	1.281	***	1.160	***	0.151		0.934	***	0.945	***	0.559	***
Birth in 1970s	0.100		0.199	***	-0.047		0.479	***	0.156	**	0.084		-0.093	
Birth in 1980s	-0.141		0.063		0.010		-0.013		0.014		-0.402		-0.637	***
Foreign ownership	0.144	**	-0.148	**	-0.028		0.031	***	0.178	***	0.357	***	0.178	**
Medium shipment growth	0.616	***	0.627	***	0.116	**	0.277	***	0.475	***	0.369	***	0.467	***
Large shipment growth	0.739	***	0.306	***	0.257	***	0.311	***	0.617	***	0.534	***	0.730	***
Enterprise produces for one industry	-0.272	*	0.367	**	-0.201		-0.159		0.018		0.121		-0.007	
Enterprise produces for two industries	-0.432	***	-0.019		0.029		-0.289	*	-0.351	***	-0.029		-0.369	**
Enterprise produces for three industries	-0.463	***	0.040		-0.352	**	-0.479	**	-0.292	**	-0.439	***	-0.266	
Enterprise employment 1-499	0.007		0.002		-0.149		0.046		0.123		-0.106		-0.269	*
Enterprise employment 500-999	0.480	***	0.333	***	-0.166		0.470	***	0.807	***	0.251	**	0.058	
Enterprise employment 1000 or more	-0.065		0.573	***	-0.372	**	0.691	***	0.460	***	0.220		0.247	
Quebec	0.395	***	-0.010		0.310	**	0.497	***	0.529	***	0.062		0.320	*
Ontario	0.230	***	-0.080		0.254	**	0.184		0.312	***	-0.255	**	0.324	*
Prairies	0.084	**	0.091		0.091		0.054		0.042		-0.251	*	-0.114	
British Columbia	0.219	*	-0.003		0.071		-0.192		0.221	*	-0.042		-0.179	
Innovative sector	0.182	***	0.357	***	0.423	***	0.012		0.104	**	0.247	***	0.093	

Note: coefficients marked *** are significantly different from zero at the 1% level for a two-tailed Chi-squared test, those marked ** are significant at the 5% level, and those marked * are significant at the 10% level.

Table 3: Determinants of the Use of at Least One Technology—Plant Characteristics and Activities

	At Least One Technology		Design and Engineering		Fabrication and Assembly		Automated Material Handling		Inspection and Communications		Information Systems		Integration and Control	
Intercept	-0.96	***	-2.22	***	-1.46	***	-2.50	***	-1.77	***	-1.83	***	2.60	***
Plant employment 100-499	0.62	***	0.62	***	0.64	***	1.73	*	0.65	***	0.67	***	0.28	***
Plant employment 500 or more	0.98	***	1.29	***	1.15	***	0.11		0.97	***	0.92	***	0.55	***
Birth in 1970s	0.16	**	0.22	***	- 0.04		0.54	***	0.22	***	0.12		0.09	
Birth in 1980s	-0.13		0.05		-0.01		0.23		0.02		-0.40	***	0.65	***
Foreign ownership	0.08		-0.21	***	- 0.08		-0.01		0.13	*	0.32	***	0.11	
Medium shipment growth	0.50	***	0.54	***	0.02	**	0.19	**	0.36	***	0.27	***	0.31	***
Large shipment growth	0.73	***	0.22	**	0.18	*	0.24	**	0.56	***	0.47	***	0.59	***
Enterprise produces for one industry	-0.38	**	0.33	**	-0.24		-0.17		-0.04		0.08		0.07	
Enterprise produces for two industries	-0.62	***	-0.07		-0.03		-0.33	**	-0.46	***	-0.07		0.39	**
Enterprise produces for three industries	-0.29	*	0.14		-0.26	*	-0.36	*	-0.13		-0.32	*	0.17	
Enterprise employment 1-499	-0.06		-0.04		-0.20	***	0.06		0.09		-0.16		0.38	**
Enterprise employment 500-999	0.27	**	0.18		-0.31	***	0.39	**	0.67	***	0.12		0.10	
Enterprise employment 1000 or more	-0.15		0.51	***	-0.46	***	0.68	***	0.43	***	0.17		0.16	
Quebec	0.67	***	0.08		0.42	***	0.61	***	0.74	***	0.14		0.45	***
Ontario	0.27	**	-0.10		0.24	*	0.21		0.33	***	-0.29	**	0.36	**
Prairies	0.09		0.09		0.08		0.10		0.05		-0.31	**	0.10	
British Columbia	0.28	**	-0.02		0.07		-0.13		0.27	**	-0.05		0.16	
R&D, contracted out	0.88	***	0.61	***	0.34	***	0.19		0.65	***	0.39	**	1.24	***
R&D, within the enterprise	0.88	***	0.77	***	0.59	***	0.57	***	0.71	***	0.64	***	0.93	***
Innovative sector	0.12	**	0.31	***	0.38	***	-0.03		0.04		0.21	***	0.08	

