Information technology and labour productivity growth: an empirical analysis for Canada and the United States

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1. Introduction

Over the past two decades, most industrialized economies have become more information technology (IT) intensive as spending on IT-related goods 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. Two inter-related forces have contributed to these developments. First, communications and information processing costs have fallen dramatically, and this has spurred and deepened globalization. Secondly, 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, 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 per cent of IT goods. This has raised questions related to the implications of IT investments.[1]

Until recently, there has been little empirical evidence that IT capital has contributed to increases in output and productivity growth.[2] In this regard, 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. However, they did find some evidence that industries with a higher proportion of high-tech capital had higher measures of economic performance.[3] 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 half of the productivity benefits imputed to IT in earlier studies, the elasticity of IT remains positive and statistically significant.

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None of these studies, however, took account of domestic and international R&D spillovers from the IT sector when analyzing the relationship between IT investment and productivity growth.[4] For a small open economy such as Canada's which relies a great deal on international trade and FDI, omitting this could potentially bias the results.[5]

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 investment from foreign and domestic sources.

Our empirical results are based on OECD industry data for Canada and the United States. We find strong evidence that IT investments and international R&D spillovers, particularly those embodied in IT imports, contribute to higher labour productivity growth in Canadian industries.

The paper proceeds with a brief description of the empirical model. In section 3, we present a general overview of the data and trends. Section 4 gives regression results. Finally, in the last section, we offer conclusions and discuss policy issues.

2. Empirical framework

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

2.1 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 spillovers. The latter consists of R&D embodied in purchases of domestic and foreign 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 foreign goods and services (S_{fi}):

$$Y_i = L_1^{\acute{a}_1} K_{1i}^{\acute{a}_2} K_{2i}^{\acute{a}_3} R_i^{\acute{a}_4} S_{di}^{\acute{a}_5} S_{fi}^{\acute{a}_6} e^{\acute{a}_0 t}, \qquad (1)$$

where $\acute{a}_1$, $\acute{a}_2$ and $\acute{a}_3$ are the output elasticities of labour input, IT capital and non-IT capital, respectively;[6] and $\acute{a}_4$, $\acute{a}_5$ and $\acute{a}_6$ 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 $\acute{a}_0$ represents the rate of exogenous 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:[7]

$$\left(\frac{\dot{y}}{y}\right)_i = \hat{a}_0 + \hat{a}_1\left(\frac{\dot{L}}{L}\right)_i + \hat{a}_2\left(\frac{\dot{K}_1}{Y}\right)_i + \hat{a}_3\left(\frac{\dot{K}_2}{Y}\right)_i + \hat{a}_4\left(\frac{\dot{R}}{Y}\right)_i + \hat{a}_5\left(\frac{\dot{S}_d}{Y}\right)_i + \hat{a}_6\left(\frac{\dot{S}_f}{Y}\right)_i + \mathring{a}_i, \qquad (2)$$

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 foreign goods and services; and ε_i is an error term.

In equation (2), the coefficients $\hat{a}_2$ through $\hat{a}_6$ represent the rates of return on various types of capital and spillover variables as explained in appendix A; $\hat{a}_0$ is the rate of exogenous technical change; finally, $\hat{a}_1$ represents the output elasticity of labour input minus one or ($\acute{a}_1$ - 1).

2.2 *Measurement of R&D Spillovers*

Here, we discuss the methodology used to construct R&D spillover variables. We assume that industry transaction flows act as carriers of R&D (Griliches 1979; Sakurai et al. 1996). Accordingly, the domestic R&D spillover variable for industry i is calculated as a weighted sum of R&D intensities across all industries with the weights being the amounts of goods and services industry i purchases 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.[8] R&D embodied in purchases of domestic goods and services $(\dot{S}_{di})$ can be specified as,

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

We distinguish R&D embodied in purchases of domestic IT goods from that embodied in non-IT goods and services by applying equation (3) separately to IT goods and non-IT goods and services. For example, R&D embodied in purchases of domestic IT goods for 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 products.

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,

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

In (4) M_{ji} is the total amount of good (or service) j imported by industry i, $\acute{a}_{jk}$ is the import share of country k for good (or service) j, $M_{ji}\acute{a}_{jk}$ is the amount of good (or service) j industry i imported from country k, and $(\dot{R}/Y)_{jk}$ is the R&D investment rate of the industry producing good (or service) 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 the country of origin. This import share is assumed to be the same across all industries. For example, if 80 per cent of Canadian computer imports come from the United States, it is assumed that imported computers from the United States account for 80 per cent of all computers used in all Canadian industries.

Subsequently, we apply equation (4) separately to IT and non-IT imports to distinguish between R&D embodied in IT imports and R&D embodied in non-IT imports. For instance, R&D embodied in IT imports is calculated as a weighted sum of R&D intensities in IT-goods producing industries in foreign countries. 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.[9]

3. The data and trends

The data used for our empirical analysis are mainly drawn from a number of OECD databases: the International Sectoral Database (ISBD) 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). We provide in appendix B details about data sources and the construction of the variables for estimation purposes. Here, we only highlight some features of the databases.

