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INFORMATION TECHNOLOGY AND LABOUR PRODUCTIVITY GROWTH: AN EMPIRICAL ANALYSIS FOR CANADA AND THE UNITED STATES

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ABSTRACT

To what extent have investments in information technology (IT) contributed to labour productivity growth? Are domestic and international R&D spillovers from the IT sector important for labour productivity growth? In this paper, we examine these questions for Canada and the United States, using a set of OECD databases. We conclude as follows: First, IT investments are an important source of labour productivity growth across Canadian industries. Second, R&D spillovers in Canada are primarily international in scope. Third, in terms of the impact of international R&D spillovers on productivity growth, those emanating from IT imports are much more important than those from non-IT imports. Finally, IT investments and international R&D spillovers embodied in IT imports have positive and significant impact on labour productivity growth across U.S. industries, but the results are less robust than those for Canada.

1. INTRODUCTION

> *"If the car had developed at the same pace as microprocessors over the past two decades, a typical car would now cost less than $5 and do 250,000 miles to the gallon".*
>
> *The Economist*, September 28, 1996

Over the past two decades, the use of information technology (IT)[1] has become more intensive in most industrialized economies, as spending on IT-related goods has increased dramatically. All sectors of the economy are experiencing significant changes in the way goods and services are produced and delivered as a result of the increased diffusion and use of information technologies. In particular, many services such as finance, insurance, and real estate; wholesale and retail trade; and communication and business services have emerged as major users of these technologies. Two inter-related forces have contributed to these developments. First, communications and information processing costs have fallen dramatically – they are now 1/10,000 of what they were just 20 years ago – and this has spurred and deepened globalization. Second, globalization, in turn, has advanced technological change by intensifying competition and expediting the diffusion of technology through international trade and foreign direct investment (FDI).

In a parallel development, overall productivity growth in OECD economies has slowed significantly since the early 1970s. The decline has been especially noticeable in the service sector, which consumes over 80 percent of IT goods. This has raised numerous questions about the implications of IT investments for productivity growth.

On a theoretical front, new growth theory predicts that physical investments should have a greater impact on productivity growth than traditional growth accounting would suggest, due to positive externalities associated with such activities. In the contributions of Romer (1986), and Grossman and Helpman (1991), these externalities arise because of "knowledge spillovers" – increases in physical investments of profit-seeking firms contribute to the general stock of knowledge upon which subsequent firms can build. In De Long and Summers (1991), investment externalities arise as a result of the "learning by doing effect" – workers and managers learn new skills and more efficient methods of production by using newly installed equipment. These models suggest that the IT sector, which has been one of the most technologically dynamic sectors of the economy over the last 20 years, is likely to have a greater impact on productivity growth than other sectors.

Until recently, however, there has been little empirical evidence that IT capital has contributed to increases in output and productivity growth,[2] and this has led to a heated debate about the "productivity paradox" (see, for example, Brynjolfsson, 1992, Meijl, 1995, and the next section of this paper for a review). In this connection, two recent studies carried out on U.S. data deserve specific mention. Berndt and Morrison (1995) examined the impact of investments in high-tech office and information technology capital on productivity growth across two-digit manufacturing industries from 1968 through 1986. They found that increases in high-tech investments are negatively correlated to multi-factor productivity growth and they tend to be labour-using. However, they did find some evidence that industries with a higher proportion of high-tech capital had higher measures of economic performance. In contrast, Brynjolfsson and Hitt (1995) argued that IT has become a productive investment for many firms. Using data from a large number of firms over the 1988-92 period, they found that while "firm effects" may account for as much as one-half of the productivity benefits imputed to IT in earlier studies, the elasticity of IT remains positive and statistically significant.

None of these studies took account of domestic and international R&D spillovers from the IT sector when analysing the relationship between IT investment and labour productivity growth.[3] Omitting this variable for a small open economy such as Canada's, which relies a great deal on international trade and FDI, could potentially bias the results. Indeed, Bernstein (1996*a*, *b*) confirmed the importance of international spillovers to Canada. His study found that many Canadian industries benefited from R&D carried out in the United States. Some recent studies have also found evidence of domestic and international R&D spillovers from the IT sector (see for example, Bernstein, 1996*b*; Meijl, 1995, and Sakurai *et al.*, 1996).

In the spirit of these studies, we derive an empirical framework that allows us to estimate the relationship between IT investment and labour productivity growth for Canada and the United States. The framework also takes into account R&D spillovers from IT and non-IT sectors from foreign and domestic sources.

The aim of this paper is twofold:

- to examine the relationship between IT investment and labour productivity growth; and
- to examine the importance for labour productivity growth of domestic and international R&D spillovers embodied in IT goods.

The paper examines these issues using a set of OECD industry databases for Canada and the United States. We find strong support for the proposition that IT investments and international R&D spillovers, particularly those embodied in imports of IT goods, contribute to higher labour productivity growth in Canadian industries. However, the results are generally less robust for the United States.

The paper proceeds with a brief review of earlier literature. In Section 3, we describe the empirical model used in our estimation. Section 4 presents a general overview of the data and general trends. In Section 5, we present regression results for both Canada and the United States. Finally, in the last section, we offer some conclusions and discuss policy issues raised by the analysis.

2. LITERATURE REVIEW

In this section, we provide a brief overview of some of the most recent empirical studies which have focused on the issues that are of interest to this paper. These include the relationship between investments in IT and productivity growth, and the importance of domestic and international R&D spillovers for productivity growth.

IT and Productivity[4]

Until recently, there has been little evidence at the industry level that IT has contributed to increases in productivity growth. The following studies in particular deserve mention.

Morrison and Berndt (1991) using a series of highly parametric models of production, analyzed two-digit U.S. manufacturing industries over the period 1968-86. They found that the marginal benefits of high-tech capital investments were less than marginal costs, indicating a general over-investment in IT. A subsequent study (Berndt and Morrison, 1995), using many of the same data, took a less structured approach and examined broad correlations of IT with two measures of productivity (labour and multi-factor productivity), as well as other variables. The authors found that there is a statistically significant negative relationship between productivity growth and the IT intensity of the capital stock based on a time-series analysis.[5] However, the authors suggested that the negative relationship may be due to possible measurement problems resulting from failures to account properly for quality changes in output.

In contrast, Siegel and Griliches (1991) found a positive and statistically significant relationship between total factor productivity growth and an industry's rate of investment in computers in the 1980s. However, they did raise concerns about the reliability of the data.

A number of recent empirical studies based on firm-level data have also confirmed a positive and statistically significant relationship between IT and productivity. Brynjolfsson and Hitt (1995) used a data set of the 300 largest firms in the U.S. economy over the time period 1988-92 and introduced three novel features in their estimation methodology: (1) it controlled for individual firms' differences in productivity by employing a "firm effects" specification; (2) it used the less restrictive translog production function instead of only the Cobb-Douglas specification; and (3) it allowed all parameters to vary between various sub-sectors of the economy. The study found that the elasticity of IT remains positive and statistically significant. Furthermore, "firm effects" were found to be highly significant. The authors suggested that these effects may account for as much as half of the productivity benefits imputed to IT in the earlier studies. Lichtenberg (1993) obtained similar results using the same data as well as some additional data sets. In fact, the study found that the marginal product of IT was at least six times as great as the marginal product of other types of capital.

In contrast, Loveman (1994) estimated a Cobb-Douglas production function using a data set which covered 60 business units of large firms from 1978-84 and found no evidence of strong productivity gains from IT investments.

To summarize, the findings of empirical studies on IT and productivity carried out on the industry-level data appear to be somewhat mixed. However, improved firm-level studies such as Brynjolfsson and Hitt (1995) suggest a positive relationship between IT and productivity growth in the United States.

Domestic and International R&D Spillovers and Productivity Growth[6]

The empirical literature on domestic and international R&D spillovers is voluminous, reflecting the important role played by this factor in economic growth. Rather than review a large number of studies, our objective is to concentrate on very recent studies, in particular those focusing on domestic and international spillovers, which are most relevant to our study.

Coe, Helpman and Hoffmaister (1997) examined the relative strength of R&D spillovers from industrial countries in the North to developing countries in the South. The data cover observations over the 1971-90 period for 77 developing countries and 22 industrial countries. The paper builds on the thesis that international trade with an industrial country plays an important role as a transmission channel for R&D spillovers to the less developed countries. The authors found that R&D spillovers from the North to the South are significant and substantial. For example, an addition of 100 U.S. dollars to either the U.S. or Japanese domestic R&D capital stock raises total GDP in the developing countries, as a group, by almost 25 dollars.

Earlier, Coe and Helpman (1995) had also measured international R&D spillovers using country-level data. This study estimated the effects of a country's own R&D capital and its imported R&D capital on total factor productivity. The study found evidence of strong and significant international R&D spillovers. It also found that the output elasticity of international R&D spillovers is virtually identical to that of domestic R&D. Furthermore, it found that the impact of foreign R&D increased over time and was greater in smaller countries.

A recent study (Branstetter, 1996) has highlighted important shortcomings in these studies in their estimation of the effects of domestic and international R&D spillovers. This study provides estimates of the impact of intranational and international R&D spillovers on innovation and productivity at the firm level, using previously unexploited panel data in five R&D-intensive sectors in the United States and Japan. The study finds robust evidence that intranational spillovers are stronger than international spillovers. A major feature of the study is that it measures R&D spillovers by identifying the technological closeness of firms as suggested in earlier studies by Griliches (1979) and Jaffe (1986). Technological closeness of firms is essentially a measure of similarity in the distribution of firms' research efforts across various technological fields. In general, a firm will receive more R&D spillovers from other firms with research programs similar to its own.[7]

Until recently, very few studies have assessed the effect of international R&D spillovers from the IT sector on productivity growth. Building on the methodology of Coe and Helpman (1995), a recent OECD study (Sakurai *et al.*, 1996) examined the relationship between R&D, technology diffusion, and productivity growth for ten OECD countries. The study found that the IT cluster of industries played a major role in the generation and acquisition of new technologies. In particular, the IT service sector in Canada and small European economies has posted higher gains from international R&D spillovers than from domestic ones, while domestic R&D was more important in the United States, Japan and Germany.

