The Importance of Innovation for Productivity

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In the 1990s, the growth rate of real per-capita income in Canada was significantly lower than in other OECD countries, particularly the United States. The most often cited reason for the phenomenal productivity performance of the U.S. economy is its dynamism and superior innovation record. If innovation is the key to improving growth in productivity and living standards, it is important to examine the key drivers of innovation and understand the nature and sources of Canada's innovation gap.

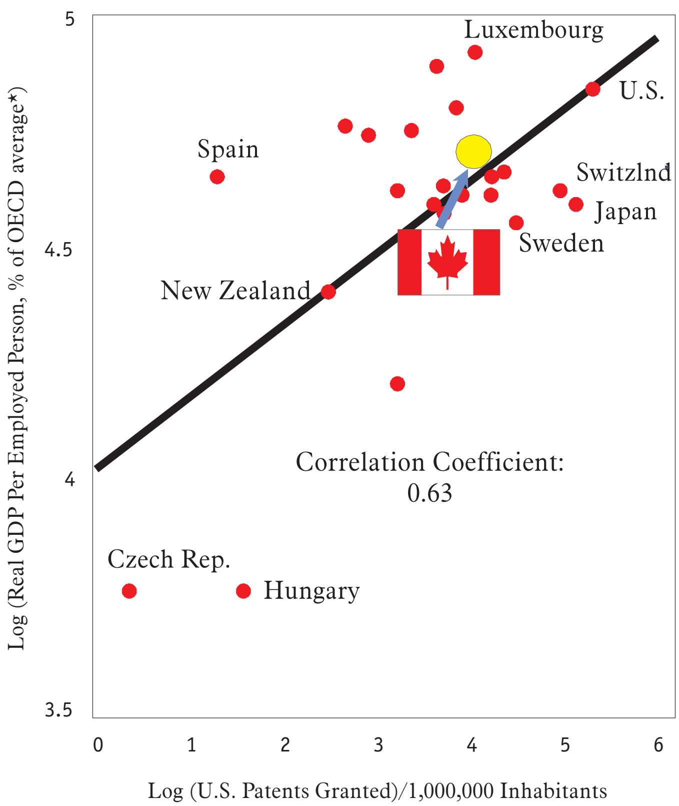
This paper first discusses the concept of innovation and its importance to both productivity and cost competitiveness. It examines empirically the linkages between innovation, productivity growth and improvements in real incomes across OECD countries and in Canadian and U.S. manufacturing industries. The paper next analyses some of the key drivers of innovation and compares Canada's innovation record with other G-7 countries. Finally, it looks at the role of government in improving Canada's innovation performance.

Innovation, Productivity and Cost Competitiveness

Canada's economic performance in the 1990s lagged far behind that of the United States — per capita real incomes in Canada are currently about 30 per cent below those in the U.S.. Although Canada has achieved a 10 per cent annual growth in nominal merchandise exports over the1990s (from $152.1 billion in 1990 to $360.0 billion in 1999), this has been due largely to a buoyant U.S. economy and the real depreciation of the Canadian dollar. However, we cannot rely on the weak dollar and the strong U.S. economy to improve the living standards and quality of life of Canadians in the future. On the contrary, the depreciating currency may actually erode the living standards of Canadians. The reality is that over 85 per cent of the income gap between Canada and the United States is due to the productivity gap. Therefore, only superior productivity performance will improve Canada's international cost competitiveness on a sustained basis, raise the standard of living and close the real income gap between Canada and the United States.

Modern growth theory identifies three key determinants of longer term productivity growth: accumulation of physical capital;

Figure 1:
Real GDP Per Employed Person* and Patents per Capita Granted in the U.S. for OECD Countries, 1995



* OECD average is a weighted average based on 1996 PPPs.
Source: Industry Canada compilations based on data from OECD and U.S. Patent and Trademark Office.

accumulation of human capital; and the rate of innovation and technological change. However, it is not appropriate to consider them as separate factors, since they interact in complex and dynamic ways and are complementary in nature. Advanced technologies are generally incorporated in the production process to improve productivity. But new investments in machinery and equipment and skills development in the labour force are also required to use state-of-the-art technologies effectively. In short, the quantity and quality of these three key factors, and the way in which they are organized, managed and utilized within a firm are what determine productivity performance.