First, the Industrial STAN database and the ISDB are used to compute labour productivity for manufacturing and services industries, respectively. Second, I-O tables from the IOD are used to calculate gross IT and non-IT investments. Note that we identify 'computers and office machinery' (Sector 16), and 'communication equipment' (Sector 18) as IT (producing) industries and the rest as non-IT producing industries. The I-O tables are available only for a selected number of years from around 1970 to around 1990. Therefore, IT and non-IT investments are available for only those years in which the I-O tables are available. 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 spillovers, which are the R&D effects 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 spillovers from foreign sources; that is, the effects embodied in purchases of imported goods and services.

There are, however, two potential problems associated with I-O tables. First, domestic investment flow sub-matrices are available only as gross rather than net capital flows. Thus, we are constrained 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 only to carry out our analysis using nominal investment and R&D data for the United States.[10]

We now turn to an overview of summary statistics and notable trends. The trends are compared between the 70s and 90s to cover our sample period in this paper. We begin with labour productivity growth.

3.1 Labour productivity growth

Table 1 presents average annual labour productivity growth by industry for Canada and the United States for the 1971-93 period.[11] The 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 results: first, in the United States, the IT producing industries -- computers and office machinery (#14 in tables 1-5) followed by communication equipment (#16) -- recorded the highest and second highest average annual labour productivity growth over the sample period. In Canada, the office and computing machinery industry had the highest labour productivity growth. However, the communication equipment industry lagged behind drugs and medicine, non-ferrous metals, shipbuilding and other transportation equipment industries.

3.2 IT investment

As depicted in columns (1) and (2) of table 2, from 1971 to 1990, the real IT investment rate in Canada[12] rose in twenty three of the twenty six manufacturing and services industries while the real non-IT investment rate increased in only seven industries. When we examine the gross investment data in nominal terms (columns 3 and 4), there is less of a pattern of increases in IT investment. One reason for this may be that the investment data in nominal terms do not take into account quality improvements in computers.

Table 3 presents U.S. nominal IT and non-IT investment rates.

3.3 Own R&D and R&D spillovers

We now turn to the R&D variables. As discussed earlier, labour productivity growth in our model depends on its own R&D as well as on R&D spillovers from other industries through purchases of domestic and imported goods and services (embodied R&D).

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 & print.	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 prod.	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 mach.	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] For the United States, the industrial chemicals industry includes drugs and medicine for the United States. [2] Other manufacturing includes professional goods for Canada. [3] Wholesale & retail trade includes restaurants and hotels. [4] Here, the total business sector is defined to include manufacturing, services and construction industries.

TABLE 2
Summary statistics on IT and non-IT real gross investment for Canada: 1971 and 1990

	Real				Nominal			
	IT rate (%) (1)		Non-IT rate (%) (2)		IT rate (%) (3)		Non-IT rate (%) (4)	
ISIC Rev. 2	1971	1990	1971	1990	1971	1990	1971	1990
1. Food, bev. & tobacco	0.13	0.81	0.35	0.42	10.51	9.71	14.55	11.37
2. Textiles & leather	0.15	0.47	0.25	0.28	7.04	7.64	17.61	8.52
3. Wood & furniture	0.11	0.17	0.17	0.12	14.64	10.45	23.67	10.43
4. Paper & print.	0.26	0.75	0.44	0.41	25.75	32.10	38.00	37.08
5. Industrial chemicals[1]	0.32	2.08	0.54	1.31	16.81	23.88	29.73	24.93
6. Drugs and medicine	0.31	0.82	0.47	0.55	11.32	9.10	21.44	9.48
7. Petroleum & coal	0.06	2.32	...	2.20	85.69	62.81	72.56	37.30
8. Rubber & plastics	0.15	1.48	0.19	0.72	17.80	21.38	36.33	26.92
9. Non-metallic mineral	0.12	0.83	0.27	0.44	11.40	16.93	17.54	18.74
10. Iron & steel	0.29	0.42	0.41	0.31	25.19	30.25	41.81	26.59
11. Non-ferrous metals	0.36	0.95	0.43	0.63	27.50	63.49	47.18	58.94
12. Metal products	0.19	0.19	0.24	0.12	8.43	6.72	15.34	7.11
13. Non-elec. mach.	0.16	0.84	0.31	0.45	4.42	7.92	8.15	9.49
14. Office & computing	...	1.71	...	2.07	9.05	13.43	159.10	7.11
15. Electric apparatus	0.27	1.65	0.44	0.84	8.58	5.55	16.90	6.97
16. Communication eq.	0.15	1.43	0.20	0.87	6.28	5.70	12.53	6.04
17. Shipbuilding	1.33	0.30	0.73	0.18	7.28	6.24	41.83	9.51
18. Other transport	0.53	0.12	0.48	0.13	6.76	5.34	20.05	4.67
19. Motor vehicles	0.26	0.49	0.41	0.35	5.63	13.66	11.55	12.35
20. Aircraft	0.23	0.31	...	0.14	3.72	6.04	6.32	8.80
21. Oth. manufact.[2]	0.07	0.52	0.19	0.26	4.61	3.61	9.11	4.13
Total Manufacturing	**0.20**	**0.84**	**0.34**	**0.48**	**13.94**	**17.33**	**23.95**	**18.28**
22. Elect., gas & water	1.45	6.03	3.00	3.26	84.70	54.30	124.83	57.96
23. Whole. & ret. trade[3]	0.64	1.15	1.13	0.63	9.37	5.10	16.12	5.51
24. Trans. & communi.	6.00	7.53	4.61	7.00	24.17	20.41	59.50	18.19
25. FIRE & bus. ser.	0.07	1.11	0.15	0.56	4.51	8.32	7.54	8.74
26. Social & per. ser.	0.78	7.48	1.38	3.88	8.55	21.21	13.97	24.97
Total services	**1.25**	**3.11**	**1.54**	**1.96**	**14.41**	**13.30**	**26.03**	**14.07**
27. Construction	0.03	0.22	0.05	0.11	4.88	4.58	9.51	5.53
Total business sector[4]	**0.80**	**2.31**	**1.03**	**1.44**	**13.29**	**13.45**	**23.83**	**14.37**