In addition, Meijl and Soete (1995) and Meijl (1995) examined the diffusion of technology through the purchase of IT goods in French industries over the 1978-92 period. The studies found that IT-related spillovers were important for productivity growth and that the measured influence increased rapidly over time.

Finally, Bernstein (1996) estimated the contribution of R&D spillovers from the Canadian communications equipment industry and the U.S. manufacturing sector to productivity growth in the Canadian manufacturing sector over the 1966-91 period. The study found: 1) the R&D spillovers from the communications equipment industry have contributed significantly to productivity growth in the manufacturing sector – about 8.5 percent of the average annual rate of productivity growth in manufacturing resulted from spillovers from the communications equipment industry; 2) this contribution increased during the post-1973 period when the productivity slowdown occurred; 3) the R&D spillovers from the U.S. manufacturing sector were the major contributor in this regard - accounting for 76 percent of the average annual rate of productivity growth in Canadian manufacturing; and 4) the social rate of return pertaining to Canadian communications equipment R&D capital is estimated at 55 percent.

3. EMPIRICAL FRAMEWORK

In this section, we first present the empirical model used to estimate the effect of IT investments and R&D embodied in IT goods on labour productivity growth across Canadian and U.S. industries. Later, we discuss the methodology used to construct R&D spillover variables.

Empirical Model

We assume that the production process is modeled by a Cobb-Douglas production function that distinguishes between own R&D and R&D embodied in purchases of domestic and imported goods and services. Specifically, the output of industry i (Y_i) is related to labour input (L_i), IT capital (K_{1i}), non-IT capital (K_{2i}), own R&D capital (R_i), R&D capital embodied in purchases of domestic goods and services (S_{di}), and R&D capital embodied in imports (S_{fi}):

$$(1) \qquad Y_i = L_i^{\alpha_1} K_{1i}^{\alpha_2} K_{2i}^{\alpha_3} R_i^{\alpha_4} S_{di}^{\alpha_5} S_{fi}^{\alpha_6} e^{\alpha_0 t},$$

where α_1, α_2 and α_3 are the output elasticities of labour input, IT capital and non-IT capital, respectively;[8] α_4, α_5 and α_6 are the output elasticities of own R&D capital, R&D capital embodied in purchases of domestic goods and services, and R&D capital embodied in imports respectively; and α_0 represents the rate of pure technical change.

From Equation (1), we can derive the following equation that expresses the labour productivity growth rate of industry i as a function of the growth rate of labour input and investment rates in various types of capital:[9]

$$(2) \quad \left(\frac{\dot{y}}{y}\right)_i = \beta_0 + \beta_1\left(\frac{\dot{L}}{L}\right)_i + \beta_2\left(\frac{\dot{K}_1}{Y}\right)_i + \beta_3\left(\frac{\dot{K}_2}{Y}\right)_i + \beta_4\left(\frac{\dot{R}}{Y}\right)_i + \beta_5\left(\frac{\dot{S}_d}{Y}\right)_i + \beta_6\left(\frac{\dot{S}_f}{Y}\right)_i + \varepsilon_i,$$

where $(\dot{y}/y)_i$ is the labour productivity growth of industry i; $(\dot{L}/L)_i$ is the growth rate of the labour input of industry i; $\dot{K}_{1i}$ is the net investment in IT physical capital; $\dot{K}_{2i}$ is the net investment in non-IT physical capital; $\dot{R}_i$ is the net investment in own R&D capital; $\dot{S}_{di}$ is the net investment in R&D capital embodied in purchases of domestic goods and services; $\dot{S}_{fi}$ is the net investment in R&D capital embodied in purchases of imports; and ε_i is an error term.

In Equation (2), the coefficients β_2 through β_6 represent the rates of return on various types of capital and spillovers; β_0 is the rate of pure technical change; finally, β_1 represents the output elasticity of labour input minus one or ($\alpha_1 - 1$).

Measurement of R&D Spillovers

Here, we discuss the methodology used to construct R&D spillover variables. Following Griliches (1979), we assume that R&D expenditure is a proxy for technology. Here, we also assume that industry transaction flows act as carriers of technology as in Sakurai *et al.* (1996).

The R&D embodied in purchases of domestic goods and services by industry i is calculated as a weighted sum of R&D intensities across all industries, with the weights being the amount of goods and services industry i purchased from other industries. Let $\dot{R}_j$ denote real R&D expenditures of industry j, Y_j its output, and X_{ji} the amount of domestically produced goods and services industry i purchased from industry j. The R&D spillover – R&D embodied in purchases of domestic goods and services ($\dot{S}_{di}$) – can be specified as[10]

$$(3) \qquad \dot{S}_{di} = \sum_j X_{ji} \left(\frac{\dot{R}}{Y} \right)_j .$$

Next, we extend Equation (3) by distinguishing between R&D embodied in purchases of domestic IT goods and non-IT goods and services. For example, R&D embodied in purchases of domestic IT goods by an industry is calculated as a weighted sum of R&D intensities in domestic IT goods-producing industries, where the weights are purchases of domestic IT goods.

Similarly, R&D embodied in imports of industry i, $\dot{S}_{fi}$ in Equation (2) is calculated as the weighted sum of foreign R&D intensities, where the weights are purchases of imports,

$$(4) \qquad \dot{S}_{fi} = \sum_j \sum_k M_{ji} \alpha_{jk} \left(\frac{\dot{R}}{Y} \right)_{jk} ,$$

and M_{ji} is the total amount of goods (or services) j imported by industry i, α_{jk} is the import share of country k for goods (or services) j, $M_{ji}\alpha_{jk}$ is the amount of goods (or services) j industry i imported from country k, and $\left(\dot{R}/Y\right)_{jk}$ is the R&D investment rate of the industry producing goods (or services) j in country k.

A key assumption underlying our estimation of R&D embodied in purchases of imports is the "import proportionality" assumption. What we observe from the data (OECD's Bilateral Trade Database) is the country's import share of a good by country of origin. This import share is assumed to be the same across all industries. For example, if 80 percent of Canadian computer imports come from the United States, it is assumed that imported computers from the United States account for 80 percent of all computers used in all Canadian industries.

Subsequently, we use Equation (4) to separate out R&D embodied in IT imports and non-IT imports.

In this paper, the sources of international R&D spillovers for Canada are assumed to be other G-7 countries (the United States, Japan, the United Kingdom, Germany, France, and Italy). The G-7 countries account for the bulk of R&D performed in the world and are the most technologically advanced countries.[11]

4. THE DATA AND TRENDS[12]

The data used for our empirical analysis are mainly drawn from a number of OECD databases:[13] the International Sectoral Database (ISDB) and the Industrial Structural Analysis (STAN) Database, the Input-Output Database (IOD), the Analytical Database of Business Enterprise R&D (ANBERD) and the Bilateral Trade Database (BTD). First, the Industrial STAN database and the ISDB are used to compute labour productivity for manufacturing and services industries, respectively. Second, input/output tables from the IOD are used to calculate gross IT and non-IT investments. Note that we identify "computers and office machinery" and "communications equipment" as IT (producing) industries and the rest as non-IT industries. Third, intramural R&D expenditures performed by the business sector are obtained from the ANBERD. The IOD together with the ANBERD are used to construct R&D embodied in purchased domestic goods and services. At the same time, imports from the BTD, the IOD and the ANBERD are used to calculate R&D embodied in imported goods and services.

There are, however, two potential problems associated with input/output tables. First, domestic investment flow sub-matrices are available only as gross capital flows and not as net capital flows. Thus, we are limited to using gross IT and non-IT investment data although the net measures would have been preferable. Second, these tables are available only in current prices for the United States. Thus, we were able to carry out our analysis using only nominal investment and R&D data for the United States.[14]

We now turn to an overview of summary statistics and notable trends. We begin with labour productivity.

Labour Productivity Growth

Table 1 presents average annual labour productivity growth by industry for Canada and the United States for the 1971-93 period.[15] Labour productivity of an industry is calculated as the ratio of real value added to total employment where total employment includes the number of employees as well as the self-employed and owner proprietors. There are two notable trends: First, in the United States, both IT producing industries – computers and office machinery and communications equipment – recorded the highest average annual labour productivity growth over the sample period. Second, in Canada, only the office and computing machinery industry experienced the fastest labour productivity growth, while the communications equipment industry lagged behind drugs and medicine; non-ferrous metals; shipbuilding and other transportation equipment industries.

IT Investment

As depicted in Table 2, from 1971 to 1990, the real IT investment rate in Canada[16] rose in twenty three of the twenty six manufacturing and services industries while the real non-IT investment rate increased in only seven industries. The increases from 1971 to 1990 were 300 percent for total manufacturing and 150 percent for total services.

