Innovation and Productivity: Summary Results for Canadian Manufacturing Establishments

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ABSTRACT

Lagging innovation performance is seen as a key factor explaining weak productivity growth in Canada. This article uses data from the Canadian Survey of Innovation 2005 and the Annual Survey of Manufactures and Logging (ASML) to estimate an econometric model linking innovation and productivity in manufacturing firms. Our main findings are that firms with higher innovation output (measured by innovation sales per employee, i.e. sales of new and improved products per employee) achieve higher labour productivity, even when size of firm, intensity of human and physical capital, and labour productivity at the beginning of the period are taken into account.

RÉSUMÉ

Le piètre rendement en matière d'innovation semble être un facteur essentiel pour expliquer la faible croissance de la productivité au Canada. Cet article montre comment les données de l'Enquête canadienne sur l'innovation de 2005 et de l'Enquête annuelle sur les manufactures et l'exploitation forestière (EAMEF) ont servi à l'élaboration d'un modèle économétrique établissant le lien entre l'innovation et la productivité dans les entreprises de fabrication. Nos principaux résultats indiquent que les entreprises dont le produit en innovation est plus élevé (selon la mesure des ventes en innovation par employé, c. à d. les ventes de produits nouveaux et améliorés par employé) atteignent une productivité du travail plus élevée, même en tenant compte de la taille de l'entreprise, de l'intensité du capital humain et physique et de la productivité du travail au début de cette période.

THE STANDARD OF LIVING AND THE QUALITY of life in a country are closely related to its level of labour productivity. Improving labour productivity not only supports increased wages but is also the best guarantor of capacity to provide public services such as health care, education,

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and environmental initiatives. However, both the level and growth rate of Canada's labour productivity have been a source of concern for some time (Hanel, 2008). Innovation is one of the principal sources of productivity growth and is also an area where Canadian industry lags behind many of its competitors according to the *Global Competititveness Report*, 2011-2012.[2]

To understand what is behind the aggregate statistics, it is necessary to examine innovation and productivity at the firm level. This is where labour and capital—the principal factors of production—are put to work more or less efficiently. By introducing new and improved products and production processes, innovating firms expand existing and create new markets, as well as improve the efficiency of their production and marketing activitie, that is, improve their productivity.

Using the framework first developed by Crépon, Duguet and Mairesse (CDM) (1998), this article analyzes the impact of innovation on labour productivity using firm-level data from the Canadian Survey of Innovation 2005 and the Annual Survey of Manufactures and Logging (ASML).

The article is organized as follows. Section one reviews the literature dealing with the issue of innovation and productivity at the firm level. Section two presents the econometric model and data used to estimate the link between innovation and productivity and section three analyzes the results. Finally, section four concludes by considering policy implications of the results and by proposing alternative avenues for future research.

Overview of the Literature

Background and CDM Model

The difficulty of measuring technical progress led economists studying the link between innovation and productivity at the firm level to initially focus their attention on research and development (R&D), an input into the innovation process. However, as Mairesse and Sassenou (1991) noted, the methodological difficulties faced in modeling the complex relationships involved, in addition to the issues of obtaining high quality data, made it quite challenging to arrive at satisfactory interpretations and conclusions on the effect of R&D on productivity.

The introduction of innovation surveys in most OECD countries[3] in the early 1990s provided data that enabled researchers to statistically document the multiple sources of innovation, the variety of types of innovation, and their relationship with the expected and achieved impact of innovation results on the performance of innovating firms. Crépon, Duguet and Mairesse (1998), inspired by earlier work of Pakes and Griliches (1984), integrated these relationships into a single system of three stages with four recursive equations:

- The first stage captures the firm's decisions regarding research activities—i.e., whether to engage in R&D and, if yes, what level of resources to allocate to this purpose. The Heckman selection equation estimates the probability that the firm performs R&D activities. Given that a firm engages in R&D, the second equation in the first stage estimates the intensity of these activities.

2 According to the Global Competitiveness Index, 2011-2012 which ranks 142 countries, Canada ranks 7th by the availability of scientists and engineers, 9th by the quality of its scientific research institutions, 10th by the number of utility patents per million popula-tion, 11th by university-industry collaboration, 24th for its capacity for innovation, 25th for company spending on R&D, and 35th by government procurement of advanced technology products (http://www.weforum.org/reports/global-competitiveness-report-2011-2012).

3 Note the United States introduced its first national innovation survey only in late 2000s. (http://www.nsf.gov/statistics/infbrief/nsf09304/)

- The second stage models innovation as a function of R&D and other variables. Innovation outcomes are measured by patents in one variant of this equation and by the percentage of innovation sales in a firm's total sales in another variant.
- The third stage of the model expresses productivity as a function of innovation output—measured either by the expected number of patents per employee or by the share of innovative sales over total sales—and other determinants of productivity, including capital, labour and skill composition, using an augmented Cobb-Douglas production function.

The estimating model deals with selection bias, the endogenous nature of innovation and R&D and the statistical properties of the underlying data. The CDM results show, for French manufacturing firms, a clear link between the innovation input intensity (R&D capital intensity), innovation output (patents or innovation sales), and firm productivity.

Crépon, Duguet and Mairesse (1998) summarize the relationships they uncovered as follows:

> "the probability of engaging in research (R&D) for a firm increases with its size (number of employees), its market share and diversification, and with the demand pull and technology push indicators. The research effort (R&D capital intensity) of a firm engaged in research increases with the same variables, except for size (its research capital being strictly proportional to size). The firm innovation output, as measured by patent numbers or innovative sales, rises with its research effort and with the demand pull and technology indicators, either directly or indirectly through their effects on research. Finally, firm productivity correlates positively with a higher innovation output, even when controlling for the skill composition of labour as well as for physical capital intensity".