Aside from these three key determinants, a country's business environment also matters. In particular, framework conditions, such as openness to trade and investment, the degree of competition in the economy, the financial system, quality of management and intellectual property protection are all important enabling factors for stimulating investment in innovation and improving productivity. In particular, the degree of competition in a particular country or sector may be one of the key factors, since lack of competition reduces the pressures on firms to adopt and use advanced technologies, re-organize workplace, rationalize production and improve productivity.

What is Innovation?

Innovation is a continuous process of discovery, learning and application of new technologies and techniques from many sources. Many of the techniques and processes are cumulative and interdependent; and the technological capacity of a firm may also be influenced by external factors such as the educational system, the research infrastructure and the functioning of the capital markets.

In this context, innovation includes both fundamental and applied innovation. Fundamental innovation, often thought of as research proper, comprises the invention of new products and processes. It is, however, a small, but important, part of total innovative effort, especially for a small open economy like Canada. The greater part of innovation actually consists of applied innovation which occurs when new products or processes developed either in Canada or in other countries, especially the United States, are utilized by Canadian-based firms, or when existing technologies are used in a new context or in new ways. Both fundamental innovation and applied innovation are enhanced by investments in R&D and human capital. In addition, investments in M&E and strong global links are important for the adoption and diffusion of new technologies. Supporting institutions provide positive feedback on the innovation process.

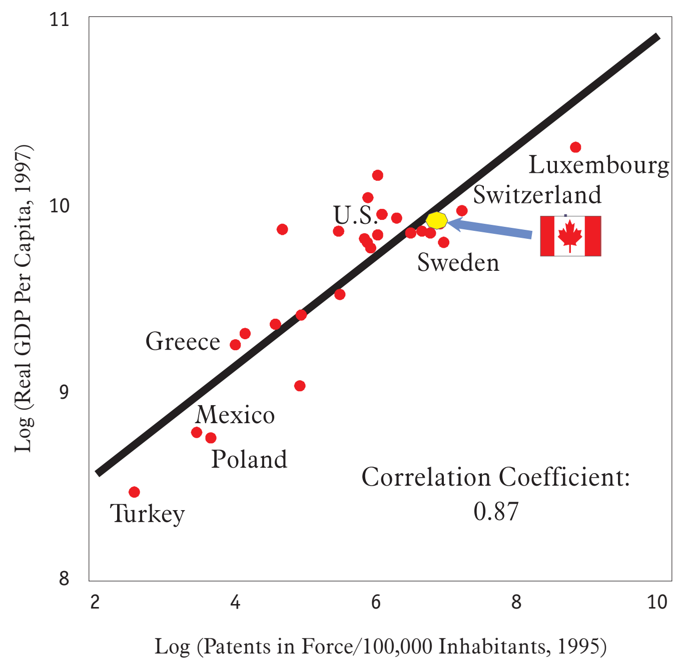
Innovation can also take the form of organizational changes and new marketing strategies which expand demand for products, support existing structures for new methods of production and increase the efficiency of the other types of innovative effort, leading to productivity improvements. Although these are potentially very important for increasing productivity, in this article we will concentrate only on fundamental and applied innovations, because of lack of data on these activities and time and resource constraints.