Table 1
Average Annual Labour Productivity Growth for Canada and the United States, 1971-93

ISIC Rev. 2	Canada	United States
1. Food, beverages & tobacco	0.97	1.75
2. Textiles, apparel & leather	2.54	2.88
3. Wood products & furniture	1.00	0.76
4. Paper & printing	0.77	0.31
5. Industrial chemicals[1]	2.65	3.24
6. Drugs and medicine	3.80	...
7. Petroleum & coal products	2.44	0.91
8. Rubber & plastic products	1.33	1.32
9. Non-metallic mineral products	1.02	1.54
10. Iron & steel	2.30	1.62
11. Non-ferrous metals	3.92	0.33
12. Metal products	1.10	1.61
13. Non-electrical machinery	0.70	2.65
14. Office & computing machines	18.74	7.78
15. Electric apparatus, nec	2.15	4.11
16. Communication equipment	3.34	5.36
17. Shipbuilding & repairing	5.25	1.29
18. Other transport	4.37	3.32
19. Motor vehicles	2.21	0.44
20. Aircraft	1.82	0.98
21. Professional goods	...	1.35
22. Other manufacturing[2]	0.53	1.50
Total manufacturing	**1.80**	**1.98**
23. Electricity, gas & water	1.68	0.95
24. Wholesale & retail trade[3]	0.66	1.33
25. Transport & communication	3.17	2.72
26. FIRE & business services	0.72	-0.94
27. Social & personal services	-0.35	-0.47
Total services	**1.13**	**0.47**
28. Construction	0.47	-1.24
Total business sector[4]	**1.24**	**0.86**

1 The industrial chemicals industry includes drugs and medicine for the United States.
2 Other manufacturing includes professional goods for Canada.
3 Includes restaurants and hotels.
4 Here, the total business sector is defined to include manufacturing, services and construction industries.

The share of IT investment across industries has increased in the last two decades, as shown in the final column of Table 2. In particular, the share of IT investment in total investment increased by about five percentage points in nine industries over the period 1971-90.

Table 2
Summary Statistics on IT and non-IT Real Gross Investment for Canada, 1971 and 1990

	IT Investment Rate (%)		Non-IT Investment Rate (%)		Share of IT Investment (%)	
ISIC Rev. 2	**1971**	**1990**	**1971**	**1990**	**1971**	**1990**
1. Food, beverages & tobacco	0.13	0.81	14.55	11.37	0.91	6.64
2. Textiles, apparel & leather	0.15	0.47	17.61	8.52	0.82	5.26
3. Wood products & furniture	0.11	0.17	23.67	10.43	0.45	1.61
4. Paper & printing	0.26	0.75	38.00	37.08	0.67	1.99
5. Industrial chemicals[1]	0.32	2.08	29.73	24.93	1.06	7.72
6. Drugs and medicine	0.31	0.82	21.44	9.48	1.44	7.96
7. Petroleum & coal products	0.06	2.32	72.56	37.30	0.08	5.86
8. Rubber & plastic products	0.15	1.48	36.33	26.92	0.41	5.19
9. Non-metallic mineral products	0.12	0.83	17.54	18.74	0.67	4.24
10. Iron & steel	0.29	0.42	41.81	26.59	0.68	1.54
11. Non-ferrous metals	0.36	0.95	47.18	58.94	0.76	1.59
12. Metal products	0.19	0.19	15.34	7.11	1.23	2.67
13. Non-electrical machinery	0.16	0.84	8.15	9.49	1.94	8.17
14. Office & computing machines	...	1.71	159.10	7.11	...	19.38
15. Electric apparatus, nec	0.27	1.65	16.90	6.97	1.55	19.19
16. Communication equipment	0.15	1.43	12.53	6.04	1.20	19.14
17. Shipbuilding & repairing	1.33	0.30	41.83	9.51	3.08	3.03
18. Other transport	0.53	0.12	20.05	4.67	2.60	2.50
19. Motor vehicles	0.26	0.49	11.55	12.35	2.22	3.81
20. Aircraft	0.23	0.31	6.32	8.80	3.57	3.45
21. Other manufacturing[2]	0.07	0.52	9.11	4.13	0.75	11.22
Total manufacturing	**0.20**	**0.84**	**23.95**	**18.28**	**0.84**	**4.41**
22. Electricity, gas & water	1.45	6.03	124.83	57.96	1.15	9.42
23. Wholesale & retail trade[3]	0.64	1.15	16.12	5.51	3.79	17.26
24. Transport & communication	6.00	7.53	59.50	18.19	9.16	29.27
25. FIRE & business services	0.07	1.11	7.54	8.74	0.89	11.23
26. Social & personal services	0.78	7.48	13.97	24.97	5.28	23.04
Total services	**1.25**	**3.11**	**26.03**	**14.07**	**4.58**	**18.11**
27. Construction	0.03	0.22	9.51	5.53	0.30	3.81
Total business sector[4]	**0.80**	**2.31**	**23.83**	**14.37**	**3.26**	**13.84**

1 The industrial chemicals industry includes drugs and medicine for the United States.
2 Other manufacturing includes professional goods for Canada.
3 Includes restaurants and hotels.
4. Here, the total business sector is defined to include manufacturing, services and construction industries.

In the service sector, the increase is more dramatic – from 4.6 percent in 1971 to18.1 percent in 1990. When we examine the gross investment data in nominal terms, the increasing trends in IT investment become less pronounced (see Table 3). This is so because the investment data in nominal terms do not take into account quality improvements in computers.

Table 3
Summary Statistics on IT and non-IT Nominal Gross Investment for Canada, 1971 and 1990

	IT Investment Rate (%)		Non-IT Investment Rate (%)		Share of IT Investment (%)	
ISIC Rev. 2	**1971**	**1990**	**1971**	**1990**	**1971**	**1990**
1. Food, beverages & tobacco	0.35	0.42	10.51	9.71	3.21	4.11
2. Textiles, apparel & leather	0.25	0.28	7.04	7.64	3.48	3.51
3. Wood products & furniture	0.17	0.12	14.64	10.45	1.16	1.10
4. Paper & print	0.44	0.41	25.75	32.10	1.69	1.25
5. Industrial chemicals[1]	0.54	1.31	16.81	23.88	3.09	5.19
6. Drugs and medicine	0.47	0.55	11.32	9.10	4.00	5.66
7. Petroleum & coal products	...	2.20	85.69	62.81	...	3.38
8. Rubber & plastic products	0.19	0.72	17.80	21.38	1.06	3.27
9. Non-metallic mineral products	0.27	0.44	11.40	16.93	2.30	2.56
10. Iron & steel	0.41	0.31	25.19	30.25	1.59	1.01
11. Non-ferrous metals	0.43	0.63	27.50	63.49	1.53	0.98
12. Metal products	0.24	0.12	8.43	6.72	2.73	1.75
13. Non-electrical machinery	0.31	0.45	4.42	7.92	6.56	5.43
14. Office & computing machines	...	2.07	9.05	13.43	...	13.38
15. Electric apparatus, nec	0.44	0.84	8.58	5.55	4.84	13.20
16. Communication equipment	0.20	0.87	6.28	5.70	3.03	13.23
17. Shipbuilding & repairing	0.73	0.18	7.28	6.24	9.09	2.86
18. Other transport	0.48	0.13	6.76	5.34	6.67	2.33
19. Motor vehicles	0.41	0.35	5.63	13.66	6.73	2.47
20. Aircraft	...	0.14	3.72	6.04	...	2.20
21. Other manufacturing[2]	0.19	0.26	4.61	3.61	4.00	6.73
Total manufacturing	**0.34**	**0.48**	**13.94**	**17.33**	**2.34**	**2.69**
22. Electricity, gas & water	3.00	3.26	84.70	54.30	3.42	5.67
23. Wholesale & retail trade[3]	1.13	0.63	9.37	5.10	10.79	11.02
24. Transport & communication	4.61	7.00	24.17	20.41	16.01	25.54
25. FIRE & business services	0.15	0.56	4.51	8.32	3.25	6.27
26. Social & personal services	1.38	3.88	8.55	21.21	13.92	15.48
Total services	**1.54**	**1.96**	**14.41**	**13.30**	**9.68**	**12.84**
27. Construction	0.05	0.11	4.88	4.58	0.95	2.26
Total business sector[4]	**1.03**	**1.44**	**13.29**	**13.45**	**7.15**	**9.68**

1 The industrial chemicals industry includes drugs and medicine for the United States.
2 Other manufacturing includes professional goods for Canada.
3 Includes restaurants and hotels.
4 Here, the total business sector is defined to include manufacturing, services and construction industries.

Table 4 presents nominal IT and non-IT investment rates for the United States. A comparison of Tables 3 and 4 indicates that there are striking similarities between the two countries. In both countries, the bulk of IT investment has taken place in the service sector. In 1990, the service sector accounted for 91 percent of all IT investments in Canada and 83 percent in the United States. This trend is evident for many services such

Table 4
Summary Statistics on IT and non-IT Nominal Gross Investment for the United States, 1972 and 1990

	IT Investment Rate (%)		Non-IT Investment Rate (%)		Share of IT Investment (%)	
ISIC Rev. 2	**1972**	**1990**	**1972**	**1990**	**1972**	**1990**
1. Food, beverages & tobacco	0.28	0.55	6.77	7.63	3.91	6.76
2. Textiles, apparel & leather	0.40	0.78	6.37	6.84	5.94	10.18
3. Wood products & furniture	0.21	0.38	6.95	5.65	2.94	6.32
4. Paper & printing	0.85	2.37	7.73	12.28	9.90	16.16
5. Industrial chemicals & drugs[1]	0.69	1.19	8.87	8.07	7.24	12.82
6. Petroleum & coal products	0.99	2.30	12.60	14.22	7.28	13.93
7. Rubber & plastic products	0.21	0.36	8.92	11.67	2.34	3.00
8. Non-metallic mineral products	0.50	0.77	10.32	9.77	4.58	7.27
9. Iron & steel	0.24	0.64	7.61	13.28	3.00	4.59
10. Non-ferrous metals	0.98	1.38	11.09	10.16	8.15	11.98
11. Metal products	0.35	0.70	5.88	6.68	5.69	9.52
12. Non-electrical machinery	0.49	0.85	5.37	6.05	8.44	12.30
13. Office & computing machines	6.43	5.95	5.83	2.88	52.43	67.39
14. Electric apparatus, nec	0.92	2.93	4.58	5.44	16.73	34.98
15. Communication equipment	1.83	5.84	6.32	7.45	22.43	43.92
16. Shipbuilding & repairing	0.52	0.69	6.40	4.20	7.52	14.09
17. Other transport	0.61	1.63	7.51	10.20	7.53	13.77
18. Motor vehicles	0.34	0.67	8.45	13.71	3.83	4.65
19. Aircraft	0.41	1.06	1.99	3.65	17.06	22.49
20. Professional goods	0.48	1.39	3.58	5.42	11.75	20.37
21. Other manufacturing[2]	0.34	0.44	5.57	4.37	5.74	9.21
Total manufacturing	**0.57**	**1.46**	**6.94**	**8.09**	**7.61**	**15.35**
22. Electricity, gas & water	0.47	3.56	15.62	22.09	2.90	13.87
23. Wholesale & retail trade[3]	0.36	1.12	4.40	6.90	7.60	13.98
24. Transport & communication	6.80	6.00	14.24	9.93	32.33	37.68
25. FIRE & business services	0.84	1.82	3.11	2.89	21.29	38.60
26. Social & personal services	0.74	1.81	6.85	5.29	9.71	25.47
Total services	**1.39**	**2.11**	**6.06**	**5.95**	**18.70**	**26.18**
27. Construction	0.09	0.20	10.14	7.75	0.87	2.48
Total business sector[4]	**1.06**	**1.87**	**6.57**	**6.51**	**10.68**	**22.30**