Variants of the CDM Model

The CDM model has inspired several similar studies; all are based on the harmonized innovation survey data collected according to guidelines provided by the Oslo Manual for gathering and interpreting innovation data (OECD, 2005). Interesting variants of the CDM framework are found in: Lööf and Heshmati (2006), who examine the link between innovation and labour productivity in Swedish manufacturing and services firms; Griffith *et al.* (2006), who compare the innovation-labour productivity nexus for France, Germany, Spain and the United Kingdom; and Van Leeuwen and Klomp (2006), who estimate the contribution of innovation to multifactor productivity growth in the Netherlands.

The Swedish study by Lööf and Heshmati (2006) is of particular interest. It uses the CDM model as the theoretical framework but adopts a different econometric strategy to overcome the problem of endogenous explanatory variables, using instrumental variable analysis instead of the asymptotic least squares method used by CDM. Results of the study show that various productivity measures such as sales per employee, value added per employee, growth of value added per employee, growth of sales, growth of profit per employee, growth of employment and, to a lesser degree, sales margins are all positively linked to innovation; of course, the estimated elasticity coefficients vary. In contrast to earlier studies that considered R&D as the sole innovation expenditure, the innovation input variable in this study includes expenditures on all aspects of innovation.

Using the Lööf and Heshmati (2006) variant of the CDM framework, the OECD published an international comparison of 18 countries, including Canada, onthe link between innovation and productivity (OECD, 2009). For most countries, exporting, large size, and being part of a group are characteristics that increase the probability that a plant or firm is innovating. These characteristics, in addition to cooperating on innovation and receiving public financial support, also determine the intensity of investment in innovation. The outcome of innovation activity, measured as the ratio of innovation sales to a firm's total sales, contributes significantly to labour productivity. Overall, when statistically significant, the estimated regression coefficients are remarkably similar for all countries, not only for the productivity equation but also for the elasticity of innovation sales to innovation expenditures and for the equation describing investment in innovation and the decision to innovate as well.

The Model and Data

Model Used

The model used in this article also follows the Loof-Hesmati methodology. The main distinction between this model and the one used for the OECD exercise is that this one used all the information available in Canadian databases (e.g. refined productivity measure; use of quantitative variables instead of binary variables when possible). Unlike the OECD study, we are not constrained by the imperative of international data comparability.

The specification of the four equations is presented below, followed by a brief discussion of explanatory variables.[4]

Selection equation

The selection probit equation (A^S) estimates the probability that a firm innovates. The binary dependent variable *INNOV_STRICT* =1, when the firm reported positive innovation expenditures and positive sales of product innovations, otherwise *INNOV_STRICT* =0.

$$(A^S)\quad INNOV\_STRICT = \beta_0^S + \beta_1^S LEMP + \beta_2^S EXPORT\_US + \beta_3^S EXPORT\_OT + \beta_4^S INTRA\_SALE + \beta_5^S GRANT + \beta_6^S GTXC + \beta_7^S FAC\_NEW + \beta_8^S FAC\_EXIST + \beta_9^S FAC\_CUSTOM + \beta_{10}^S MKTSH02 + \Sigma_n \beta_n^S SIC + \varepsilon^S$$

(If INNOV_STRICT= 1)

The vector of explanatory variables includes:

- *LEMP* employment in log form;
- *EXPORT_US* percentage of sales exported to the United States;
- *EXPORT_OT* percentage of sales exported to other foreign markets;
- *INTRA_SALE* share of total revenue from other plants in the group;
- *GRANT* government support by grant;
- *GTXC* R&D tax credit;
- *FAC_NEW* seeking new markets is seen as an important success factor for the firm;
- *FAC_EXIST* satisfying existing customers is seen as an important success factor for the firm;
- *FAC_CUSTOM* developing custom designed products is seen as an important success factor for the firm;
- *MKTSH02* plant's market share at beginning of period 2002;
- *SIC* industry dummy variables (see the list in Box 1 for the definition); and
- ε error term

4 As explained before, the CDM framework addresses specific economic problems such as potential selection bias and endogeneity between several variables. See the note below Table 5 for a short explanation of variables added or transformed to deal with these econometric issues. Note that more information on the tests performed is available in the longer version of the paper (Therrien and Hanel, 2010).

Innovation investment equation

The first equation (A^1) estimates the log of the total expenditure per employee invested in innovation activities (*LRTOTPE)*.[5]

$$(A^1)\quad LRTOTPE = \beta_0^1 + \beta_1^1\, LEMP + \beta_2^1\, EXPORT\_US + \beta_3^1\, EXPORT\_OT + \beta_4^1\, MIC + \beta_5^1 COOP + \beta_6^1\, GRANT + \beta_7^1\, GTXC + \beta_8^1\, RD\_OUT + \beta_9^1 MKTSHO2 + \Sigma_n \beta_n^1\, SIC + \varepsilon^1$$

In addition to explanatory variables defined above, equation A^1 includes :

- *MIC* share of total revenue from sales to the most important customer or client which is not part of the firm;
- *COOP* cooperation on innovation;
- *RD_OUT* R&D contracted-out.

For estimation purposes, we use the two-stage Heckman procedure (Heckit) for equations A^S and A^1.