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

TABLE 3
Summary statistics on IT and non-IT nominal gross investment for US: 1972 and 1990

	IT investment rate (%)		Non-IT investment rate (%)	
ISIC Rev. 2	1972	1990	1972	1990
1. Food, beverages & tobacco	0.28	0.55	6.77	7.63
2. Textiles, apparel & leather	0.40	0.78	6.37	6.84
3. Wood products & furniture	0.21	0.38	6.95	5.65
4. Paper & print.	0.85	2.37	7.73	12.28
5. Industrial chemicals[1]	0.69	1.19	8.87	8.07
6. Petroleum & coal products	0.99	2.30	12.60	14.22
7. Rubber & plastic products	0.21	0.36	8.92	11.67
8. Non-metallic mineral prod.	0.50	0.77	10.32	9.77
9. Iron & steel	0.24	0.64	7.61	13.28
10. Non-ferrous metals	0.98	1.38	11.09	10.16
11. Metal products	0.35	0.70	5.88	6.68
12. Non-electrical machinery	0.49	0.85	5.37	6.05
13. Office & computing mach.	6.43	5.95	5.83	2.88
14. Electric apparatus, nec	0.92	2.93	4.58	5.44
15. Communication equipment	1.83	5.84	6.32	7.45
16. Shipbuilding & repairing	0.52	0.69	6.40	4.20
17. Other transport	0.61	1.63	7.51	10.20
18. Motor vehicles	0.34	0.67	8.45	13.71
19. Aircraft	0.41	1.06	1.99	3.65
20. Professional Goods	0.48	1.39	3.58	5.42
21. Other manufacturing[2]	0.34	0.44	5.57	4.37
Total manufacturing	**0.57**	**1.46**	**6.94**	**8.09**
22. Electricity, gas & water	0.47	3.56	15.62	22.09
23. Wholesale & retail trade[3]	0.36	1.12	4.40	6.90
24. Transport & communication	6.80	6.00	14.24	9.93
25. FIRE & business services	0.84	1.82	3.11	2.89
26. Social & personal services	0.74	1.81	6.85	5.29
Total services	**1.39**	**2.11**	**6.06**	**5.95**
27. Construction	0.09	0.20	10.14	7.75
Total business sector[4]	**1.06**	**1.87**	**6.57**	**6.51**

[1] For the United States, the industrial chemicals industry includes drugs and medicine. [2] Other manufacturing includes professional goods for Canada. [3] Wholesale & retail trade includes restaurants and hotels. [4] Here, the total business sector is defined to include manufacturing, services and construction industries.

In table 4, we present a measure of the R&D investment rate (R&D expenditure as a percentage of value added, $\dot{R}/Y$) by industry for both Canada and the United States.[13] The data indicate quite clearly that R&D is still overwhelmingly performed in the manufacturing industries. Yet services account for an increasing share of total R&D intensity.[14] Although not shown in table 4, 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 per cent of total intramural R&D expenditures in Canada and 14 per cent 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 the textile, apparel and leather, non-ferrous metals, and the communication equipment industries.

International R&D spillovers are of great importance, especially in small open economies (see, for example, Papaconstantinou et al. 1996 and Coe and Helpman 1995). Table 5 shows the patterns of R&D spillovers in Canada and the United States.