Note: coefficients marked *** are significantly different from zero at the 1% level for a two-tailed Chi-squared test, those marked ** are significant at the 5% level, and those marked * are significant at the 10% level.

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Together, the importance of the size and growth variables substantiates the hypothesis that more successful establishments are likely to include technology adoption as part of their strategy set. This accords with evidence that a plant's market-share growth is related to its use of advanced technology (Baldwin, Diverty, and Sabourin, 1995) and that both market-share and profitability are related to technological innovation (Baldwin, Chandler, Le and Papailiadis, 1994).

Technology incidence is higher for plants born in the 1970s. This group are young enough to be less constrained by obsolescence and inflexible capital than plants born prior to 1970.

The coefficients attached to the variables controlling for enterprise-level diversity indicate that plants specializing in production for one industry are more likely to use an advanced technology than those who produce for two or three industries; however, enterprises who diversify production across four or more industries are the most likely of the four groups to use technology. Therefore, it is either specialization or extensive diversification that leads to an increase in the probability that advanced technology is used in the production process.

There is no monotonic scale effect at the enterprise level, only a higher probability that medium-sized enterprises will use advanced technology than either small or large firms. Thus, enterprise scale effects are exhausted for firms above 1000 employees.

Plant location also has a strong impact on the probability of using at least one technology, with establishments located in Central Canada and British Columbia being more likely to use an advanced technology than those in the Prairies and the Maritimes.

There are three results that indicate technology intensity is part of a larger scientific competence. First, foreign-owned plants have a positive and significant coefficient. Second, plants in the more innovative industries are also more likely to adopt advanced technology. Finally, when research and development activity is added (Table 3), this variable has a positive and significant coefficient.

Differences in technology adoption at different stages of production process (Table 2, columns 2 to 7) are investigated by examining technology use in each functional group--in design and engineering, fabrication and assembly, automated material handling, inspection and communications, manufacturing information systems, and integration and control. A technology user at this disaggregated level is defined as a plant that adopts at least one technology from the particular group of technologies in question, regardless of whether the plant uses any technology from any other stage of the production process (i.e., another functional group).

For the different stages of the production process, only the coefficients attached to the plant-employment and shipment-growth variables are consistent across all functional groups with those found in column 1, Table 2. The innovative industry coefficient can be included as well if the materials handling group, a seldom used technology set, is excluded.

Foreign ownership has a significant and positive coefficient in the inspection and communications, information systems, and integration and control groups. Larger enterprise size increases technology incidence in design and engineering as well as inspection and communications technologies. The newer plants, born in the 1970s, are more intensive users of technologies everywhere but in fabrication and assembly. Nevertheless, the dominant factors determining the incidence of technology adoption are plant level economies of scale, as measured by employment size, and success, as measured by shipment growth.

The R&D activity variable is strongly related to technology incidence across all functional groups (Table 3). The probability of adopting technology increases significantly when R&D is undertaken.[3] These results hold both at the overall level and at the disaggregated level. Research and development, done either within the enterprise or contracted out, increases the probability of technology adoption. R&D that is carried out within the enterprise has the strongest effect on the probability of technology adoption, the exception being the integration and control group.

The strongest effects in this model, then, are associated with plant size, output growth, and research and development activity. This small group of factors are all plant-level measures of competency. Enterprise level variables have a weaker relationship to the incidence of technology use.