1 The industrial chemicals industry includes drugs and medicine for the United States.
2 Other manufacturing includes professional goods for Canada.
3 Includes restaurants and hotels.
4 Here, the total business sector is defined to include manufacturing, services and construction industries.

as communications and transport, finance, insurance, real estate, business services, and community, social and personal services. Contrary to the rising trend of the IT investment rate in the services sector, the non-IT investment rate in both countries declined over the same period.

Several additional points are worth noting. First, the extent of IT investment is much lower in Canada than in the United States, and, the (nominal) IT investment rate in the Canadian manufacturing sector was only 0.5 percent in 1990, compared to 1.5 percent in the U.S. manufacturing sector over this period. Second, this is also true for the services sector – Canada had a nominal IT investment rate of 1.7 percent compared to about 2 percent in the United States. Third, Canada lags behind the United States in terms of IT investment rate in virtually all industries except for the transport and communications industry.

R&D

We now turn to the R&D variables. As discussed earlier, labour productivity growth in our model depends not only on the direct R&D efforts that industries themselves undertake, but also on R&D acquired from other industries through purchases of domestic and imported goods and services (embodied R&D). Thus, we identify two types of R&D spillover sources: domestic and international. Following the recent OECD study (1996*e*), we also construct "total technology intensity" indicators at the industry level combining both performed R&D and embodied R&D. The OECD study argued that direct R&D investment rates are an inadequate measure of the technological sophistication of industries. A more appropriate measure should take into account not only the direct R&D investment rates of a particular industry but also the embodied R&D.

Direct R&D Efforts

In Table 5, we present a measure of the R&D investment rate (R&D expenditure as a percentage of value added) by industry for both Canada and the United States. The data indicate quite clearly that R&D is still overwhelmingly performed in the manufacturing industries. However, services account for an increasing share of total R&D expenditures.[17] Although they are not shown in Table 5, it is worth noting that the two IT-producing industries account for the bulk of R&D performed in both countries. In 1993, they accounted for 26 percent of total intramural R&D expenditures in Canada and 14 percent of total intramural R&D expenditures in the United States. However, the R&D investment rate in the Canadian manufacturing sector is much lower than that in the United States except for textile, apparel and leather, non-ferrous metals, and the communications equipment industries.

R&D Spillovers - Total Embodied R&D

Tables 6 and 7 show the patterns of R&D diffusion in Canada and the United States. Several familiar messages emerge.

First, the services sector is making the greatest use of embodied technology in both countries. Transportation and communications equipment and community, social and personal services show up as important users of technology. A few manufacturing industries are also top technology users. These include, for Canada, motor vehicles, rubber and plastic products, and iron and steel, and for the United States, textiles, apparel and leather, and iron and steel.

Table 5
R&D Investment Rates For Canada and the United States, 1973-76, and 1990-93

	Canada		**United States**	
ISIC Rev. 2	**1973-76**	**1990-93**	**1973-76**	**1990-93**
1. Food, beverages & tobacco	0.52	0.45	0.79	1.13
2. Textiles, apparel & leather	0.25	0.91	0.29	0.56
3. Wood products & furniture	0.11	0.46	0.51	0.53
4. Paper & printing	0.57	0.76	0.76	1.08
5. Industrial chemicals[1]	2.81	2.41	7.81	12.02
6. Drugs and medicine	7.47	11.37	...	...
7. Petroleum & coal products	8.44	9.11	8.58	11.91
8. Rubber & plastic products	0.73	0.68	4.41	2.94
9. Non-metallic mineral products	0.44	0.49	1.94	2.32
10. Iron & steel	0.86	0.72	0.96	0.90
11. Non-ferrous metals	3.73	5.29	2.55	2.75
12. Metal products	0.40	0.98	1.18	1.58
13. Non-electrical machinery	1.38	1.60	2.45	4.02
14. Office & computing machines	8.97	35.47	73.56	44.18
15. Electric apparatus, nec	2.65	2.37	17.93	3.11
16. Communication equipment	14.77	30.01	24.24	22.27
17. Shipbuilding & repairing	0.04	0.00	0.09	0.69
18. Other transport	3.19	0.40	6.48	19.72
19. Motor vehicles	0.53	0.78	10.67	19.98
20. Aircraft	17.11	23.17	45.26	32.29
21. Professional goods	...	...	7.71	15.14
22. Other manufacturing[2]	0.51	1.18	3.09	2.26
Total manufacturing	**1.70**	**3.43**	**6.55**	**8.40**
23. Electricity, gas & water	1.06	1.08	...	...
24. Wholesale & retail trade[3]	0.10	0.26	...	...
25. Transport & communication	0.16	0.47	...	...
26. FIRE & business services	0.28	0.83	...	...
27. Social & personal services	0.00	0.00	...	...
Total services	**0.17**	**0.54**	**0.09**	**0.69**
28. Construction	0.01	0.03	...	...
Total business sector[4]	**0.71**	**1.30**	**2.14**	**2.48**

1 The industrial chemicals industry includes drugs and medicine for the United States.
2 Other manufacturing includes professional goods for Canada.
3 Includes restaurants and hotels.
4 Here, the total business sector is defined to include manufacturing, services and construction industries.

Second, the gap in technological sophistication between industries in Canada and the United States – measured by total technology intensity – appears to be smaller than the direct R&D investment rates in Table 5 would suggest. In fact, the two IT industries in Canada surpassed their counterparts in the United States in total technology intensity

Table 6
Pattern of Technology Diffusion in Canada, 1973-76 and 1990-93

	Total Technology Intensity[1]		Share of Acquired Technology		Share of Acquired Technology by Imports	
ISIC Rev. 2	**1973-76**	**1990-93**	**1973-76**	**1990-93**	**1973-76**	**1990-93**
1. Food, beverages & tobacco	1.75	2.09	70.51	78.68	43.05	49.01
2. Textiles, apparel & leather	1.59	3.59	84.57	74.60	59.70	64.37
3. Wood products & furniture	1.20	2.32	90.64	80.32	59.95	57.24
4. Paper & printing	2.14	3.10	73.41	75.61	45.73	49.14
5. Industrial chemicals	6.76	9.48	58.50	74.60	48.07	60.70
6. Drugs and medicine	10.98	17.33	31.93	34.38	61.63	55.54
7. Petroleum & coal products	13.22	23.53	36.15	61.30	43.25	51.58
8. Rubber & plastic products	4.47	7.16	83.73	90.50	68.76	76.48
9. Non-metallic mineral products	1.96	3.63	77.52	86.42	54.03	68.86
10. Iron & steel	2.93	5.03	70.52	85.74	48.22	54.81
11. Non-ferrous metals	8.10	12.78	53.91	58.59	33.56	46.83
12. Metal products	2.64	4.46	84.75	77.96	40.89	48.03
13. Non-electrical machinery	3.39	4.97	59.24	67.79	63.95	70.38
14. Office & computing machines	68.38	95.10	86.88	62.70	95.95	89.03
15. Electric apparatus, nec	7.00	7.84	62.10	69.73	48.82	57.79
16. Communication equipment	25.10	53.62	41.15	44.02	58.88	69.31
17. Shipbuilding & repairing	4.30	25.56	99.06	99.97	65.92	53.71
18. Other transport	8.81	11.79	63.81	96.57	72.47	91.95
19. Motor vehicles	13.58	30.87	96.12	97.48	91.43	93.74
20. Aircraft	32.02	41.18	46.56	43.73	82.79	69.07
21. Other manufacturing	2.08	5.04	75.61	76.53	67.43	79.00
Total manufacturing	**5.48**	**11.39**	**68.90**	**69.86**	**69.01**	**74.93**
22. Electricity, gas & water	3.79	3.42	71.96	68.38	79.15	68.54
23. Wholesale & retail trade	1.00	1.12	89.88	76.68	70.54	49.31
24. Transport & communication	2.55	5.32	93.87	91.15	49.49	37.42
25. FIRE & business services	0.48	1.34	40.46	38.33	45.68	45.90
26. Social & personal services	1.09	3.30	100.00	100.00	76.74	83.59
Total services	**1.26**	**2.14**	**82.99**	**75.00**	**62.46**	**54.70**
27. Construction	1.74	1.91	99.45	98.29	37.11	34.39
Total business sector[2]	**2.59**	**4.31**	**75.14**	**72.73**	**63.96**	**65.75**

1 Total technology intensity includes direct R&D, R&D embodied in purchases of domestic goods, and R&D embodied in purchases of imported goods.

2 Here, the total business sector is defined to include manufacturing, services and construction industries.

for the period 1990-93. This is simply due to the fact that embodied R&D (acquired technology) represents a much larger share of total technology intensity in Canada than in the United States. Over the 1990-93 period, the share of acquired technology was over 72 percent for all industries (excluding primary) in Canada, compared to 59 percent in the United States.