First, the gap in technological sophistication between industries in Canada and the United States -- measured by total R&D intensity $(\dot{R}/Y + \dot{S}_d/Y + \dot{S}_f/Y)$[15] -- appears to be smaller than what R&D investment rates ($\dot{R}/Y$) in table 4 would suggest. In fact, the two IT industries in Canada surpassed their counterparts in the United States in total R&D intensity for the period 1990-93. This is due to the fact that R&D embodied in imports represents a sufficiently larger share of total R&D intensity in Canada than in the United States.[16] For a more recent period of 1990-93, R&D embodied in imports of Canadian industries accounted for about 66 per cent of total R&D intensity, while it accounted for a negligible 8 per cent in U.S. industries.[17]

Although not shown here, the share of R&D embodied in IT goods in total R&D intensity increased in Canada but declined in the United States.

4. Regression analysis

This section discusses the estimated results of equation (2). Regressions were 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 regressed the annual average labour productivity growth rate of an industry on the IT and non-IT investment rates for each of the five sub-periods (evaluated at the beginning of the period) and the mean values of the R&D variables over the same time periods. Time dummies for these sub-periods were introduced to allow for period-specific effects on labour productivity growth not attributable to investment and R&D variables.[19]

TABLE 4
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 & print.	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 prod.	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 mach.	8.97	35.47	73.56	44.18
15. Electric apparatus, nec	2.65	2.37	17.93	3.11
16. Communication eqpt.	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] For the United States, the industrial chemicals industry includes drugs and medicine.
[2] Other manufacturing includes professional goods for Canada. [3] Wholesale & retail trade includes restaurants and hotels. [4] Here, the total business sector is defined to include manufacturing, services and construction industries.

TABLE 5
R&D spillovers in Canada and the United States: 1973-76 and 1990-93

	Canada				United States			
	Total R&D intensity[1]		Share of R&D embodied in imports[2]		Total R&D intensity[1]		Share of R&D embodied in imports[2]	
ISIC Rev. 2	1973-76	1990-93	1973-76	1990-93	1973-76	1990-93	1973-76	1990-93
1. Food, bev. & tobacco	1.75	2.09	43.05	49.01	2.74	4.11	1.77	4.76
2. Textiles & leather	1.59	3.59	59.70	64.37	3.31	5.63	3.63	5.45
3. Wood & furniture	1.20	2.32	59.95	57.24	2.00	2.69	2.26	6.43
4. Paper & print.	2.14	3.10	45.73	49.14	3.05	5.48	3.65	7.30
5. Industrial chemicals[3]	6.76	9.48	48.07	60.70	12.79	20.77	2.98	6.53
6. Drugs and medicine	10.98	17.33	61.63	55.54	...	...	...	...
7. Petroleum & coal	13.22	23.53	43.25	51.58	16.13	27.32	2.82	6.45
8. Rubber & plastics	4.47	7.16	68.76	76.48	8.86	12.07	2.09	5.93
9. Non-metallic mineral	1.96	3.63	54.03	68.86	4.35	6.29	2.47	6.70
10. Iron & steel	2.93	5.03	48.22	54.81	3.69	6.39	7.69	8.57
11. Non-ferrous metals	8.10	12.78	33.56	46.83	10.77	12.76	10.57	9.48
12. Metal products	2.64	4.46	40.89	48.03	3.58	4.61	4.20	8.99
13. Non-elec. mach.	3.39	4.97	63.95	70.38	6.24	7.91	2.55	10.46
14. Office & computing	68.38	95.10	95.95	89.03	125.08	67.39	1.09	14.57
15. Electric apparatus	7.00	7.84	48.82	57.79	23.84	9.90	2.11	10.87
16. Communication eq.	25.10	53.62	58.88	69.31	39.95	36.05	2.17	12.24
17. Shipbuilding	4.30	25.56	65.92	53.71	5.14	4.70	2.28	9.34
18. Other transport	8.81	11.79	72.47	91.95	21.17	46.97	3.14	6.48
19. Motor vehicles	13.58	30.87	91.43	93.74	22.56	49.36	2.58	8.71
20. Aircraft	32.02	41.18	82.79	69.07	63.81	52.11	3.44	9.99
21. Professional goods	...	...	...	...	10.71	21.25	3.24	11.76
22. Oth. manufact.[4]	2.08	5.04	67.43	79.00	6.45	5.97	4.61	7.64
Total Manufacturing	**5.48**	**11.39**	**69.01**	**74.93**	**11.93**	**16.53**	**3.05**	**8.93**
23. Elect., gas & water	3.79	3.42	79.15	68.54	2.61	5.12	1.42	6.62
24. Whole. & ret. trade[5]	1.00	1.12	70.54	49.31	0.80	2.36	1.37	7.25
25. Trans. & communi.	2.55	5.32	49.49	37.42	4.35	4.95	3.21	8.13
26. FIRE & bus. ser.	0.48	1.34	45.68	45.90	0.95	1.91	1.63	6.64
27. Social & per. ser.	1.09	3.30	76.74	83.59	2.22	3.49	2.48	6.96
Total services	**1.26**	**2.14**	**62.46**	**54.70**	**1.59**	**2.74**	**2.31**	**7.14**
28. Construction	1.74	1.91	37.11	34.39	3.85	4.31	1.26	6.10
Total business sector[6]	**2.59**	**4.31**	**63.96**	**65.75**	**4.81**	**5.84**	**2.64**	**8.01**