Innovation sales equation

The second equation (A^2) estimates the log of product innovation sales per employee (*LISPE).*

$$(A^2)\quad LISPE = \beta_0^2 + \beta_1^2\, GP + \beta_2^2\, LEMP + \beta_3^2 PROCESS + \beta_4^2\, HC + \beta_5^2\, LGIPE + \beta_6^2\, S\_INTRA + \beta_7^2\, S\_PUB + \beta_8^2\, S\_MARKET + \beta_9^2 LRTOTPE + \beta_{10}^2 LVAPE02 + \Sigma_n \beta_n^2\, SIC + \varepsilon^2$$

The set of explanatory variables includes variables specified above and the following:

- *GP* the plant is part of a group;
- *PROCESS* introduction of a process innovation;
- *LGIPE* physical capital per employee in log form;
- *HC* human capital;
- *S_PUB* source of ideas for innovation from public institutions;
- *S_MARKET* source of ideas for innovation from market sources ;
- *S_INTRA* source of ideas for innovation from in-house; and
- *LVAPE02* labour productivity at the beginning of the period (2002).

Labour productivity equation

The final equation (A^3) is a production function estimating labour productivity measured as the log of value added per employee (LVAPE).

$$(A^3)\quad LVAPE = \beta_0^3 + \beta_1^3 GP + \beta_2^3 LEMP + \beta_3^3 LISPE + \beta_4^3 PROCESS + \beta_5^3 HC + \beta_6^3 LGIPE + \beta_7^3 LVAPE02 + \Sigma_n \beta_n^3 SIC + \varepsilon^3$$

A brief discussion of the variables used in the four equations follows.

Decision to innovate (A^S) and investment in innovation inputs (A^1)

The decision to innovate, investing in innovation, the innovation performance and productivity are in one way or another influenced by the size of the firm. The employment variable *(LEMP)* is present in all equations as a control variable.

In general, exporters tend to be more innovative (Becker and Egger, 2007) and more productive (Tybout, 2001; Wagner 2007) than firms serving only the domestic market. This is partly explained by the fact that only the most competitive firms can challenge foreign competition and succeed in exporting. As well, consistent with the exporting hypothesis, there is evidence that participation in foreign markets allows firms to acquire new knowledge that makes them more efficient (De Loecker, 2006). According to Baldwin and Gu (2003), Canadian-owned exporters of manufactured products, especially new entrants to foreign markets and young firms, appear to benefit from both of these effects. Owing to Canada's close integra-

5 Innovation expenditures include both in-house and external R&D, R&D by parent company; acquisition of machinery, equipment, computer hardware and and software, linked to new or improved products; and acquisition of external knowledge, training and the cost of activities for the market introduction of innovations (see Question 23 in the Survey of innovation, 2005 for details).

tion with the U.S. economy, sales to the U.S. market represented by *(EXPORT_US)* may present less of a challenge than exports to other areas *(EXPORT_OT)*. The latter may require more specific competencies, including the capacity to innovate.

Previous results (OECD, 2009; Peters, 2008) show that establishments that are part of a larger entity are more likely to innovate and to spend more on innovation. This may be the case for many smaller establishments that can tap into a firm's resources and expertise. We test whether the "strength" of the link with the larger enterprise plays a role in an establishment's behaviour with regard to innovation and innovation spending. The strength of the link is expressed as the share of total revenue that comes from other establishments of the enterprise *(INTRA _SALE)*.

Finally, as stressed in the management literature, choosing to focus on one important client or to diversify the number of clients is believed to have an impact on the innovation behaviour of establishments. Firms generating a high proportion of total revenue from their most important client *(MIC)* are likely to face less incertitude with regard to the adoption of their innovation. Often, the innovation may have been created in collaboration with, or in response to the demand of, their most important client. The hypothesis behind this variable can be traced back to the characterization of the customer and specialized supplier relationship in Pavitt (1984).

Factors that are deemed by a firm to be responsible for its success (i.e. in terms of ranking "high" on the Lickert scale) are likely to be related to the decision to innovate. The active search for new markets *(FAC_NEW)*, satisfying existing customers *(FAC_EXIST)*, and developing custom-designed products *(FAC_CUSTOM)* are success strategies believed to be closely associated with the decision to innovate.

Government support reduces the marginal cost of innovation and hence reduces one of the principal obstacles to innovation (Czarnitzki, Hanel and Rosa, 2011). The decision to innovate may be induced by government support as is the case in some European countries (Griffith *et al.*, 2006). Two binary variables identifying whether a firm claimed R&D tax credits *(GTXC)* and/or received R&D grants *(GRANT)* are included in the selection and innovation expenditure equations.[6] Establishments, especially smaller ones that do not conduct regular R&D activity, may contract out specific research and development tasks to private or public R&D institutes. On the other hand, access to external R&D may complement a firm's internal R&D competencies. Thus, it is not *a priori* clear whether contracting out R&D is a substitute for, or a complement to, intensity of innovation expenditures. In case the firm contracts out R&D, the sign and statistical significance of the regression coefficient of the dummy variable *(RD_OUT)* indicate whether and how strongly this strategy affects the firm's investment in innovation activity. Finally, the profitability of innovation is expected to be higher the greater the firm's market share *(MKTSH02)*.

Innovation output equation

The output of innovation is measured by the log of sales of new and improved products and services per employee *(LISPE)*. In addition to the log of innovation expenditures per employee *(LRTOTPE)* and the log of firm employment *(LEMP)*, it includes three specific sources of information on innovation (*S_INTRA*, *S_PUB*, and *S_MARKET*). Earlier studies show that innovation feeds not only on R&D competen-

6 Unfortunately, quantitative information on the amounts of the subsidies and tax credits are not available from our database.