Technology Intensity

Intensity of technology use is measured here with a variable that ranges between 0 and 22, corresponding to the number of advanced technologies the plant is using in its production process. The vector of independent variables is first limited to characteristics, and then expanded to include R&D activities as was done previously. Coefficients are estimated using ordinary least squares regression techniques.[4] To facilitate easier interpretation, the sum of the coefficients on each dummy variable set is constrained to zero in the manner of Suits (1983).

In the regression that only includes plant characteristics as independent variables (Table 4, Column 1), plant size and shipment growth are the variables with the most power in explaining the intensity of technology adoption. The number of technologies used by a

[3] When the plant research and development variable is included in addition to the other characteristics (Table 3), the signs and significance of the other variables remain much the same. Plant-level employment and shipment growth are still the key characteristics determining technology adoption, while the effects of foreign ownership and being in an innovative industry are slightly weaker.

[4] Since the nature of the dependent variable in Model 2 is count data, using least squares regression may not be as appropriate as negative binomial regression. Results found by estimating Model 2 using the negative binomial technique are essentially the same, with a few notable exceptions. First, the relative importances of R&D increases significantly, to the point where engaging in this activity is important as plant size in determining the number of technologies adopted. Full negative binomial results are presented in Appendix A.

plant increases monotonically both with the plant's employment size and with its growth. Large plants, and plants where output is growing, use more technologies; small plants, and plants where output growth is negative or small, use fewer technologies. This result is similar to that produced in the case of technological incidence.

Also similar to the model of technology incidence, there is a set of plant-level competencies that are significantly related to the number of technologies adopted. These include foreign-ownership, production in an innovative industry, and regional location of the plant. The age effect here is similar to that described in the incidence section. Plants born in the 1970s adopt a slightly larger number of technologies than older or younger plants.

In contrast to Model 1, where high levels of enterprise diversification increase the *incidence*, enterprise-level diversification decreases technology *intensity*. Plants that specialize by producing for just one industry use significantly more technologies, on average, than those who diversify.

Another difference between the two models is that technology intensity increases monotonically with the employment size of a multi-plant enterprise. While the effect of scale on the probability of using at least one advanced technology may be exhausted at less than 1000 employees, this is not the case for the number of technologies employed. Establishments that are part of a larger multi-plant enterprise enjoy scale advantages—the pooling of resources, capital, information, experience and expertise—over and above those at the plant level, which permit them to use a larger number of technologies, on average, in their production processes.

When plant research and development activity measures are included in the model (column 2), the coefficients change very little from those in column 1. Coefficients on those variables with the most explanatory power (size, growth) drop slightly, but the significance levels and relative importance are not altered.

Plants performing research and development use advanced technology more intensively than those not doing so. Plants engaged in R&D use somewhere between 0.9 and 1.2 more technologies, on average, than plants that are not R&D performers. Performing R&D within the enterprise results in more technologies being used than when R&D is contracted out.

Table 4.0
Determinants of the Number of Technologies Adopted

	Plant Characteristics (R^2=0.292, n=3800)		Plant Characteristics and Activities (R^2=0.363, n=3640)	
Intercept	3.32		3.29	***
Plant employment 1-99	-1.89	***	-1.86	***
Plant employment 100-499	0.10		0.08	
Plant employment 500 or more	1.79	***	1.78	***
Plant birth before 1970	-0.05		-0.09	
Plant birth in 1970s	0.20	*	0.24	***
Plant birth in 1980s	-0.16		-0.15	
Plant is foreign owned	0.20	***	0.15	***
Plant is domestically owned	-0.20	***	-0.15	***
Negative or small shipment growth	-0.68	***	-0.55	***
Medium-sized shipment growth	0.03		-0.08	
Large shipment growth	0.65	***	0.63	***
Enterprise produces for one industry	0.51	***	0.43	***
Enterprise produces for two industries	-0.18		-0.35	***
Enterprise produces for three industries	-0.46	***	-0.17	
Enterprise produces for four or more industries	0.13		0.09	
Stand alone plant	-0.39	***	-0.28	**
Enterprise employment 1-499	-0.37	***	-0.33	***
Enterprise employment 500-999	0.33	***	0.13	
Enterprise employment 1000 or more	0.43	***	0.47	***
Maritimes	-0.15		-0.25	*
Quebec	0.53	***	0.75	***
Ontario	0.02		-0.01	
Prairies	-0.25	***	-0.32	***
British Columbia	-0.14		-0.18	*
Innovative sector	0.24	***	0.20	***
Non-innovative sector	-0.24	***	-0.20	***
R&D contracted out	n/a		0.23	**
R&D within the enterprise	n/a		0.53	***
No R&D done	n/a		-0.76	***