Table 7
Pattern of Technology Diffusion in the United States, 1973-76 and 1990-93

	Total Technology Intensity[1]		Share of Acquired Technology		Share of Acquired Technology by Imports	
ISIC. Rev. 2	**1973-76**	**1990-93**	**1973-76**	**1990-93**	**1973-76**	**1990-93**
1. Food, beverages & tobacco	2.74	4.11	70.96	72.40	1.77	4.76
2. Textiles, apparel & leather	3.31	5.63	91.33	90.00	3.63	5.45
3. Wood products & furniture	2.00	2.69	74.32	80.34	2.26	6.43
4. Paper & printing	3.05	5.48	75.09	80.22	3.65	7.30
5. Industrial chemicals & drugs	12.79	20.77	38.94	42.14	2.98	6.53
6. Petroleum & coal products	16.13	27.32	46.79	56.41	2.82	6.45
7. Rubber & plastic products	8.86	12.07	50.17	75.65	2.09	5.93
8. Non-metallic mineral products	4.35	6.29	55.36	63.11	2.47	6.70
9. Iron & steel	3.69	6.39	73.97	85.91	7.69	8.57
10. Non-ferrous metals	10.77	12.76	76.33	78.44	10.57	9.48
11. Metal products	3.58	4.61	67.11	65.83	4.20	8.99
12. Non-electrical machinery	6.24	7.91	60.68	49.14	2.55	10.46
13. Office & computing machines	125.08	67.39	41.19	34.44	1.09	14.57
14. Electric apparatus, nec	23.84	9.90	24.78	68.60	2.11	10.87
15. Communication equipment	39.95	36.05	39.33	38.22	2.17	12.24
16. Shipbuilding & repairing	5.14	4.70	98.31	85.25	2.28	9.34
17. Other transport	21.17	46.97	69.42	58.02	3.14	6.48
18. Motor vehicles	22.56	49.36	52.69	59.52	2.58	8.71
19. Aircraft	63.81	52.11	29.07	38.04	3.44	9.99
20 Professional goods	10.71	21.25	27.98	28.76	3.24	11.76
21. Other manufacturing	6.45	5.97	51.99	62.18	4.61	7.64
Total manufacturing	**11.93**	**16.53**	**45.08**	**49.13**	**3.05**	**8.93**
22. Electricity, gas & water	2.61	5.12	96.67	86.45	1.42	6.62
23. Wholesale & retail trade	0.80	2.36	89.19	70.62	1.37	7.25
24. Transport & communication	4.35	4.95	98.00	85.98	3.21	8.13
25. FIRE & business services	0.95	1.91	90.88	63.60	1.63	6.64
26. Social & personal services	2.22	3.49	96.08	80.13	2.48	6.96
Total services	**1.59**	**2.74**	**94.54**	**74.66**	**2.31**	**7.14**
27. Construction	3.85	4.31	97.74	83.91	1.26	6.10
Total business sector[2]	**4.81**	**5.84**	**58.18**	**59.17**	**2.64**	**8.01**

1 Total technology intensity includes direct R&D, R&D embodied in purchases of domestic goods, and R&D embodied in purchases of imported goods.
2 Here, the total business sector is defined to include manufacturing, services and construction industries.

Third, imports account for a larger share of technology acquired in Canada than in the United States as a source of acquired technology (R&D embodied in imports), though their importance appears to be growing in both countries. Foreign sources of R&D spillovers are more important than domestic sources in Canada, while domestic sources represent almost all of total acquired technology in the United States. For the more recent period 1990-93, technology embodied in imports accounted for about 66 percent of total acquired technology for Canadian industries, while it accounted for only a negligible 8 percent in U.S. industries.

Fourth, although this is not shown, it is worth noting that Canada relies almost exclusively on the United States for its embodied technology in imports, while the United States acquires embodied technology from a number of other trading partners. For instance, over the 1990-93 period, 86 percent of total imported embodied technology in Canada emanated from the United States. In contrast, Canada accounted for only 16 percent of such R&D spillovers for the United States.

R&D Diffusion - the IT Sector as a Source of Embodied R&D

In Table 8 and Table 9, we present measures of R&D spillovers received from purchasing capital and intermediate goods from the two industries that produce IT.

Table 8
Pattern of Information Technology Diffusion in Canada, 1973-76 and 1990-93

	Share of IT in Total Acquired Technology[1]		**Share of Acquired IT by Imports**	
ISIC Rev. 2	**1973-76**	**1990-93**	**1973-76**	**1990-93**
1. Food, beverages & tobacco	16.06	16.06	83.35	79.88
2. Textiles, apparel & leather	8.40	12.95	73.30	87.17
3. Wood products & furniture	7.01	15.50	73.30	77.42
4. Paper & printing	11.36	14.60	82.55	78.73
5. Industrial chemicals & drugs	7.10	8.67	81.90	85.62
6. Drugs & medicine	0.00	13.29	…	92.48
7. Petroleum & coal products	0.00	11.62	…	91.31
8. Rubber & plastic products	3.33	9.98	100.00	90.25
9. Non-metallic mineral products	7.83	18.61	73.30	90.31
10. Iron & steel	12.13	17.73	68.69	74.96
11. Non-ferrous metals	4.49	10.19	61.33	81.49
12. Metal products	8.18	12.34	64.37	68.96
13. Non-electrical machinery	8.40	13.30	68.74	77.31
14. Office & computing machines	93.14	93.32	96.71	89.08
15. Electric apparatus, nec	22.62	21.77	65.04	77.29
16. Communication equipment	83.66	93.28	56.38	68.87
17. Shipbuilding & repairing	24.29	62.83	27.22	36.45
18. Other transport	8.52	16.03	85.12	97.91
19. Motor vehicles	3.93	3.78	60.16	67.60
20. Aircraft	4.72	3.68	56.69	90.49
21. Other manufacturing	12.12	37.95	85.12	88.91
Total manufacturing	**4.31**	**24.89**	**75.63**	**76.12**
22. Electricity, gas & water	51.56	49.01	93.77	87.36
23. Wholesale & retail trade	57.54	28.33	90.92	79.84
24. Transport & communication	37.87	43.13	35.45	27.10
25. FIRE & business services	42.72	44.10	88.21	86.44
26. Social & personal services	62.68	45.23	90.43	85.18
Total services	**48.42**	**42.09**	**73.71**	**62.47**
27. Construction	9.65	14.01	33.90	35.49
Total business sector[2]	**28.04**	**30.18**	**72.98**	**68.55**

1 Total acquired technology includes R&D embodied in purchases of domestic goods and imported goods.
2 Here, the total business sector is defined to include manufacturing, services and construction industries.

Table 9
Pattern of Information Technology Diffusion in the United States, 1973-76 and 1990-93

	Share of IT in Total Acquired Technology[1]		Share of Acquired IT by Imports	
ISIC Rev. 2	**1973-76**	**1990-93**	**1973-76**	**1990-93**
1. Food, beverages & tobacco	10.49	6.97	0.93	5.32
2. Textiles, apparel & leather	9.97	5.62	1.25	6.32
3. Wood products & furniture	10.96	7.05	0.88	5.82
4. Paper & printing	26.24	20.11	1.14	5.64
5. Industrial chemicals & medicine	9.56	5.17	1.03	6.33
6. Petroleum & coal products	8.87	5.08	0.87	5.39
7. Rubber & plastic products	3.74	2.09	0.90	7.23
8. Non-metallic mineral products	14.14	7.00	0.79	5.55
9. Iron & steel	14.34	6.23	3.06	5.39
10. Non-ferrous metals	10.39	6.01	5.31	5.60
11. Metal products	11.07	8.86	1.10	5.50
12. Non-electrical machinery	11.56	12.88	1.21	7.38
13. Office & computing machines	93.12	93.60	1.04	14.66
14. Electric apparatus, nec	13.74	44.69	1.93	12.20
15. Communication equipment	87.02	82.83	2.04	12.45
16. Shipbuilding & repairing	26.56	10.08	1.13	6.76
17. Other transport	4.11	3.99	1.10	6.30
18. Motor vehicles	5.22	3.60	7.06	22.38
19. Aircraft	20.49	8.06	1.47	12.02
20. Professional goods	44.23	53.69	2.22	14.14
21. Other manufacturing	17.72	19.59	2.44	9.64
Total manufacturing	**26.34**	**22.23**	**1.79**	**12.31**
22. Electricity, gas & water	11.16	23.01	0.99	5.16
23. Wholesale & retail trade	33.29	22.84	0.83	5.96
24. Transport & communication	46.50	35.84	2.91	5.96
25. FIRE & business services	66.12	54.15	1.08	7.03
26. Social & personal services	23.36	20.41	2.58	11.87
Total services	**40.77**	**32.66**	**1.96**	**7.19**
27. Construction	4.85	4.04	1.05	6.19
Total business sector[2]	**29.54**	**25.73**	**1.86**	**9.46**

1 Total acquired technology includes R&D embodied in purchases of domestic goods and imported goods.
2 Here, the total business sector is defined to include manufacturing, services and construction industries.

In the first column of these Tables, we present the share of IT in acquired technology for Canada and the United States. The data indicate quite clearly that the share of IT in total acquired technology is increasing in Canada but declining in the United States. In Canada, this share has risen from 28 percent in the early 1970s to over 30 percent in the early 1990s. In the United States, however, this share has declined from about 30 percent to 26 percent over the same period.

In addition, the tables show two additional trends. First, both in Canada and the United States, service industries receive a much greater share of R&D spillovers from the IT sector than do the manufacturing industries. However, the growth rate of R&D spillovers from the IT sector has been much greater in the Canadian manufacturing industries: they have registered a share gain of twenty percentage points over the last two decades. Second, a greater proportion of the acquired information technology in Canada (about 69 percent) comes through imports, especially from the United States. In contrast, the United States relies mainly on domestic sources for its acquisition of R&D spillovers from the IT sector.