[1] Total R&D intensity includes its own R&D, R&D embodied in purchases of domestic goods and services, and R&D embodied in imports ($\ddot{R}/Y+\ddot{S}_d/Y+\ddot{S}_f/Y$). [2] The ratio of $\ddot{S}_f/Y$ to ($\ddot{R}/Y+\ddot{S}_d/Y+\ddot{S}_f/Y$). [3] Industrial chemicals industry includes drugs and medicine for the United States. [4] Other manufacturing includes professional goods for Canada. [5] Wholesale & retail trade includes restaurants and hotels. [6] Here, the total business sector is defined to include manufacturing, services and construction industries.

4.1 Results for Canada

The estimated results of equation (2) estimation for Canada and the United States are reported in tables 6 and 7, respectively.[20] We first discuss the empirical results for Canada. The first three columns of table 6 report the results based on real investment and real R&D expenditures[21] after correcting for R&D double counting[22] 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 embodied in purchases of goods and services. Specification (2) corresponds exactly to equation (2) where the embodied R&D is decomposed into that embodied in domestic goods and services, and in imports. Specification (3) distinguishes R&D embodied in IT goods and non-IT goods and services for both domestic and international R&D. The last three columns of this table correspond to the three specifications mentioned above for nominal investment and R&D data.

We will first focus on the estimated results based on real investment and R&D data. As discussed earlier, the coefficients of the real physical investment variables such as IT and non-IT investments, and R&D investment, are interpreted as the rate of return to investment. This is based on the assumption that the (average) rate of return to investment is equalized across sectors.[23]

Three variables are found to be robustly correlated with labour productivity growth at the 5 per cent level. These are 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 at the 5 per cent level in all specifications. The time period dummies for the 1976-80, 1986-89 and 1990-93 periods are statistically significant at the 5 per cent level. The constant term, interpreted as exogenous technical change, is also statistically significant at the 5 per cent level.

The coefficients on the real IT investment rate are statistically significant in all specifications at the 5 per cent level. The rate of return on IT investments is between 27 and 36 per cent per year. Our results are consistent with the findings of two other recent studies that also found positive correlations between productivity growth and IT investment (Siegel and Griliches 1991; Brynjolfsson and Hitt 1995). Both studies found that there are high returns to IT investments and that the rates of return to IT capital are higher in services than in the manufacturing sector.

The real non-IT investment rate has the expected positive sign in all specifications, though the coefficient is not statistically different from zero at the 5 per cent level. This is a somewhat surprising result. The insignificant impact of non-IT investments on labour 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

TABLE 6
Regression results for Canada for 1971-1993
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	0.027	0.030	0.037	0.030	0.032
	(4.394)	(4.398)	(4.871)	(5.072)	(5.007)	(5.262)
Growth of labour input	-0.827	-0.741	-0.646	-0.660	-0.716	-0.689
	(6.263)	(6.876)	(5.850)	(3.676)	(5.510)	(5.825)
IT investment rate	0.359	0.357	0.272	0.331	0.364	0.238
	(3.599)	(3.915)	(3.060)	(2.258)	(2.957)	(1.808)
Non-IT investment rate	0.017	0.017	0.008	0.002	0.018	0.017
	(1.481)	(1.516)	(0.739)	(0.131)	(1.598)	(1.582)
R&D investment rate	0.217	0.062	-0.011	0.267	0.079	0.040
	(3.334)	(1.190)	(0.211)	(3.213)	(1.392)	(0.629)
Domestic R&D spillover	---	-0.034	---	---	-0.222	---
		(0.251)			(1.805)	
Domestic R&D spillover embodied in IT goods	---	---	-0.066	---	---	-0.108
			(0.399)			(0.798)
Domestic R&D spillover embodied in non-IT goods	---	---	0.234	---	---	-0.126
			(0.900)			(0.631)
International R&D spillover	---	0.236	---	---	0.298	---
		(4.300)			(4.427)	
International R&D spillover embodied in IT imports	---	---	0.368	---	---	0.376
			(4.217)			(3.833)
International R&D spillover embodied in non-IT imports	---	---	0.092	---	---	0.098
			(2.172)			(2.260)
Period 2: 1976-1980	-0.021	-0.021	-0.022	-0.023	-0.021	-0.020
	(2.551)	(2.764)	(2.999)	(2.255)	(2.610)	(2.659)
Period 3: 1981-1985	-0.014	-0.015	-0.013	-0.016	-0.016	-0.012
	(1.461)	(1.831)	(1.635)	(1.410)	(1.927)	(1.458)
Period 4: 1986-1989	-0.018	-0.024	-0.025	-0.028	-0.028	-0.024
	(2.430)	(3.654)	(3.816)	(3.538)	(4.076)	(3.456)
Period 5: 1990-1993	-0.044	-0.047	-0.043	-0.042	-0.046	-0.041
	(4.345)	(4.971)	(4.573)	(3.268)	(4.587)	(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.