Innovation and Productivity: Empirical findings

International Evidence

Figure 1 shows a strong positive relationship between per capita patents granted in the U.S. and labour productivity, while Figure 2 shows a strong positive relationship between domestic patents in force per capita and GDP per capita, across OECD countries. The data show that countries with higher output measures of fundamental innovation have higher labour productivity and higher incomes; and countries with less innovation have lower labour productivity and lower incomes. Further, we found that patents granted in the U.S. accounts for about 40 per cent of variation in productivity levels across OECD countries; and a 10 per cent increase in U.S. patents granted is associated with a 1.6 per cent increase in the county's relative labour productivity. Similarly, the differences in domestic patents in force between OECD countries explains about 75 per cent of the cross national variation in GDP per capita; and a 10 per cent increase in domestic patents is associated with a 2.9 per cent increase in GDP per capita.

Figure 2:
Real GDP Per Capita* and Patent in Force per Capita OECD Countries**



* In US$ based on prices and PPPs in 1990
** Excluding Italy and the U.K. for whom the data on patents in force are not available
Source: Industry Canada compilations based on data from the U.N.

The Canadian Evidence

Across Canadian manufacturing industries, we looked at the relationship between two measures of productivity (labour productivity and total factor productivity (TFP) growth), and at three key drivers of innovation: investment in research and development, investment in machinery and equipment and human capital. Table 1 shows that all three indicators of innovative activity are positively correlated with labour productivity levels and TFP growth across Canadian manufacturing industries. However, multiple regression analysis indicated that the relationship between these three innovation drivers and the two productivity measures is significantly weaker across Canadian manufacturing industries than across the U.S. industries.

Table 1:

Correlation Coefficients between Innovative Activity and Productivity in Canada

Innovation Drivers	Average Labour Productivity (Log GDP per employed person)	Innovation Drivers	TFP Average Growth
R&D spending per worker	0.35	R&D intensity*	0.31
M&E spending per worker	0.63	M&E intensity*	0.33
Average share of workers with University degrees	0.43	Average share of workers with University degrees	0.44

* R&D intensity refers gross expenditure on R&D/GDP and M&E intensity refers to investment in M&E/GDP

Table 2:

Correlation Coefficients between Innovative Activity and Productivity in the United States

Innovation Drivers	Average Labour Productivity (Log GDP per employed person)	Innovation Drivers	TFP Average Growth
R&D spending per worker	0.61	R&D intensity*	0.22
M&E spending per worker	0.73	M&E intensity*	0.20
Average share of workers with University degrees	0.70	Average share of workers with University degrees	-0.02

The U.S. Evidence

The correlations between the three innovation variables and labour productivity levels in the U.S. manufacturing industries are positive and significantly stronger than in Canada (Table 2). However, the correlations between the innovation variables and TFP growth in the U.S. is much weaker. This discrepancy is further reinforced by the results of the regression analysis across U.S. manufacturing industries. While the innovation indicators jointly explain about 84 per cent of cross industry variation in labour productivity levels, they explain almost none of the variation in TFP growth across U.S. manufacturing industries. The U.S. regression results indicate that M&E investment has the strongest impact on labour productivity of any of the innovation inputs. In the United States, a 10 per cent increase in M&E nvestment is associated with a 4.3 per cent increase in labour productivity, while a 10 per cent increase in human capital leads to only a 0.3 per cent increase in labour productivity.[1]

Key Drivers of Innovation

Fundamental Innovation

In this subsection, we investigate the relationship between fundamental innovation and a number of characteristics of the business environment thought to enhance innovation. Common proxies for fundamental innovation are R&D intensity, R&D personnel per capita and patents in force per capita. As expected, the three measures of fundamental innovation are highly correlated among themselves (Table 3). Further, they are highly correlated with a number of business framework variables: intellectual property protection, quality of financial services, financial resources for technological development, openness of the domestic economy, quality of technological and general infrastructure and quality of management (Table 4). However, regression results show that R&D personnel per capita, the strength of intellectual property rights and technological infrastructure are the only significant determinants of R&D intensity. These three, plus strength of the domestic economy, are significant determinants of per capita patents in force.