Box 1
List of Variables

Symbol	Description
COOP	Plant co-operated on innovation activities
EXPORT_OT	Percentage of plant's total revenue exported to destinations other than the United States
EXPORT_US	Percentage of plant's total revenue exported to the United States
FAC_CUSTOM	Developing custom designed products is the most important factors for plant' success
FAC_EXIST	Satisfying existing clients is the most important factors for plant' success
FAC_NEW	Seeking new markets is the most important factors for plant' success
INTRA_SALE	% of plants total revenue in 2004 from other plants in the firm
GP	Operations of your plant are part of a larger firm
GRANT	The plant(firm) used government R&D grants
GTXC	The plant (firm) used R&D tax credits
HC	Human capital (percentage of full time employees with university degree)
LEMP (LEMP02)	Log of employment (Log of employment for beginning of period (2002))
LGIPE	Proxy for physical capital (Cost of energy and fuel per employee)
LISPE	Log of innovation sales per employee
LLPE	Log of total revenue per employee
LRTOTPE	Log of total innovation expenditures per employee
LVAPE	Log of value added per employee
LVAPE02	Log of value added per employee at beginning of period (2002)
MIC	% of plants total revenue in 2004 from the most important customer
MKSH02	Plant's market share at beginning of period (share of plant's output over industry output)
PROCESS	Plant introduced a new or significantly improved production process, distribution method, or support activity for its goods or services
RD_OUT	R&D contracted out
S_INTRA	Internal sources of information on innovation
S_PUB	Information on innovation from public sources
S_MARKET	Sources of information on innovation from market partners
INDUSTRY	Industry dummy variables are included in all equations.
Food + Tobacco	Food and Tobacco (NAICS: 311-312)
Textile	Textile, Clothing and Leather (NAICS: 313-316)
Wood	Wood products (NAICS: 321)
Paper	Paper and Printing (NAICS: 322-323)
Petro + Chem	Petroleum, Chemical and Plastics & Rubber (324-326)
Non-metal	Non-metal products (NAICS: 327)
Fabricated metal	Primary metal and Fabricated metal products (NAICS: 331-332)
M&E + Telecom	Machinery, Electrical, Electronic computer and communication (NAICS: 334-335)
Transport Equipment	Transportation (including aerospace) (NAICS: 336)
NEC	Furniture and NEC manufacturing industries (NAICS: 337-339)

cies, but also on ideas and suggestions from other internal sources such as management (especially in smaller firms without a regular R&D division) and sales and marketing and production staff, as well as from various external sources. Since the measure of innovation outcomes *(LISPE)* is the value of new and improved product sales per employee, it is expected that it is closely associated with information from market partners such as clients and suppliers and from public research institutions (Baldwin and Hanel, 2003; Landry and Amara, 2003).

Human capital, which is represented by the proportion of university graduates in the firm's total employment *(HC)*, is also included in the innovation output equation. Skilled workers in different areas (researchers, engineers, managers, marketing staff) are critical to the commercialization process of innovation (Industry Canada, 2006; Government of Canada, 2007).

Productivity equation

We measure labour productivity as value added per employee. In conformity with production function theory, both human capital *(HC)*, and physical capital, which is represented by the cost of fuel and energy per employee *(LGIPE)* are included in the productivity equation.[7]

Labour productivity is also expected to be affected by its innovation activity—i.e. by the outcome of product innovation *(LISPE)* and of process innovation *(PROCESS)*. Firms with higher productivity at the beginning of the period *(LVAPE02)* are likely to report higher productivity at the end of the period and this variable is therefore added to the model.

The Data

The data are from the Canadian Survey of Innovation 2005 on manufacturing and logging industries (reference period 2002 to 2004) linked to the Annual Survey of Manufactures and Logging.[8] The target population of the survey is establishments with 20 or more employees and at least $250,000 in revenues according to Statistics Canada's Business Register (June 2005 version). The linked survey has a total of 6,109 observations. From the 6,109 observations, we kept only those in the manufacturing sector with positive revenue and with 20 or more employees according to data from the Annual Survey of Manufactures and Logging.[9] The Canadian final sample thus consisted of 5,355 observations.

Comparison of innovating and non-innovating firms

Before turning to the analysis of the econometric results, we first provide a brief descriptive analysis of the data presented in Table 1. First, 68 per cent of the establishments (3,629 out of 5,355) described themselves as innovators in terms of having introduced either a new or improved product or process in the previous three years. The average productivity level *(VAPE)* of the innovators is 11 per cent higher (i.e. $11,000 value added per employee higher) than for non-innovators.[10]

As regards firm characteristics, innovators tend to be larger (*EMP:* average of 109 employees for innovators versus 70 employees for non-innovators) and more likely to be part of a larger enterprise (*GP*: 37 per cent versus 31 per cent). Innovators have, on average, a higher share of university graduates in their workforce (*HC:* 10 per cent versus 7 per cent). There is, however, no statistically significant difference in physical capital intensity (*GIPE*) between the two groups. Innovators are also more exposed to the international market by exporting a higher share of their products (to the United States as well as to other foreign markets) than non-innovators. Regarding business strategies, both innovators and non-innovators devote a similar share of

7 Due to data constraints, we used expenditure on electricity and fuel in manufacturing activities as a proxy for physical capital. Energy consumption is closely related to physical capital and has been successfully used as a surrogate for capital (e.g. Hillman and Bullard, 1978).

8 For more information on the survey, go to http://www.statcan.ca/english/sdds/4218.htm

9 Note that some firms with less than 20 employees were found in the database. The survey population was defined using the June 2005 version of Statistics Canada's Business Register. The annual Survey of Manufactures and Logging includes data from 2002 and 2005.

10 The result that innovative firms are more productive than non-innovative firms also holds when computing a simple regression model where firm size and human and physical capital are taken into account.