TABLE 7
Regression results for the United States for 1972-1993
Dependent variable: growth of labour productivity (135 observations)

Independent Variables	(1)	(2)	(3)
Constant	0.008	0.007	0.004
	(1.191)	(1.113)	(0.586)
Growth of labour input	-0.421	-0.424	-0.394
	(4.005)	(3.566)	(3.447)
Nominal IT investment rate	0.535	0.553	0.179
	(4.740)	(4.247)	(1.505)
Nominal non-IT investment rate	-0.048	-0.023	0.039
	(0.773)	(0.336)	(0.489)
Nominal R&D investment rate	0.033	0.0622	0.017
	(1.459)	(0.964)	(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	-0.015	-0.015
	(2.169)	(2.165)	(2.104)
Period 3: 1982-1984	0.023	0.024	0.027
	(3.030)	(3.121)	(3.627)
Period 4: 1985-1989	0.009	0.010	0.015
	(1.532)	(1.580)	(2.523)
Period 5: 1990-1993	0.003	0.003	0.008
	(0.343)	(0.422)	(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.

various types of conventional non-IT investment goods. Second, theoretically, the gross investment data we used in this study may be less appropriate. Only one component of gross investment, net investment, is considered to increase labour productivity growth while the other component, replacement investment, is made to maintain existing labour productivity levels.[24] The measurement error associated with using gross non-IT investment is likely to bias the coefficient towards zero.

Nonetheless, the coefficients of IT investment are statistically different from zero at the 5 per cent level despite using gross investment data. 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 semiconductors (Lowe, 1996).[25] As a result, replacement IT investment is improperly deflated leading 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 labour productivity growth in specification (1) at the 5 per cent level. The estimated rate of return is about 22 per cent per year. This is consistent with existing studies, which present rates of return from 10 per cent to 50 per cent (see, for example, Griliches 1994, and 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 multicollinearity problem between the two variables (see appendix C). This suggests 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 spillovers have a significant impact on labour productivity growth at the 5 per cent level as shown in specification (2). Indeed, our data show that the share of R&D embodied in purchases of foreign goods and services has increased over time and now accounts for almost 75 per cent of total R&D intensity in manufacturing industries.[26] The estimated rate of return to international R&D spillovers is about 24 per cent 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 R&D spillovers embodied in both IT and non-IT imports are found to have a positive and statistically significant impact on labour productivity growth at the 5 per cent level. The international R&D spillovers embodied in IT imports in Canada have a greater impact on labour productivity growth than those embodied in non-IT imports: the estimated rate of return to

R&D embodied in IT imports is about 37 per cent per year, while the rate of return to R&D embodied in non-IT imports is found to be only 9 per cent. 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 at the 5 per cent level 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 to IT investments across Canadian industries. In a recent study, Brynjolfsson and Hitt (forthcoming) suggest that the rate of return to investments in IT 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 to 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 5 per cent level. None of the coefficients on the interaction terms between IT investment and period dummies are statistically significant at the 5 per cent level.

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 IT? To examine this, we introduce a dummy variable for the service industries in specification (3). The results, although not reported in table 6, indicate that the coefficients on the dummy for service industries are positive but not statistically different from zero at the 5 per cent level. This 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 expenditures 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 6. 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.

4.2 Regression results for the United States

Now we estimate equation (2) using the U.S. data. Although discussed earlier, we would like to reiterate 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 7 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 with the U.S. data, depending on the specification. It is significant at the 5 per cent level in specifications (1) and (2) but not in specification (3). The rate of return to IT investment ranges from 18 per cent to 55 per cent 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 at the 5 per cent level 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 at the 5 per cent level. 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 7) 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 labour productivity growth (with a t-ratio of 3.34). The rate of return is estimated to be just over 7 per cent per year. This is consistent with the results obtained in most U.S. studies (see, for example, Griliches 1994).

Similar to the results obtained for Canada, the domestic R&D spillover effects are found to be statistically insignificant at the 10 per cent level for the United States as shown in specifications (2) and (3).

International R&D spillovers are found to be insignificant at the 10 per cent level 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 of international R&D spillovers embodied in IT imports on labour productivity growth at the 5 per cent level.[27]

5. Summary and conclusions

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

Our major findings are as follows.