With these data trends in mind, we now proceed to a discussion of results obtained from regression analysis, in which we relate labour productivity growth to IT investment, and measures of technology such as performed R&D and R&D spillovers from IT and non-IT sectors.

5. REGRESSION ANALYSIS

This section discusses the estimated results of Equation (2). Regressions are performed on a pooled cross-section time-series data set consisting of 27 industries and 5 sub-periods (1971-75, 1976-79, 1980-85, 1986-89, 1990-93).[18] We regress the annual average labour productivity growth rate of an industry to the IT and non-IT investment rates of each of the five sub-periods (evaluated at the beginning of the period) and the mean values of the R&D and technology diffusion variables over the same time periods. Time dummies for these sub-periods are introduced to allow for period-specific effects on labour productivity growth not attributable to investment and R&D variables.

Results for Canada

Results for the Equation (2) estimation for Canada and the United States are reported in Tables 10 and 11 respectively. We first discuss the empirical results for Canada. The first three columns of Table 10 report the results based on real investment and real R&D expenditures[19] after correcting for R&D double counting,[20] while the last three columns report the results based on nominal investment and nominal R&D data without correcting for R&D double counting. Specification (1), shown in the first column, considers own R&D and physical investments, but does not consider R&D spillovers. Specification (2) corresponds exactly to Equation (2) where embodied R&D variables are decomposed into those embodied in domestic goods and services and in imports. Specification (3) distinguishes R&D spillovers embodied in IT goods and non-IT goods and services for both domestic and international embodied R&D variables. The last three columns of this Table correspond to three specifications mentioned above for nominal investment and R&D data.

We will focus first on the estimated results based on real investment and R&D data. As discussed earlier, the coefficients of real physical investment variables such as IT and non-IT investments, and R&D investment are interpreted as the rate of return on investment. This is based on the assumption that the (average) rate of return on investment is equalized across sectors.[21] Three variables are found to be robustly correlated with labour productivity growth: labour input growth (negative), the IT investment rate (positive), and international R&D spillovers (positive). The estimated coefficients of these variables remain relatively stable and significant in all specifications. The time period dummies for the 1976-80, 1986-89 and 1990-93 periods are statistically significant. The constant term, interpreted as exogenous technical change, is also statistically significant.

The coefficients on the real IT investment rate are statistically significant at the five percent level. The rate of return on IT investments is between 27 and 36 percent per year. Our results are consistent with the findings of two other recent studies that also found positive correlation between productivity growth and IT investment (Siegel and Griliches, 1991; Brynjolfsson and Hitt, 1995). Both studies found that there are high returns on IT investments and that the rates of return on IT capital are higher in services than in the manufacturing sector.

Table 10
Regression Results For Canada, 1971-93
(Dependent Variable: Growth of Labour Productivity, 135 observations)

	Real Investment and R&D Double Counting Corrected			Nominal Investment and R&D Double Counting not Corrected		
Independent Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Constant	0.030 (4.394)	0.027 4.398	0.030 (4.871)	0.037 (5.072)	0.030 (5.007)	0.032 (5.262)
Growth of labour input	-0.827 (6.263)	-0.741 (6.876)	-0.646 (5.850)	-0.660 (3.676)	-0.716 (5.510)	-0.689 (5.825)
IT investment rate	0.359 (3.599)	0.357 (3.915)	0.272 (3.060)	0.331 (2.258)	0.364 (2.957)	0.238 (1.808)
Non-IT investment rate	0.017 (1.481)	0.017 (1.516)	0.008 (0.739)	0.002 (0.131)	0.018 (1.598)	0.017 (1.582)
R&D investment rate	0.217 (3.334)	0.062 (1.190)	-0.011 (0.211)	0.267 (3.213)	0.079 (1.392)	0.040 (0.629)
Domestic R&D spillover	---	-0.034 (0.251)	---	---	-0.222 (1.805)	---
Domestic R&D spillover embodied in IT goods	---	---	-0.066 (0.399)	---	---	-0.108 (0.798)
Domestic R&D spillover embodied in non-IT goods	---	---	0.234 (0.900)	---	---	-0.126 (0.631)
International R&D spillover	---	0.236 (4.300)	---	---	0.298 (4.427)	---
International R&D spillover embodied in IT imports	---	---	0.368 (4.217)	---	---	0.376 (3.833)
International R&D spillover embodied in non-IT imports	---	---	0.092 (2.172)	---	---	0.098 (2.260)
Period 2: 1976-1980	-0.021 (2.551)	-0.021 (2.764)	-0.022 (2.999)	-0.023 (2.255)	-0.021 (2.610)	-0.020 (2.659)
Period 3: 1981-1985	-0.014 (1.461)	-0.015 (1.831)	-0.013 (1.635)	-0.016 (1.410)	-0.016 (1.927)	-0.012 (1.458)
Period 4: 1986-1989	-0.018 (2.430)	-0.024 (3.654)	-0.025 (3.816)	-0.028 (3.538)	-0.028 (4.076)	-0.024 (3.456)
Period 5: 1990-1993	-0.044 (4.345)	-0.047 (4.971)	-0.043 (4.573)	-0.042 (3.268)	-0.046 (4.587)	-0.041 (4.346)
R^2	0.55	0.65	0.68	0.39	0.62	0.67
R^2 adjusted	0.52	0.62	0.65	0.35	0.59	0.64

Note: Heteroscedasticity-adjusted t-statistics are shown in parentheses.

The real non-IT investment rate has the expected positive sign, though its coefficients are not statistically different from zero. This is a somewhat surprising result. The insignificant impact of non-IT investments on productivity growth may have resulted from a number of factors. First, non-IT investment goods are highly heterogeneous, and the estimated returns to non-IT investments are a mixture of varying returns to various types of conventional non-IT investment goods. Second, the gross investment data we used in this study may be less appropriate at the theoretical level. Only one component of gross investment, net investment, is considered to increase productivity growth while the other component, replacement investment, is made to maintain existing productivity

Table 11
Regression Results For the United States, 1972-93
(Dependent Variable: Growth of Labour Productivity, 135 observations)

Independent Variables	(1)	(2)	(3)
Constant	0.008 (1.191)	0.007 (1.113)	0.004 (0.586)
Growth of labour input	-0.421 (4.005)	-0.424 (3.566)	-0.394 (3.447)
Nominal IT investment rate	0.535 (4.740)	0.553 (4.247)	0.179 (1.505)
Nominal non-IT investment rate	-0.048 (0.773)	-0.023 (0.336)	0.039 (0.489)
Nominal R&D investment rate	0.033 (1.459)	0.0622 (0.964)	0.017 (0.282)
Domestic R&D spillover	---	-0.051 (0.440)	---
Domestic R&D spillover embodied in IT goods	---	---	0.070 (0.800)
Domestic R&D spillover embodied in non-IT goods	---	---	0.062 (0.340)
International R&D spillover	---	-0.056 (0.063)	---
International R&D spillover embodied in IT imports	---	---	1.868 (2.643)
International R&D spillover embodied in non-IT imports	---	---	-1.960 (1.221)
Period 2: 1977-1981	-0.015 (2.169)	-0.015 (2.165)	-0.015 (2.104)
Period 3: 1982-1984	0.023 (3.030)	0.024 (3.121)	0.027 (3.627)
Period 4: 1985-1989	0.009 (1.532)	0.010 (1.580)	0.015 (2.523)
Period 5: 1990-1993	0.003 (0.343)	0.003 (0.422)	0.008 (1.071)
R^2	0.39	0.39	0.43
R^2 adjusted	0.35	0.34	0.37

Note: Heteroscedasticity-adjusted t-statistics are shown in parentheses.

levels.[22] The measurement error associated with using gross non-IT investment is likely to bias the coefficient toward zero.

Nonetheless, the coefficients of IT investment are statistically different from zero at the 5 percent level even though gross investment data were used. It is equally interesting to observe that real IT investment data only reflect quality improvement in computers (based on hedonic prices for computers) but not in other IT goods such as semi-conductors.[23] As a result, replacement IT investment is improperly deflated and this leads to an under-estimation of net investment. Therefore, it is not certain whether net investment is more appropriate than gross investment for empirical studies.

Canada's own R&D variable is significantly related to productivity growth in specification (1). The estimated rate of return is about 22 percent per year. This is consistent with existing studies, which present rates of return from 10 percent to 50 percent (see for example, Griliches, 1994; Mohnen, 1992). However, once R&D spillovers are introduced as in specification (2), this significant relationship disappears. This may be due mainly to the strength of the correlation between own R&D and domestic R&D spillovers. The correlation of own R&D and domestic spillovers is 0.65 implying a possible multi-collinearity problem between the two variables. Our results suggest that Canadian industries may not benefit from R&D undertaken in other Canadian industries.

We also consider international R&D spillovers along with the own R&D variable and domestic R&D spillovers. The international R&D spillover has a significant impact on productivity growth as shown in specification (2). Indeed, our data show that the share of technology acquired from imports has increased over time and now accounts for almost 75 percent of all technology acquired externally by manufacturing industries. Our results confirm the previous findings that international R&D spillovers have a strong and significant effect on productivity growth (Bernstein, 1996*a*, and Coe and Helpman, 1995). The estimated rate of return on R&D embodied in imports is about 24 percent per year. A principal conclusion that emerges from this discussion is that R&D spillovers are primarily an international phenomenon for Canada.

In specification (3), we investigate whether international R&D spillovers embodied in IT imports affect labour productivity growth. We do this by introducing R&D spillovers embodied in IT and non-IT imports separately. In this case, the international diffusion of R&D embodied in both IT and non-IT imports is found to have a positive and statistically significant impact on productivity growth. The international diffusion of R&D embodied in IT imports in Canada has a greater impact on productivity growth than that of R&D embodied in non-IT imports: the estimated rate of return on R&D embodied in IT imports is about 37 percent per year, while the rate of return on R&D embodied in non-IT imports is found to be only 9 percent. Clearly, our results indicate that international R&D spillovers from the IT sector played a dominant role in Canada over the past two decades.