Applied Innovation

Applied innovation occurs when an advanced technology is applied in the production process. We looked at two measures of applied innovation: the use of specialized robots in manufacturing and internet users per capita. The two proxies for applied innovation are positively correlated with R&D intensity, research personnel and investment in related equipment (Table 5). In the multiple regression analysis, ICT investment intensity and number of researchers per capita are jointly significant determinants of the number of internet users per capita.

Canada's Innovation Record

The level of innovation in Canada lags behind the United States on most of the key indicators, and lags behind other G7 economies on many variables (Table 6). Canada's gross domestic expenditure on research and development is below all G7 countries, with the exception of Italy. Canadians register a much lower number of patents per capita in the United States than either the Americans or Japanese. Similarly, Canada's expenditure on M&E as a percentage of GDP is the lowest in the G7. However, Canada's performance is better when investment in ICT as a percentage of GDP is compared across the G7; Canada ranks third on this measure, just below the U.S. Further, Canada does have a higher proportion of R&D personnel than the United States, but it still only ranks 4th among the G7.[2]

Table 3:
Correlation between Input and Output Measures of Innovation in OECD Countries

Input measures	Output measure: Log (US Patents Granted per million inhabitants)
R&D intensity*	0.80
Log (R&D personnel /1000 population)	0.77

* R&D intensity refers to gross expenditure on R&D/GDP

Table 4:
Correlation Coefficients between Fundamental Innovation and the Business Framework[a]

Business Framework Variables[b]	R&D intensity	Patents in force per 1000 residents (log values) variables
Intellectual property rights	0.67	0.76
Strength of the domestic economy	0.56	0.50
Internationalization	0.42	0.60
Finance	0.59	0.80
Technology infrastructure	0.70	0.68
Quality of Management	0.53	0.70
General infrastructure	0.72	0.83
Financial resources for technology	0.74	---

a Correlations are calculated across the 47 developed and developing countries for which the IMD World Competitiveness Yearbook tabulates data.

b The definition and source of the business framework variables are as follows: Intellectual property rights — index out of five based on evaluation of national patent laws, (Ginarte and Park, 1997); Strength of the domestic economy — macro-economic evaluation of the domestic economy, *World Competitiveness Yearbook* (WCY) 1999; Internationalization — Extent to which the country participates in international trade and investment, WCY 1999; Finance — performance of capital markets and quality of financial services, WCY 1999; Technology infrastructure — availability and penetration of new technology infrastructure and communications investment, WCY 1999; Quality of management — extent to which companies are managed in an innovative, profitable and responsible manner, WCY 1999; General infrastructure — extent to which natural, technical and communications resources are adequate to serve the basic needs of business, WCY 1999; Financial resources for technology — extent to which lack of sufficient financial resources constrains technological development, WCY 1999.

Table 5:
Correlation Coefficients between Applied Innovation and Selected Determinants in OECD Countries

Drivers of Applied Innovation	Use of Specialized robots in manufacturing (log robots/10000 Manufacturing workers)	Drivers of Applied Innovation	Internet Use (log Internet users/1000 inhabitants)
R&D intensity*	0.75	R&D intensity*	0.33
Log (Researchers/ 10,000 labour force)	0.71	Log (R&D personnel / 1000 population)	0.50
M&E intensity*	0.31	ICT intensity*	0.65

* R&D intensity refers gross expenditure on R&D/GDP, M&E intensity refers to investment in M&E/GDP and ICT intensity refers to investments in hardware and software (information and communications technology)/GDP.

There is, however, some evidence that Canada's innovation levels are slowly catching up with those in the United States and other G7 economies. The innovation gap measured by GERD/GDP has narrowed between 1990 and 1997; Canada's R&D intensity grew at 1.4 per cent per annum, while the other G7 economies experienced a decline. Similarly, the M&E intensity grew faster than all other G7 economies, excepting the United States, and Canada tied with Italy with the fastest growing ICT intensity. Further Canada experienced the fastest average annual percentage growth in patents granted in the United States between 1992 and 1997. Nevertheless, Canada ranked behind the United States, France and Italy in the average annual percentage growth of R&D personnel per capita. Overall, the progress on the innovation front bodes well for future productivity performance.