IT investments are an important source of labour productivity growth across Canadian industries. The private rates of return on IT investments are found to be high -- on average, about 30 per cent 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 labour 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, for the U.S., international R&D spillovers, in the aggregate, are found not to be significant at the 5 per cent level. However, there is some evidence to suggest that international R&D spillovers from the IT sector are significant at the 5 per cent level and much more important than spillovers from the non-IT sector.

The implications of our findings for the empirical literature are important. First, IT investment is much more important at the margin than non-IT investment in determining labour productivity growth for both Canada and the United States. Second, the results show that R&D spillovers in Canada are primarily international in scope. Third, international R&D spillovers embodied in IT imports are more important than R&D spillovers embodied in non-IT imports with regard to contributions to labour productivity growth for both Canada and the United States.

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 argued by Bernstein (1996), 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 labour 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 the 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.

Appendix A

Empirical model relating labour productivity to investment and technology

Taking the logarithm of the Cobb-Douglas production function (equation 1) and then taking the first order derivatives with respect to time t gives the standard output growth equation,

$$\frac{\dot{Y}_i}{Y_i} = \alpha_1 \frac{\dot{L}_i}{L_i} + \alpha_2 \frac{\dot{K}_{1i}}{K_{1i}} + \alpha_3 \frac{\dot{K}_{2i}}{K_{2i}} + \alpha_4 \frac{\dot{R}_i}{R_i} + \alpha_5 \frac{\dot{S}_{di}}{S_{2i}} + \alpha_6 \frac{\dot{S}_{fi}}{S_{2i}} + \alpha_0 \qquad \text{(A1)}$$

where dots denote the first derivatives with respect to time and the parameters α_1 - α_6 are output elasticities. Equation (A1) shows the rate of growth of output as the sum of the rate of exogenous 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 (A1) and using the definitions for the output elasticities α_2, α_3, α_4, α_5 (for example, α_3, the output elasticity with respect to non-IT capital, equals $\partial Y_i/\partial K_{2i}(K_{2i}/Y_i)$), equation (A1) can be rewritten as:

$$\frac{\dot{y}_i}{y_i} = -(1-\alpha_1)\frac{\dot{L}_i}{L_i} + \frac{\partial Y_i \dot{K}_{1i}}{\partial K_{1i} Y_i} + \frac{\partial Y_i \dot{K}_{2i}}{\partial K_{2i} Y_i} + \frac{\partial Y_i \dot{R}_i}{\partial R_i Y_i} + \frac{\partial Y_i \dot{S}_{di}}{\partial S_{di} Y_i} + \frac{\partial Y_i \dot{S}_{fi}}{\partial S_{fi} Y_i} + \alpha_0 \qquad \text{(A2)}$$

where $y_i = Y_i/L_i$, the labour productivity of industry i. 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. β_2 to β_6 represent the marginal product of various types of capital or the gross rate of return.

Appendix B

Data Sources and Definitions

Variable	Description	Sources
Y_i	Value-added in 1985 prices	Data for manufacturing industries is obtained from OECD (1996) Structural Analysis Industrial (STAN) database[1]; data for service industries is obtained from OECD (1995) International Sectoral Database (ISDB)[2]
L_i	Total employment = number of employees plus self-employed	Data for manufacturing industries is obtained from the STAN; data for service industries is obtained from the ISDB.
K_{1i}	IT investment	Obtained from the OECD (1995) Input-Output Database[3] -- capital flow matrices for domestic and imported goods. IT-related sectors are Sector 16 (Office and computing machinery), and Sector 18 (Radio, TV, and communications equipment).
K_{2i}	Non-IT investment	Obtained from the OECD Input-Output Database -- capital flow matrices for domestic and imported goods.
R_i	R&D Expenditures	Obtained from the OECD (1996) Analytical Database for Business Enterprise R&D (ANBERD)[4]
X_{ji}	Domestic intermediate and capital good flows from industry j to industry i	Obtained from the OECD Input-Output Database

$\acute{a}_{jk}$	Import share of country k for good import j	Obtained from the OECD (1996) Bilateral Trade Database (BTD)[5]
M_{ji}	Total imports of good j by industry i	Obtained from the OECD Input-Output Database -- imported intermediate goods and imported investment goods flow matrices

[1] OECD (1996) STAN Database for Industrial Analysis -- this database provides the most complete internationally comparable data on industrial activity (employment, exchange rate, purchasing power parity rate, exports, imports, gross fixed capital formation, labour compensation, production, value added) for 22 OECD countries. 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 covers 49 manufacturing industries.
[2] OECD (1995) International Sectoral Database -- 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 the total factor productivity index.
[3] OECD (1996) Input-Output Database -- the I-O 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] OECD (1996) Analytical Database for Business Enterprise R&D -- the database provides current price business enterprise total intramural expenditure on R&D (BERD) for 26 manufacturing and service industries in 15 OECD countries.
[5] OECD (1996) Bilateral Trade Database -- 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.