Table 1
Comparison of Innovators and Non-Innovators

	Innovators	Non-innovators
Variable (unit)	Mean	Mean
Value added per employee ($Th)	**107.00**	**96.27**
Innovator strict (% of innovative firms with positive innovation expenditures and innovation sales)	**0.61**	**0.00**
Number of employees	**109.10**	**70.14**
Export to U.S. market (% of revenue)	**0.29**	**0.21**
Export to other destination (% of revenue)	**0.06**	**0.03**
Part of a larger group (% of firms)	**0.37**	**0.31**
Total revenue from other plants in the firm (%)	**0.06**	**0.04**
Human capital (% with university degree)	**0.10**	**0.07**
Physical capital (cost of energy and fuel per employee in $Th)	7.09	6.73
Total revenue from the most important customer (%)	**0.27**	**0.29**
Use of R&D tax credit (% of firms)	**0.52**	**0.15**
Use of government R&D grant (% of firms)	**0.12**	**0.02**
Seeking new markets is an important factor for plant' success (% firms)	**0.40**	**0.24**
Satisfying existing clients is an important factor for plant' success (% firms)	0.88	0.89
Developing custom designed products is an important success factors (% firms)	**0.45**	**0.28**
Food and Tobacco industries (% of firms(	0.12	0.11
Textile industry	**0.05**	**0.09**
Wood industry	**0.08**	**0.10**
Paper industry	0.09	0.08
Petro and Chemical industries	**0.13**	**0.10**
Non-metal industry	0.04	0.04
Fabricated Metal industry	**0.15**	**0.20**
M&E and Telecommunications industries	**0.19**	**0.11**
Transport Equipment industry	0.06	0.06
NEC industry	**0.10**	**0.12**
Number of observations*	3,629	1,726

Note: Bold means average of innovators is significantly different than the average of non-innovator at the 5% level.
**Because of missing data and the use of log, the number of observations used in the econometric model for VAPE is 3,611 (instead of 3,629) for the sub-sample of innovators.

Source: Authors' calculations based on Statistics Canada Survey of Innovation 2005.

sales to their most important client (*MIC*: at a little less than 30 per cent of their sales); but innovators are more likely to see the active search for new markets *(FAC_NEW)* and developing custom-designed products *(FAC _CUSTOM)* as important success factors than non-innovators. Satisfying existing clients is seen as equally important for innovators and non-innovators.

Table 2 provides information on the sub-sample of firms and plants that are considered to be innovators in the "strict sense"—i.e. that

Table 2

Comparative Data for "Strict" Innovators

Variable (unit)	Mean
Value added per employee ($Th)	103.76
Innovation sales per employee (ln $Th)	3.21
Innovation expenditures per employee (ln $Th)	2.42
Number of employees	111.22
Export to U.S. market (% of revenue)	0.29
Export to other destinations (% of revenue)	0.07
Part of a larger group (% of firms)	0.37
Total revenue from other plants in the firm (%)	0.06
Human capital (% with university degree)	0.11
Physical capital (cost of energy and fuel per employee in $Th)	5.62
Total revenue from the most important customer (%)	0.27
Use of R&D tax credit (% of firms)	0.61
Use of government R&D grant (% of firms)	0.14
Co-operation on innovation activities (% of firms)	0.27
R&D contracted out (% of firms)	0.19
process innovation (% of firms)	0.72
Internal sources of information on innovation (% of firms)	0.23
Information on innovation from public sources (% of firms)	0.03
Sources of information on innovation from suppliers (% of firms)	0.2
Seeking new markets is an important factor for plant' success (% firms)	0.45
Satisfying existing clients is an important factor for plant' success (% firms)	0.86
Developing custom designed products is an important success factors (% firms)	0.51
Food and Tobacco industries	0.13
Textile industry	0.05
Wood industry	0.06
Paper industry	0.08
Petro and Chemical industries	0.14
Non-metal industry	0.04
Fabricated Metal industry	0.13
M&E and Telecommunications industries	0.22
Transport Equipement industry	0.05
NEC industry	0.11
Number of observations *	2,273

* Because of missing data and the use of log, the number of observations used in the econometric model for *VAPE* is 2,261 (instead of 2,273) for the sub-sample of innovators.

Source: Authors' calculations based on Statistics Canada Survey of Innovation 2005.

Table 3

Econometric Results: Equation A^S: Decision to Innovate (Innovation "strict") – Two-stage Heckman (Heckit) Procedure

	without lag (1)	with lag (2)	SME only (3)	Large only (4)
LEMP (LEMP02)	0.0657**	0.0613*	0.0493	0.1161
EXPORT_US	-0.1611	-0.2233*	-0.1572	-0.3018
EXPORT_OT	0.5300**	0.4425*	0.6892***	-0.2507
INTRA-SALE	0.0033**	0.0033*	0.0037*	0.0003
FAC_NEW	0.4380***	0.4211***	0.4539***	0.3617***
FAC_EXIST	-0.156*	-0.156	-0.126	-0.1808
FAC_CUSTOM	0.4112***	0.4396***	0.3434***	0.7966***
GTXC	0.8129***	0.8217***	0.8741***	0.6409***
GRANT	0.3161***	0.3100***	0.2350**	0.7248***
MKTSH02		-0.0011		
rho	-0.27**	-0.33**	-0.351**	0.001
N (unweighted)	5,355	4,312	4,417	938

Note: The statistically significant value of *rho* (the correlation coefficient between the error terms of the selection and outcome equations) shows the importance of correcting for selection bias by using the Heckit procedure.