The period-specific dummy variables are negative and significant except for 1981-85 in most specifications. This is consistent with the productivity slowdown in Canada since 1973.

Although not reported in this table, we also test the hypothesis as to whether there is any evidence of declining rates of return on IT investments across industries in Canada. In a recent study, Brynjolfsson and Hitt (forthcoming) suggest that the rate of return on investments in information technology will decrease as firms increase their investments – as is generally the case for all types of investments. Using a sample of U.S. firms, they found evidence of declining rates of return on investments in computers over the 1987-89 period. To examine this possibility, we introduce interaction terms between the IT-investment rate and dummy variables for the five sub-periods in specification (3). The joint hypothesis that the coefficients of the interaction terms equal zero is not rejected at the five percent level. None of the coefficients on the interaction terms between IT investment and period dummies are statistically significant.

Lastly, our empirical model allows us to examine how service industries fared relative to manufacturing industries in terms of labour productivity growth, conditional upon the independent variables used in our model. Are service industries particularly slow in reaping the productivity gains of information technology? To examine this, we introduce a dummy variable for the service industries in specification (3). The results, although not reported in Table 10, indicate that the coefficients on the dummy for service industries are positive but not statistically different from zero. It suggests that the explanatory variables in our model explain almost all the differences in labour productivity growth between services and manufacturing industries.

Next, we estimate all the specifications once again but this time we use *nominal* investment and R&D expenditure data without correcting for R&D double-counting. The idea is to examine the significance of these data measurement issues for our results. The regression results are reported in the last three columns of Table 10. Overall, the results are not significantly different from those reported in the first three columns. It is interesting to observe that, from an empirical point of view, these data measurement issues do not play an important role.

To sum up, the results so far support the following three conclusions:

- First, IT investments are an important source of productivity growth across Canadian industries;
- Second, international R&D spillovers are much more important than domestic R&D spillovers in Canada; and
- Third, international R&D spillovers embodied in IT imports are more important than those embodied in non-IT imports in their contribution to productivity growth.

Regression Results for the United States

Now we estimate Equation (2) using the U.S. data. We would like to reiterate what we stated earlier, namely that the IT and non-IT investment data and the R&D expenditure data for the United States are available only in current prices. Table 11 presents regression results for all three specifications. The U.S. empirical results are somewhat different from those obtained for Canada.

The IT investment effect on labour productivity growth is generally higher but somewhat less robust in the case of the U.S. data, depending on the specification. It is significant in specifications (1) and (2) but not in specification (3). The rate of return on IT investment ranges from 18 percent to 55 percent per year. The direction of the results seems to be consistent with other studies using U.S. data (Brynjolfsson and Hitt, 1995; Lichtenberg, 1993; and Siegel and Griliches, 1991). As for Canada, the non-IT investment rate is found to be insignificant for labour productivity growth in U.S. industries.

The most surprising result is the insignificance of the own R&D variable in all three specifications. This is contrary to a large number of U.S. studies, which found a positive and significant impact of direct R&D on productivity. However, when we use a more conventional empirical specification (not reported in Table 11), which does not distinguish between IT and non-IT investments and excludes R&D spillovers, direct R&D is found to have a positive and statistically significant impact on productivity growth (with a t-ratio of 3.34). The rate of return is estimated to be just over 7 percent per year. This is consistent with the results obtained in most U.S. studies (see, for example, Griliches, 1994).

As in the results obtained for Canada, the domestic R&D spillover effects for the United States are found to be statistically insignificant, as can be seen in specifications (2) and (3).

International R&D spillovers are found to be statistically insignificant for the United States as shown in specification (2). However, when we distinguish between international R&D embodied in IT and non-IT imports as in specification (3), we find a strong and significant effect on productivity growth of international R&D spillovers embodied in IT imports.[24]

Comments on Results

The empirical results for Canada are more robust and consistent with other empirical studies. The U.S. results are less robust but still indicate that IT investments and R&D spillovers embodied in IT imports are important for productivity growth. Admittedly, the quality of U.S. data in our sample is less satisfactory. First, labour productivity growth for four important U.S. industries may have been under-estimated. The U.S. labour productivity data for the non-electrical machinery, office and computing machinery, electrical apparatus, and communications equipment industries are calculated using the price deflator for the fabricated metals industry and not the price deflator of each of the four industries. This may have resulted in the under-estimation of labour productivity growth in these industries and this may have weakened our U.S. results. Second, the absence of real investment and R&D data is another shortcoming.

Further improvements in the quality of data could have strengthened our empirical results. These include the availability of net, rather than gross, IT and non-IT investment data in real terms, and real investment data reflecting quality improvement in investment goods, especially those related to information technology (not just computers).

6. SUMMARY AND CONCLUSIONS

Until recently, few empirical studies have focused on the relationship between productivity growth and IT. Potentially the most important issue is whether investments in IT contribute to productivity growth. A second issue is whether domestic and international R&D spillovers from the IT sector are important for productivity growth. In this paper, we have examined these issues for Canada and the United States.

Our major findings are as follows.

- IT investments are an important source of productivity growth across Canadian industries. The private rates of return on IT investments are found to be high – on average, about 30 percent per year. The results from the U.S. data are found to be generally consistent with the Canadian results, although somewhat less robust.
- The R&D spillovers in Canada are primarily international in scope. We find that international R&D spillovers from both IT and non-IT sectors contribute significantly to productivity growth across Canadian industries. However, the spillovers from the IT sector are greater than those from the non-IT sector.
- In contrast to the results for Canada, international R&D spillovers, in the aggregate, are found not to be significant in the U.S. data. However, there is some evidence to suggest that international R&D spillovers from the IT sector are significant and much more important than those from the non-IT sector for U.S. industries.

The implications of our findings for the empirical literature are significant. First, IT investment is much more important at margin than non-IT investment in determining productivity growth. Second, the results provide stronger empirical support for the thesis that R&D spillovers in Canada are primarily international in scope. This confirms the findings of earlier studies for Canada such as Bernstein (1996*a*) and Coe and Helpman (1995). However, the latter study observed that spillovers between countries were larger in small, open economies, and that foreign R&D was at least as important as domestic R&D for small countries in stimulating productivity. Third, international R&D spillovers embodied in IT imports are more important than R&D spillovers embodied in non-IT imports in contributing to productivity growth.

The implications of our findings are also potentially significant for trade and industrial policies, especially R&D policies in small open economies like Canada's. First, the existence of large international spillovers in our data does not suggest that they are substitutes for own R&D. Indeed, it is quite possible that own R&D and R&D spillovers are complementary, meaning that firms must invest in R&D to benefit from other firm's R&D. This is a promising area for further research. Second, as was argued by Bernstein (1996*a*), any cost-benefit analysis of government R&D policies must take into account R&D spillovers; otherwise, the benefits associated with these policies will be under-estimated. Third, the significance of IT investments and large international R&D spillovers embodied in IT imports for productivity growth in Canada suggest that industrial policies should increasingly focus on these industries in the new global knowledge-based economy. In this economy, diffusion of IT-related technologies is as important as their creation. Finally, the significance of large international R&D spillovers for the Canadian economy underlines the importance of trade and investment policies that help us capture new ideas and knowledge developed abroad.

NOTES

1. In most cases information technology includes computer hardware and component manufacturing, computer software development and various computer-related services combined with communications equipment and component manufacturing and telecommunications services.
2. There is one related empirical study by De Long and Summers (1991) based on international cross-country data which found that equipment investment has a highly beneficial impact on economic growth, and that the spillovers from equipment investment are very substantial. However, the study does not separate IT from other equipment capital.
3. A useful survey of technology diffusion and externalities can be found in Mohnen (1992, 1996) and OECD (1996*e*).
4. For recent surveys, see Brynjolfsson (1992); and Morrison and Berndt (1991).
5. However, their cross-sectional analysis shows a positive relationship.
6. A number of useful surveys exist in the field of R&D and R&D spillovers. See for example, Griliches (1994) and Mairesse and Mohnen (1994).
7. Similar to measures of R&D spillovers across firms based on their technological closeness, a commonly used measure of disembodied technology across industries is based on inter-industry patent flows (Scherer, 1982; Evanson and Putman, 1993; and Meijl, 1995). The interindustry patent flows show the proportion of patented inventions originating in one industry but used in other industries. The larger the proportion of patented inventions originating in other industries that an industry uses, the greater the spillover benefits that the industry receives from these other industries.
8. If the coefficients $\alpha_1, \alpha_2, \alpha_3$ add up to one, the production function exhibits constant returns to scale with respect to labour and physical capital. In a competitive economy with constant returns-to-scale production, the coefficients $\alpha_1, \alpha_2, \alpha_3$ equal the shares of total income accrued to labour input, IT capital and non-IT capital respectively.
9. A detailed derivation of Equation (2) is provided in Appendix A.
10. In our estimation of embodied R&D, we do not distinguish between R&D embodied in purchases of capital goods from that in intermediate goods, as in OECD study (1996*e*), given that the focus of this paper is on R&D embodied in IT goods rather than the different roles played by capital and intermediate goods in diffusing R&D.
11. It should be noted that the recent OECD study on technology diffusion (OECD 1996*e*) treats domestic diffusion differently from international diffusion. To estimate domestic technology diffusion, the OECD used a modified version of the Leontief inverse rather than the direct input-output flows used in this paper to measure second-round R&D gains. Admittedly, these second-round R&D gains are

important in the process of embodied technology diffusion. However, this methodology has shortcomings as well: First, the domestic and international diffusion of technology does not receive a uniform treatment since the OECD's measure of international diffusion does not capture these second-round gains whereas its measure of domestic diffusion effects does. This presents a difficulty in comparisons of domestic and international technology diffusion. Second, the Leontief inverse tends to magnify the measurement problem inherent in input-output matrices.