Notes

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1 For debate about the 'productivity paradox', see Brynjolfsson (1993) and Meijl (1995). Brynjolfsson (1993) puts forward four factors to explain this paradox: measurement errors, lags, distribution and mismanagement, but it is still unclear whether the productivity paradox arises from a problem of measurement or from real economic effects.
2 See Gera, Gu and Lee (1998) for an extensive literature review.

3 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 data. In contrast, Loveman (1994) using a data set of 60 large firms from 1974-84 found no evidence of strong productivity gains from IT investments.

4 A useful survey on technology diffusion and externalities can be found in Mohnen (1996) and OECD (1996).

5 Some recent studies have found evidence of domestic and international R&D spillovers from the IT sector (see, for example, Bernstein 1996, Meijl 1995, and Sakurai et al. 1996) but they did not consider the role of IT investment.

6 If the coefficients $\acute{a}_1$, $\acute{a}_2$, $\acute{a}_3$ sum 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 $\acute{a}_1$, $\acute{a}_2$, $\acute{a}_3$ equal the shares of total income accrued to labour input, IT capital and non-IT capital respectively.

7 The investment rate (or investment intensity) is defined as expenditure on investment divided by total output. This applies to investment on all three types of capital inputs; i.e., IT, non-IT and R&D. See appendix A for the relationship between the investment rate and capital stock growth and a detailed derivation of equation (2).

8 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 (see, for example, OECD, 1996). This is because we focus on R&D embodied in IT goods rather than on the roles played by capital and intermediate goods in R&D diffusion.

9 It should be noted that the recent OECD study on R&D spillovers (OECD, 1996) treats domestic spillovers differently from international spillovers. To estimate domestic R&D spillovers, the study used a modified version of the Leontief inverse rather than 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 spillovers; i.e. those embodied in goods and services. However, this methodology has shortcomings as well. First, the domestic and international R&D spillovers do not receive a uniform treatment since the OECD's measure of international spillovers does not capture these second-round gains whereas its measure of domestic spillovers does. This presents a difficulty in comparing domestic with international R&D spillovers. Second, the Leontief inverse tends to magnify the measurement problem inherent in input-output matrices.

10 Fortunately, the data on investment and R&D for Canada are available both in constant and current prices. 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 that of ours. Moreover, I-O tables for the United States are available only in current prices.

11 For the United States, nominal value-added data for non-electrical machinery, office & computing machinery, electric apparatus and communication 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 are obtained from Statistics Canada.

12 It is computed as the ratio of real IT investment to real value-added. As discussed earlier, the I-O tables are available only for a selected number of years. We present IT investment rates for the first and last year for which they are available.

13 R&D data are averaged over three years from 70s to 90s to avoid cyclical fluctuations.

14 A recent OECD study (1996) 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, and so on are increasingly engaged in research activities. Third, certain activities formerly carried out by manufacturing are now assigned to service sector ‘spin-off’ firms, e.g. software firms.

15 Total R&D intensity includes industry’s own R&D, R&D embodied in purchases of domestic goods and services, and R&D embodied in imports.

16 Over the 1990-93 period, the share of R&D embodied in purchased goods and services $(\ddot{S}_d/Y+\ddot{S}_f/Y)$ was over 72 per cent for all industries (excluding primary) in Canada, compared to 59 per cent in the United States.

17 Although not shown, it is worth noting that Canada relies almost exclusively on the United States for its R&D embodied in imports, while the United States acquires embodied R&D from a number of other trading partners. For instance, over the 1990-1993 period, 86 per cent of total R&D embodied in imports in Canada emanated from the United States. In contrast, Canada accounted for only 16 per cent of such R&D embodied in imports for the United States.

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

19 Industry dummies are not introduced in our regression analysis. However, when we do include a service dummy into regressions to capture differences in labour productivity growth between manufacturing and services industries, this is not found to be significant.

20 Correlation matrices for the variables used in our regression analyses are available on request.

21 R&D deflators from Rose (1996) and Dagenais, Mohnen and Therrier (1996) are used. However, 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.

22 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 Statistics Canada 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.

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

24 A referee suggested that the discussion about gross versus net capital flows is important, but it may not be critical if ‘replacement’ investment is a fairly constant proportion of total investment. 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.

25 A referee suggested that when effective prices of IT investment are dropping, they may not reflect 'quality' over time effectively. This is, in fact, an important issue in this type of estimation.

26 Previous studies such as Bernstein (1996) and Coe and Helpman (1995) found that international R&D spillovers have a strong and significant effect on total factor productivity growth.

27 Similar to the results for Canada, we found no evidence of decreasing returns to IT investments. Although we do not report the results in table 7, when we introduce interaction terms between the IT investment rate and the period dummies, none of the coefficients on the interaction terms are statistically significant.

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