Another mitigating factor is Canada's openness to international trade and investment. With a lower capacity for domestic fundamental innovation than most of the G7, it is important that Canada be open to the diffusion of innovation and knowledge developed elsewhere. In this respect, Canada has the highest trade openness of any G7 country, and is second only to the United States in FDI openness. However, Canada's international linkages are dominated by its economic relations with the United States.[3] Further, Canada trails the United States in all the key determinants of a healthy business climate: intellectual property protection, strength of the domestic economy, quality of financial institutions and quality of management.

The Role of Government[4]

The existence of R&D spillovers, economies of scale in innovation and information asymmetries between the producers and users of innovation leads to sub-optimal investment in private markets. Governments can play a significant role in addressing market failures, encouraging private sector innovation and stimulating communications networks within and between nations. This is particularly true for small open economies like Canada where small and medium sized companies have difficulty bringing innovations to market, and thus rely heavily on the international diffusion of new technologies.

Government innovation policy can take three major forms. First, the promotion of fundamental and applied innovation can be achieved by having a competitive business framework via a balanced approach to the IP regime, through tax

Table 6:

Innovation Performance of the G7 Economies: Selected Indicators

Indicator[a]	Canada	France	Germany	Italy	Japan	US	UK
GERD/GDP, 1997 (per cent)	1.6	2.2	2.3	1.1	2.9	2.7	1.9
Average annual per cent growth of GERD/GDP ratio, 1990-1997	1.4	-1.3	-2.9	-3.0	-0.7	-0.6	-2.5
Average patents granted to foreigners in the U.S., per 100,000 inhabitants, 1992-97	8.6	5.4	9.5	2.3	20.3	25.6	4.8
Average annual per cent growth of patents granted in the U.S., 1992-1997	6.4	1.9	3.8	1.9	3.8	5.2	5.4
R&D personnel total economy, per 1000 population, 1997	4.4	5.5	5.6	2.5	7.1	3.7	4.8
Average annual per cent growth of R&D personnel nationwide per capita, 1989-1997	1.2	1.3	-1.8	1.3	1.0	1.7	0.4
M&E/GDP, 1998 (per cent)	8.5	8.6	9.1	10.8	—[b]	11.3	10.4
Average annual per cent growth of real M&E/GDP ratio, 1990-1998	4.8	-0.6	-1.7	0.1	—	4.9	1.7
ICT Expenditure on hardware, software and telecommunications (per cent of GDP), 1997	7.5	6.4	5.6	4.3	7.4	7.8	7.6
Average annual per cent growth of ICT intensity, 1992-1997	2.6	2.3	1.5	2.6	6.1	1.6	2.0
Exports plus imports of goods and services/GDP, 1998 (per cent)	81.2	49.3	55.7	48.7	20.4	24.3	54.2
Inward and outward FDI stock/GDP, 1997 (per cent)	45.6	23.7	24.3	18.0	7.1	19.0	50.6
Strength of patent rights (out of 5), 1995	3.2	4.0	3.8	4.2	3.9	4.9	3.6
Strength of the domestic economy (out of 100), 1999	61.5	60.6	62.4	57.1	54.1	93.5	56.5
Quality of management (out of 100), 1999	67.7	55.9	62.4	52.7	53.5	78.2	60.6
Finance (out of 100), 1999	66.2	61.5	69.4	54.1	57.1	85.3	65.3