*** indicates a level of statistical significance at 1%, ** indicates a level of statistical significane at 5%, and * indicates a level of statitstical significance at 10%

Table 4

Econometric Results: Equation A^1: Innovation input – Log (Innovation expenditures/ employee) (*LRTOTPE*)

	without lag (1)	with lag (2)	SME only (3)	Large only (4)
LEMP (LEMP02)	-0.1255***	-0.1957***	-0.1914***	0.0398
EXPORT_US	0.2745**	0.3717***	0.4192***	-0.1588
EXPORT_OT	1.055***	1.055***	1.1223***	0.4933
MIC	0.0034**	0.0049**	0.0042**	-0.0001
COOP	0.1534**	0.1415*	0.1302	-02318
GTXC	-0.1041	-0.2089	-0.159	-0.025
GRANT	0.091	0.041	0.0813	0.2261
RD_OUT	.2349***	0.1443	0.2018**	0.2841*
MKTSH02		0.057***		
N (unweighted)	2,273	1,789	1,786	476

*** indicates a level of statistical significance at 1%, ** indicates a level of statistical significane at 5%, and * indicates a level of statitstical significance at 10%

reported both innovation expenditures and innovation sales. This is the sub-sample that is used in the econometric model (more specifically in equations A1 through A3). The average labour productivity of "strict" innovators is slightly lower ($103, 760) than productivity ($107,000) of all firms that declared to have innovated (cf. Column 1 in Table 2). Strict innovators spent on average 11 per cent of their total expenditures on innovation activities and 22 per cent of their total sales came from sales of innovative products.[11]

The comparison with all innovators shows that a slightly larger proportion of the "strict" innovators used various government support programs; however, only the difference with respect to R&D tax credits is statistically significant. The average log of innovation sales per employee (LISPE) is 3.21 or roughly $25,000 per employee.[12] More than one out of four firms cooperated on innovation activities with other firms and institutions and almost one in five contracted out R&D.

Interpretation of the estimated model

The results of the three stage, four equation model using the expanded Canadian dataset are presented in Table 3-6. Four variants of the model are estimated.

The first two variants, presented in columns (1) and (2), are based on a data set that includes firms of all sizes. The main difference between these two variants is the use in variant (2) of variables (employment, market share and productivity level) describing firm characteristics *at the beginning of the period*. Introducing the productivity level at the beginning of the period (*LVAPE02*) among the explanatory variables separates the effect of innovation on productivity in 2004 from the effect of the pre-existing level of productivity in 2002, while adding the firm's market share (*MKTSH02)*[13] gives useful information on whether the firm has a dominant in the Canadian market. Note, however, that not all firms are in both the 2002 ASML and the 2004 ASML. Using the data for the years 2002 and 2004 thus results in a loss of about one thousand observations. This is why the results obtained using the whole sample are also presented and analyzed.

Finally, since other studies suggest that the size of the firm matters both for innovation and for productivity, separate estimates were also made for small and medium sized firms (SMEs), those employing less than 150 persons, and the large ones; these results are presented in columns (3) and (4) respectively.

Overview of estimation results: model variants with firms of all sizes

Decision to innovate

The probability that a firm is a strict innovator increases with the size of firm as measured by employment. This corroborates findings from other Canadian innovation studies (Baldwin and Hanel, 2003; Baldwin and Gellatly, 2003; Gault, 2003). The probability of a firm being a strict innovator increases only with the proportion of exports to destinations other than the familiar U.S. market. This presumably suggests that exporting to overseas markets is more demanding but also more rewarding. The integration of the plant within the firm matters as well, even though its effect on innovation is limited. Plants that generate an important proportion of their revenues from sales to other plants of their firm (*INTRA_SALE)* are marginally more likely to be strict innovators.

The strategic orientation of a firm is an important determinant of innovation. Firms that attribute their success to strategies based on the search for new markets are more likely to innovate, as are firms that develop custom-designed products. In contrast, firms that focus their strategies on satisfying existing clients are

11 According to a Statistics Canada protocol, it was not possible to publish the average spending on innovation activities per employee (coefficient of variation of this descriptive variable too high). We therefore present the average share of innovation expenditures and innovation sales. Note, however, that the intensity of innovation expenditures and sales by employee in dollar terms was used in the regressions.

12 See footnote above. The same issue (Statistics Canada protocol) prevented us from presenting a more precise figure

13 Note that the denominator of that variable is the 2002 gross output (in current prices) by industry, sourced from Statistics Canada "Industry Productivity KLEMS 1961-2003" (Statistics Canada, 2008).

Table 5

Econometric Results: Equation A^{2}: Innovation output – Log (Innovation sales/employee) (*LISPE*)

	without lag (1)	with lag (2)	SME only (3)	Large only (4)
GP	0.006	0.0108	-0.0175	0.1454
LEMP	-0.0438	-0.03	-0.0659	-0.077
PROCESS	0.2257**	0.3558***	0.1756**	0.2718
HC	0.6730**	.5723*	0.5855**	0.6802
LGIPE	0.2710***	0.2462***	0.2654***	0.2415***
S_intra	0.1236	0.2041*	0.2131**	-0.1123
S_pub	-0.0237	-0.0976	-0.0429	-0.0402
S_market	0.3565***	0.3942***	0.3200***	0.3919**
LRTOTPE	0.3256***	0.3108***	0.3259***	0.3649***
LVAPELAG		0.131*		
N (unweighted)	2,243	1,745	1,755	476

Note: To deal with selection bias, an additional variable (Mills ratio derived from the value of rho in A1) is added to the model (not shown in Table but results available upon request). Tests have been performed to assess whether the potential endogeneity between innovation expenditures and innovation sales was important enough to require instrumental variable (IV) regression. Since the exogeneity tests have not rejected the exogeneity of innovation expenditures as a determinant of innovation sales, the equation is estimated using simple ordinary least squares. See Therrien, Hanel 2010 for more details on the tests performed.