12. See Appendix B for a detailed description of the data used.

13. Statistics Canada data are used to adjust OECD data to avoid R&D double counting and convert nominal investment and R&D data to real investment and R&D data. A detailed discussion is provided in the next section.

14. Fortunately, they are available both in constant and current prices for Canada. Although Jankowski (1993) calculates R&D price deflators for 12 U.S. industries for the 1969-88 period, his industrial classification is significantly different from ours. In addition, input/output tables are available only in current prices for the United States.

15. For the United States, nominal value-added data for non-electrical machinery, office & computing machinery, electrical equipment and communications equipment are deflated by the price deflator of fabricated metals to convert them into real terms. However, real value-added data for these industries for Canada were obtained from Statistics Canada.

16. It is computed as the ratio of real IT investment to real value added.

17. A recent OECD study (1996*e*) suggested that the increasing share of services in total business R&D can be traced to three different factors. First, R&D has always existed in services (commercial R&D firms, design and engineering firms etc.) and may have increased in recent years. Second, new areas, such as multimedia, publications on CD-ROM rather than paper etc. are increasingly engaged in research activities. Third, certain activities formerly carried out by manufacturing are now assigned to services sector "spin-off" firms, e.g. software firms.

18. For the United States, the five sub-periods are slightly different from those for Canada: 1972-76, 1977-81, 1982-84, 1985-89, and 1990-93.

19. R&D deflators from Rose (1996) and Dagenais, Mohnen and Therrien (1996) are used. The R&D embodied in imported goods is computed using ratios of nominal R&D expenditures to nominal value added in foreign industries since we do not have real R&D data for these foreign industries.

20. The costs associated with R&D are, in fact, embedded in the costs of the traditional factors of production. For example, the labour input includes the costs of R&D personnel while capital input includes laboratories and machinery used for R&D. We are able to correct this double-counting problem by separating total R&D expenditures into labour costs, material costs, and capital expenditures using the R&D component ratios in Statscan Catalogue no. 88-202. We also correct this

problem in the IT and non-IT investment data. As it turns out, this adjustment is negligible across most industries except for the two IT-producing sectors.

21. The null hypothesis that there is no heteroscedasticity is rejected in all regressions. Therefore, we only report heteroscedasticity-adjusted *t* statistics.

22. In fact, when we estimate the impact of aggregate (the sum of IT and non-IT investments) net investment and aggregate replacement investment separately on productivity growth using a specification similar to Equation (2), the net investment rate is found to have a strong positive impact on productivity growth, while the replacement investment rate is not significant.

23. See Lowe (1996).

24. As in the results for Canada, we found no evidence of decreasing returns to IT investments. Although we do not report the results in Table 11, when we introduce interaction terms between the IT investment rate and the period dummies, none of the coefficients on the interaction terms between IT investment and period dummies are statistically significant.

APPENDIX A:
EMPIRICAL MODEL RELATING PRODUCTIVITY TO INVESTMENT AND TECHNOLOGY

Assume that the production of industry i can be characterized by the following Cobb-Douglas function,

$$\text{(A1)} \quad Y_i = L_i^{\alpha_1} K_{1i}^{\alpha_2} K_{2i}^{\alpha_3} R_i^{\alpha_4} S_{di}^{\alpha_5} S_{fi}^{\alpha_6} e^{\alpha_0 t}.$$

The above production function expresses the output (Y_i) of industry i as a function of its labour input L_i; IT physical capital K_{1i}; non-IT physical capital K_{2i}; own R&D capital R_i; R&D capital embodied in purchases of domestic goods and services S_{di}; and R&D capital embodied in imported goods S_{fi}. The parameters $\alpha_1 - \alpha_6$ are output elasticities.

Taking the logarithms of Equation (A1) and then taking the first order derivatives with respect to time *t*, we have a standard output growth equation,

$$\text{(A2)} \quad \frac{\dot{Y}_i}{Y_i} = \alpha_1 \frac{\dot{L}_i}{L_i} + \alpha_2 \frac{\dot{K}_{1i}}{K_{1i}} + \alpha_3 \frac{\dot{K}_{2i}}{K_{2i}} + \alpha_4 \frac{\dot{R}_i}{R_i} + \alpha_5 \frac{\dot{S}_{di}}{S_{2i}} + \alpha_6 \frac{\dot{S}_{fi}}{S_{2i}} + \alpha_0,$$

where the dots denote the first derivatives with respect to time.

Equation (A2) shows the rate of growth of output as the sum of the rate of pure technical change and a weighted sum of rates of growth of labour, IT capital, non-IT capital, R&D capital, R&D capital embodied in purchases of domestic goods and services, and R&D capital embodied in imports.

Subtracting the growth rate of labour input $\dot{L}_i / L_i$ from both sides of Equation (A2) yields the following equation for the labour productivity growth rate of industry *i*:

$$\text{(A3)} \quad \frac{\dot{y}_i}{y_i} = -(1-\alpha_1) \frac{\dot{L}_i}{L_i} + \alpha_2 \frac{\dot{K}_{1i}}{K_{1i}} + \alpha_3 \frac{\dot{K}_{2i}}{K_{2i}} + \alpha_4 \frac{\dot{R}_i}{R_i} + \alpha_5 \frac{\dot{S}_{di}}{S_{di}} + \alpha_6 \frac{\dot{S}_{fi}}{S_{fi}} + \alpha_0,$$

where $y_i = Y_i / L_i$, the labour productivity of industry *i*.

Using the definition for output elasticities $\alpha_2, \alpha_3, \alpha_4, \alpha_5$, (for example, α_3, the output elasticity with respect to non-IT capital, equals $\partial Y_i / \partial K_{2i} \cdot K_{2i} / Y_i$), Equation (A4) can be rewritten as:

$$\text{(A4)} \quad \frac{\dot{y}_i}{y_i} = -(1-\alpha_1) \frac{\dot{L}_i}{L_i} + \frac{\partial Y_i}{\partial K_{1i}} \frac{\dot{K}_{1i}}{Y_i} + \frac{\partial Y_i}{\partial K_{2i}} \frac{\dot{K}_{2i}}{Y_i} + \frac{\partial Y_i}{\partial R_i} \frac{\dot{R}_i}{Y_i} + \frac{\partial Y_i}{\partial S_{di}} \frac{\dot{S}_{di}}{Y_i} + \frac{\partial Y_i}{\partial S_{fi}} \frac{\dot{S}_{fi}}{Y_i} + \alpha_0$$

Letting $\beta_1 = -(1-\alpha_1)$, $\beta_2 = \partial Y_i / \partial K_{1i}$, $\beta_3 = \partial Y_i / \partial K_{2i}$, $\beta_4 = \partial Y_i / \partial R_i$, $\beta_5 = \partial Y_i / \partial S_{di}$, $\beta_6 = \partial Y_i / \partial S_{fi}$, and $\beta_0 = \alpha_0$ and adding an error term ε_i, we obtain Equation (2) in the main text.

APPENDIX B: DATA SOURCES AND DEFINITIONS

Variable	Description	Sources
	Value added in 1985 prices – for manufacturing industries – for service industries	 OECD Structural Analysis Industrial (STAN) Database[1] OECD International Sectoral Database (ISDB)[2]
L_i	Employment, number of employees plus self-employed – for manufacturing industries – for service industries	 OECD STAN Database OECD ISDB
$\dot{K}_{1i}$	IT investment, domestically sourced and imported investment goods flows from office & computing machines and radio, TV & communications equipment	OECD Input-Output Database (IOD)[3] domestically sourced and imported investment goods flows submatrices
$\dot{K}_{2i}$	Non-IT investment, domestically sourced and imported investment goods flows from all other industries excluding those from office & computing machines and radio, TV & comm. equipment	OECD IOD domestically sourced and imported investment goods flows submatrices
$\dot{R}_i$	R&D expenditures	OECD Analytical Database for Business Enterprise R&D (ANBERD)[4]
X_{ji}	the amount of domestic intermediate and investment goods flows from j to i	OECD IOD domestic intermediate goods flows and domestically sourced investment goods flows submatrices
α_{jk}	country k's imports of good j /total imports of good j	OECD Bilateral Trade Database (BTD)[5]
M_{ji}	Total imports of good j by industry i	OECD IOD imported intermediate goods and imported investment goods submatrices[6]

1 This database provides the most complete internationally comparable OECD data on industrial activity (employment, exchange rate, purchasing power parity rate, exports, imports, gross fixed capital

formation, labour compensation, production, value added). It was created to fill the gap that exists between detailed data collected through industrial surveys, which lack international comparability, and national accounts, which are internationally comparable but are only available at fairly aggregated levels. The data cover 49 manufacturing industries for 22 OECD countries.

2 The database provides consistent industry data for 14 OECD countries for 2 primary, 13 manufacturing, 2 utility and 7 service industries based on the wealth of industrial and national accounts statistics published by national and international statistical agencies. It contains value-added, employment, gross fixed capital formation, gross capital stock, gross capital stock for machinery and equipment, foreign trade, labour compensation, gross operating surplus, net indirect taxes and total factor productivity index.

3 These input-output tables break down inter-industrial transaction flows of goods and services into those that are domestically produced and those that are imported, and into intermediate and capital goods. The tables are available for 10 OECD countries based on the second revision of the International Standard Industrial Classification (ISIC, Rev. 2).

4 The database presents current price business enterprise total intramural expenditure on R&D (BERD) for 26 manufacturing industries in 15 OECD countries.

5 The database is derived from the OECD's Foreign Trade by Commodities Data System (FTS). Imports and exports are grouped according to the country of origin and the country of destination of the goods. The data have been converted from UN SITC to an ISIC classification scheme that matches STAN, I/O and ANBERD databases.

6 All these databases are available from the OECD.

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