a The source of the innovation indicators are as follows: GERD/GDP — OECD, EAS (MSTI Database) and Science Technology and Industry Outlook 1998, OECD ; Patents in the U.S. per 100,000 inhabitants — Trajtenberg (2000); R&D personnel nationwide per capita — Science Technology and Industry Outlook 1998, OECD; M&E/GDP — OECD ; ICT Expenditure on Hardware, software and Telecommunications — OECD Science, Technology and Industry Scoreboard 1999, obtained from ADB database and World Information Technology Services Alliance (WITSA)/ International Data Corporation (IDC), 1998; Exports plus imports of Goods and services/GDP — World Investment Report 1999, Foreign Direct Investment and the Challenge of Development, United Nations; Inward and outward FDI stock/GDP — World Investment Report 1999, Foreign Direct Investment and the Challenge of Development, United Nations. The definition and source of the business framework variables are as follows: Intellectual property rights — index out of five based on evaluation of national patent laws, Ginarte and Park (1997); Strength of the domestic economy — macro-economic evaluation of the domestic economy, World Competitiveness Yearbook (WCY) 1999; Finance — performance of capital markets and quality of financial services, WCY 1999; Quality of management — extent to which companies are managed in an innovative, profitable and responsible manner WCY 1999.

b Available data for Japanese M&E investment is not comparable to the other G7 countries due to national differences in the classification of investment.

incentives, through research subsidies, by undertaking public sector R&D, and by helping firms, especially SME's, with the adoption and diffusion of new technologies. Second, the government can facilitate a well functioning national innovation system by investing in knowledge infrastructure to facilitate the development and flow of knowledge among universities, firms and government labs. Finally, governments could develop micro-economic frameworks that facilitate the international transfer of technologies and knowledge, remove barriers to commercialization of innovations and the application and diffusion of new knowledge and technologies, and encourage market forces to reallocate resources from less to more innovative activities.

The Canadian government has undertaken several initiatives to encourage R&D spending, to stimulate innovation, to facilitate the creation, diffusion and use of knowledge, to promote commercialization of innovations in Canada and to encourage the adoption and diffusion of new technologies. These measures include generous R&D tax incentives, the Canadian Foundation for Innovation, the Canadian Institute of Health Research, the Network of Centres of Excellence, the Industrial Research Assistance Program (IRAP), Technology Partnership Canada, Investment Partnerships Canada, School Net/CAP, Canada Research Chairs, etc. In addition, in the recent Throne speech, the federal government has announced its commitment to double federal R&D spending by 2010. Furthermore, recent fiscal measures will make the Canadian tax system more competitive and encourage innovation and risk taking in Canada.

In short, the Canadian government has been active in promoting innovation and facilitating the diffusion of new knowledge and technologies, and encouraging commercialization of innovations in Canada. Canada, however, needs to pay more attention to education and training needs of the knowledge-based economy, invest more in R&D and machinery and equipment. Further, Canada's business framework and the regulatory system should be flexible, dynamic and competitive vis-a-vis other OECD countries, especially the United States.

Notes

* This article is based on a longer paper by the same name, forthcoming in the Industry Canada Research Volume *Productivity Issues in a Canadian Context*. The reader should refer to the complete paper for more details and a complete presentation of the empirical results. The views expressed in this paper are of the authors only and do not reflect in any way those of either Industry Canada or the Government of Canada. Email: rao.someshwar@ic.gc.ca.

1 The regression coefficient on R&D intensity is negative, though this is likely an artifact of the high levels of multicollinearity between the innovation inputs.

2 However, Canada ranks 6th in the G7 for the total R&D personnel in business per capita, only ahead of the United Kingdom.

3 In spite of our high trade openness, Canada was ranked 24th out of 47 countries on internationalization by the 1999 World Competitiveness Yearbook, partly because of our poor export market diversification (the heavy reliance on the U.S. market), the lower share of trade in commercial services in total trade and slower growth in FDI relative to the other countries ranked.

4 Policy approaches for dealing with Canada's poor innovation performance are discussed in Hirshhorn, Nadeau and Rao (forthcoming).

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