*** indicates a level of statistical significance at 1%, ** indicates a level of statistical significane at 5%, and * indicates a level of statitstical significance at 10%

Table 6

Econometric Results: Equation A^{3}: Productivity – Log (Value Added/employee) (*LVAPE*)

	without lag (1)	with lag (2)	SME only (3)	Large only (4)
GP	0.1618***	0.1360***	0.1516***	0.1264
LEMP	0.0328**	-0.0191	-0.0001	0.1038*
*LISPE**	0.2214***	0.1777**	0.1778***	0.3500***
PROCESS	-0.1134***	-0.089**	-0.077**	-0.224**
HC	0.1495**	0.2132*	0.1539	0.1294
LGIPE	0.1795**	0.1501***	0.1826***	0.1625***
LVAPELAG		0.2689***		
N (unweighted)	2,243	1,745	1,755	476

Note: To deal with selection bias, an additional variable (Mills ratio derived from the value of rho in A1) is added to the model (not shown in Table but results available upon request). * Tests have been performed to assess whether the potential endogeneity between innovation sales and productivity was important enough to require instrumental variable (IV) regression. The exogeneity tests showed that the variable LISPE was endogeneous to *LVAPE*. Therefore the equation was estimated using a two-stage least squares procedure with an instrumental variable used for innovation sales. The instrumental variable for innovation sales, LISPE, in equation A3 is: Z (*LISPE*) = [*LRTOTPE, S_INTRA; S_PUB; S_MARKET*]. See Therrien, Hanel 2010 for more details on the tests performed

*** indicates a level of statistical significance at 1%, ** indicates a level of statistical significane at 5%, and * indicates a level of statitstical significance at 10%

Source: Authors' calculations based on Statistics Canada Survey of Innovation 2005.

less likely to innovate. Public support for innovation through R&D tax credits or grants encourages R&D activity and increases the probability of a firm being a strict innovator.

Results from Model (2) show that the positive effect of size on the probability of being a strict innovator almost vanishes (the coefficient is barely statistically significant at the 10% level) when we control for the size of the firm at the beginning of the period. Other than the reduced coefficient of the employment variable, and some changes in the effect of exporting on the decision to innovate, there is not much difference between the two models.

Innovation input equation

Since investment in innovation is to a large extent a fixed cost, the intensity of investment in innovation as measured by total innovation expenditures per employee.

The strong link between exporting to countries other than the United States and investment in innovation is confirmed (Table 4). However, even firms that export to the U.S. market spend more per employee on innovation than non-exporters.

Firms that cooperate on innovation are more likely to spend more on innovation than those that do not. This suggests that cooperation is unlikely to be undertaken as a cost-saving measure, but rather to increase the scope of the project or to complement the firm's competency. Similarly, contracting out R&D does not seem to be a cost-reducing strategy. The positive elasticity estimate suggests that firms with higher innovation expenditure intensity are also more likely to contract out R&D instead of using R&D contracts as substitutes for their own innovation activities.

Interestingly, while fiscal incentives and direct subsidies to innovation are positively associated with the probability of being a strict innovator (cf. the interpretation of the selection equation above), they are not associated with greater innovation expenditure intensity.[14] Finally, firms with a larger market share at the beginning of the period invest in innovation more per employee than those with a smaller market share.

Innovation output equation

The innovation output equation shows the contribution of various variables to innovation output (LISPE) measured as the value of new and improved products—product innovations—per employee (Table 5). This equation assesses, among other factors, the importance of innovation expenditures (LRTOTPE) for innovation sales. The elasticity of LISPE with respect to LRTOTPE is 0.33.

Several other variables have an important effect on the output of innovation. First of all, only innovations inspired by ideas from market partners (customers, suppliers, competitors, consultants and commercial R&D laboratories) enhance the commercial success of innovation. This finding corroborates earlier results by Baldwin and Hanel (2003), underlining the importance of the market orientation of innovation. The fact that sources of information internal to the firm (sales, marketing, production) do not seem to contribute to innovation sales may be interpreted as an indication that their contribution is already included in total innovation expenditures.

More capital-intensive firms, especially those with high levels of human capital, are more successful at commercializing innovations. As well, innovating firms that introduce process as well as product innovations derive more sales from innovation than those introducing only product innovations.

Finally, firms with a higher productivity level at the beginning of the period (model variant (2))

14 It should be noted that quantitative variables (real amount of R&D grants and tax credit) would be needed to obtain a better idea of the causal effect on firms' innovation expenditure intensity. As noted before, such data were not available with the database used.

derive more sales from innovation at the end of period than those with a lower initial productivity level. This means that firms that were already outperforming other firms in terms of productivity are more likely to be successful innovators (measured by innovation sales) in the next period. Also, it is interesting to note that adding productivity at the beginning of the period does not change the sign and impact of other core variables; in particular, the impact of innovation expenditure intensity remains similar.

Productivity equation

Finally, the productivity results (Table 6) shows that firms with higher innovation sales per employee (*LISPE*) obtain higher labour productivity expressed as log of value added per employee (*LVAPE*). Productivity also increases slightly with the size of establishment and when the establishment is part of a larger enterprise. Conforming to economic theory, both human and physical capital intensity are important co-determinants of labour productivity.