Note: coefficients marked *** are significantly different from zero at the 1% level for a two-tailed Chi-squared test, those marked ** are significant at the 5% level, and those marked * are significant at the 10% level. Those marked n/a are not applicable to that specific model.

Conclusion

Technology *incidence* in the Canadian manufacturing sector is related mainly to establishment size, growth in shipments, and whether or not an enterprise performs R&D. Other less important but still significant factors include the level of diversification, producing for an innovative industry, foreign ownership, and regional location. Technology *intensity* is generally related to the same variables, with two notable exceptions. First, technology *intensity* is strongly related both to plant and enterprise size, where *incidence* is only strongly relate to the plant size. Second, specialization of the parent firm is found to have a greater effect on the number of technologies used than diversity of the parent. In contrast, specialization of the parent firm decreases the likelihood that advanced technology is used.

The results reported here broadly conform to the pattern of technology adoption that has been reported in the United States (Dunne 1991, 1994).

- First, establishment size is the single most important characteristic related to both technological incidence and intensity in Canada, with larger plants having a greater receptor capability for technology use.
- Second, both Canadian and U.S. results find that the performance of R&D is strongly related to the incidence and intensity of technology adoption.
- Third, both Canadian and U.S. results show that variations in technology incidence and intensity occur across sectors, but are only weakly related to the age of the plant. Coefficients on age variables are generally weak or non-significant. Industry effects, on the other hand, are always significant, and often quite large in both incidence and intensity models.
- Fourth, the Canadian and U.S. results suggest there is no consistent relationship between technology use and diversification.

There are, however, some differences in the Canadian and U.S. results in three areas, with regards to the effects of enterprise size, output growth, and foreign ownership. Each of these variables is found to have a significant positive effect on technology use in Canada, but not in the United States. However, since the variables employed in the Canadian analysis were either not used in the US analysis, or were specified differently, the Canadian results should be regarded as adding to our knowledge about determinants of technology use rather that about differences between the two countries.

Appendix A

Table 4A:
Determinants of the Number of Technologies Adopted
(Negative Binomial Regression Technique)

	Plant Characteristics (LL=-6059.0, n=3800)	Plant Characteristics and Activities (LL=-5736.5, n=3640)	
Intercept	-0.650***	-0.163	***
Plant employment 100-499	0.887 ***	0.787	***
Plant employment 500 or more	1.124 ***	1.077	***
Plant birth in 1970s	0.209 ***	0.190	***
Plant birth in 1980s	-0.127	-0.165	
Plant is foreign owned	0.228 ***	0.134	*
Medium-sized shipment growth	0.655 ***	0.482	***
Large shipment growth	0.711 ***	0.541	***
Enterprise produces for one industry	0.103	0.075	
Enterprise produces for two industries	-0.175	-0.232	**
Enterprise produces for three industries	-0.407 *	-0.212	
Enterprise employment 1-499	-0.066	-0.108	
Enterprise employment 500-999	0.488 ***	0.295	***
Enterprise employment 1000 or more	0.410 ***	0.325	**
Quebec	0.297 ***	0.418	***
Ontario	-0.021	0.069	
Prairies	-0.219 *	-0.213	**
British Columbia	-0.076	-0.751	
Innovative sector	0.317 ***	0.226	***
R&D contracted out	n/a	1.065	***
R&D within the enterprise	n/a	1.141	***

Note: coefficients marked *** are significantly different from the omitted category at the 1% level for a two-tailed test, those marked ** are significant at the 5% level, and those marked * are significant at the 10% level. Those marked n/a are not applicable to that specific model. LL is the log-likelihood.

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