Firms introducing a process innovation in addition to a product innovation have lower labour productivity than other innovative firms.[15] While this result is counterintuitive and stands in contrast with other studies (see Griliches (1998) for the United States; Criscuolo and Gaskell (2003) for the United Kingdom; and Hanel (2000) and Baldwin and Gu (2004) for Canada), some explanations can be proposed. First, the model used focuses primarily on product innovators, and therefore the negative coefficient on productivity is relative to product innovators that do not introduce process innovation. It is therefore possible to think that firms introducing both product and process innovations are introducing complex change (and maybe more radical innovations) in their manufacturing processes, leading to a short-term negative impact on labour productivity. Second, the effect of process innovation is not as well captured in the Canadian survey as the effect of product innovation. To mirror the measurable effect of product innovation (as measured by sales per employee from innovative products), we would need a variable that would assess the cost saving from process innovation.[16] Without such a variable, it is hard to assess the effect of process innovation that would lead directly to productivity gains.

Finally, including labour productivity at the beginning of the period as an additional explanatory variable (model variant (2)) does not change the results discussed above. Even though labour productivity in 2002 is an important determinant of productivity in 2004, it does not significantly change the effect of innovation sales on labour productivity. The estimated elasticity of productivity on innovation sales is slightly lower (0.18), but within the same range as the elasticity estimated in the first model (0.22) with contemporaneous variables. In conclusion, the results show, in no uncertain terms, that product innovation contributes significantly to higher productivity.

Overview of estimation results for SMEs and large firms

Previous studies suggested that the size of firm is an important determinant of innovation and that SMEs do not innovate in the same way as large firms (Acs and Audretsch, 1988; Baldwin and Hanel, 2003; Baldwin and Gellatly, 2003). This raises the question of whether the effect of

15 To explore further the relationship between labour productivity and process innovation we experimented by replacing PROCESS by specific forms of process innovation. When labour productivity is regressed on the specific effects of process innovations such as increased production flexibility and increased speed of delivery of goods and services, the correlation is still negative and statistically significant.

16 The elasticity of productivity on the cost saving from process innovation, an estimate of which is available in the German innovation survey, is positive and statistically significant (Peters, 2008).

innovation on productivity is also different between the two groups. To determine to what extent the size of firm matters, the model was estimated separately for small and medium sized firms employing less than 150 persons and for the larger firms.

The results for SMEs and large firms are presented respectively in the 3rd and 4th columns in Table 3-6; they indeed show some notable differences between the two size categories. First, since most large firms export, exporting does not discriminate between innovators and non-innovators and investment in innovation for large firms. Similarly, human capital does not have a significant effect on innovation sales and labour productivity in large firms. In contrast, human capital increases innovation sales, but not labour productivity, in SMEs.

While the elasticity of innovation sales to innovation expenditures is comparable between the two groups, Table 6 shows that the elasticity of labour productivity to innovation sales per employee (LISPE) is twice as large in big firms (0.35) as in the SME group (0.18).

Conclusion

This article extends and refines the Canadian model included in the 18-country OECD study of the relationship between innovation and productivity performance at the firm level (OECD, 2009). Results of the present study confirm that higher innovation expenditure intensity is conducive to better innovation outcomes (higher innovation sales per employee); and in turn highly innovative firms are more productive. Factors directly contributing to higher productivity are: a skilled workforce; higher physical capital intensity; and, as noted above, higher intensity of innovation sales.

The results of each stage of our model help to better understand the innovation process and its contribution to productivity. Our main results suggest that exporting (only outside of the U.S. market), size of firm, and use of direct or indirect government support are factors increasing the probability to innovate and having positive innovation sales.

Exports (both to the U.S. and outside of the U.S. market), cooperation with other firms and organizations, and a high share of the firm's revenue coming from sales to its most important client are all factors correlated with higher innovation expenditures per employee. Moreover, firms with a higher market share at the beginning of the period tend to spend more on innovation by the end of the period.

Firms with higher innovation expenditures per employee also generate more innovation sales per employee (an increase of 1 per cent of innovation expenditures per employee is associated with an increase of 0.33 per cent of innovation sales per employee). Firms introducing both product and process innovations generate more innovation sales per employee than those introducing only product innovation.

Finally, results from the model show that firms generating more innovation sales per employee achieve higher labour productivity, even when their size and intensity of human and physical capital are taken into account. An increase of 1 per cent of innovation sales per employee is associated with an increase of labour productivity of 0.22 per cent). It is worth noting that firms that are more productive at the beginning of the period derive more sales from innovation and are also still more productive by the end of the period.

The policy implication of these results is certainly interesting given that aggregate productivity growth in the Canadian business sector has been weak in recent years. Updated evidence (OECD, 2008) confirms results highly publicized a few years ago (Government of Canada, 2002) which show that Canada has a high percentage of innovators (using a broad definition, including technology adopters), but realizes lower innovation sales than most OECD countries. As shown by this study, innovation sales and productivity are highly correlated, and a weak performance in selling innovative products seems to be an important barrier for higher productivity performance.

However, some results require further investigation. First, public funding seems to induce firms to innovate, but not to allocate more resources to innovation. This could be symptomatic of weak coordination/design of existing government programs involving collaboration and support to business R&D, innovation and cooperation. R&D is only one, though often the most important, of several activities leading to successful innovation. The finding that R&D tax credits and R&D grants do not induce firms to increase their innovation expenditures and hence innovation performance is puzzling (see also Czarnitski, Hanel and Rosa, 2011).

Second, the present study did not convincingly address the link between process innovation and productivity. Process innovation is particularly important in Canadian manufacturing industry where about half of innovating firms introduce new processes. Information on the quantitative impact of various types of process innovations on production cost would be needed to better analyse the impact of process innovation on productivity. The new Canadian Survey of Innovation and Business Strategies (SIBS) released in November 2010 includes such information and will therefore be useful to better understand the link between innovation process, its impact on production cost and productivity.

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