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R&D AND PRODUCTIVITY GROWTH IN CANADIAN COMMUNICATIONS EQUIPMENT AND MANUFACTURING

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EXECUTIVE SUMMARY

Productivity and the factors of production are the two sources of output growth in an economy. Productivity growth generally arises from technological improvements, scale economies and other sources of efficiency gains over time. Indeed, it is important for a society to have a stable and positive long-term productivity growth rate, because the associated gains lead to improvements in living standards.

It is primarily advances in the state of knowledge through technological change which determine productivity growth over long periods of time; research and development (R&D) investments contribute directly to knowledge accumulation. Investment in R&D generates new products and production processes, and thereby contributes to productivity improvements. A distinctive feature of R&D investment is that the benefits from R&D activities spill over among firms and other organizations. Productivity growth in an industry, therefore, depends on its own R&D activities, as well as on the R&D efforts of other knowledge-generating industries. This implies that productivity growth is influenced by joint cumulative R&D activity. The significance of R&D spillovers in generating productivity growth has stimulated a growing interest in the sources of R&D spillovers. It has also been observed that high-tech industries exhibit relatively high rates of productivity growth and are important sources of R&D spillovers. Firms operating in the Canadian communications and other electronic equipment industries are centres of knowledge-based activity. Hence, this industry provides an important opportunity to consider the role of R&D investment generally in improving productivity performance.

This paper addresses three major issues.

The first issue has to do with estimating the effects of R&D spillovers from the communications equipment industry on the structure of production or factor intensities (i.e., the labour-output, intermediate input-output, physical capital-output, and R&D capital-output ratios) of the Canadian manufacturing sector (measured as net of the communications equipment industry). In addition, because spillovers from the United States have significant effects on Canadian factor requirements, those emanating from the U.S. manufacturing sector are also included. In order to determine whether the production structure of the communications equipment industry differs from that of other manufacturing industries, the effects of R&D spillovers on factor intensities in the communications equipment industry are also estimated. In this case, R&D spillovers derive from both the Canadian manufacturing sector and the U.S. electrical products industry.

The second issue relates to the contribution of R&D spillovers to productivity growth. Productivity growth in Canadian manufacturing is measured and decomposed, so that the sources of growth, and especially the contribution of spillovers from the communications equipment industry and the U.S. manufacturing sector, can be determined. In addition, a similar analysis is conducted with respect to productivity growth in the communications equipment industry, where spillovers emanate from the Canadian manufacturing sector and the U.S. electrical products industry. The results of these analyses enable us to consider the extent to which R&D capital accumulation by producers in one segment of the economy influences productivity growth of producers in other industries or sectors.

The first two issues address the effects of R&D spillovers from the viewpoint of its user or receiver. Turning to the source of spillovers, the third issue pertains to an estimation of the private and social rates of return to R&D capital. Private rates of return measure the benefits that accrue to those engaged in R&D activities; social rates of return measure the benefits that accrue to the users of the investment.

Several conclusions are reached in this paper.

First, between 1966 and 1991 the average annual rate of productivity growth in the communications equipment industry was 1.24 percent, while the growth rate for manufacturing averaged 0.50 percent. Thus, the rate of productivity growth in communications equipment was 150 percent higher than in manufacturing. Moreover, unlike manufacturing (which suffered a productivity slowdown in the post-1973 period — from 1.08 percent to 0.23 percent), the average annual productivity growth in the communications equipment industry increased by 46 percent, from 0.94 percent to 1.37 percent.

Second, as a source of spillovers, the communications equipment industry affects the production structure (i.e., factor intensities) of the manufacturing sector. Indeed, it is estimated that a 1 percent expansion of R&D capital in the communications equipment industry leads to an increase of 0.15 percent in knowledge intensity for the entire manufacturing sector. This magnitude is quite large in light of the fact that this effect emanates from a single three-digit standard industrial classification industry. In addition, spillovers from the communications equipment industry reduce factor intensities associated with physical capital, labour and intermediate inputs (such as materials).

In terms of relative importance, the R&D spillovers from the U.S. manufacturing sector generate greater effects on Canadian manufacturing factor intensities than spillovers from the communications equipment industry. It is noteworthy that the R&D capital inputs between the two North American manufacturing sectors are substitutes. A 1 percent increase in U.S. manufacturing R&D capital leads to a 0.52 percent reduction in the domestic knowledge intensity in Canadian manufacturing.

Third, factor intensities in the Canadian communications equipment industry are affected by spillovers from both Canadian manufacturing and the U.S. electrical products industry. Both sources of spillovers reduce labour and intermediate input intensities and increase the intensity of physical capital. However, the spillovers from Canadian manufacturing reduce the R&D intensity of the communications equipment industry. A 1 percent increase in the R&D capital of Canadian manufacturing leads to a 0.38 percent decline in the R&D intensity of the communications equipment industry. Combining the results of spillovers between communications equipment and manufacturing, we can see that expanding R&D capital in the communications equipment industry increases the R&D intensity of manufacturing production. This result then mitigates the need (when all other elements are held constant) for further R&D expansion in the communications equipment industry. The spillovers from the U.S. electrical products industry increase the R&D intensity in the Canadian communications equipment industry. Between these two industries, R&D capital stocks are therefore complementary. In addition, R&D capital from the U.S. electrical products industry has a greater impact on the production structure of the Canadian communications equipment industry than R&D capital from Canadian manufacturing. A 1 percent increase in R&D capital in the U.S. electrical products industry causes R&D intensity to rise by 0.65 percent in the Canadian communications equipment industry.

Fourth, the communications equipment industry is a source of important productivity gains in Canadian manufacturing. Between 1966 and 1991, about 8.5 percent of the average annual rate of productivity growth in manufacturing was accounted for by spillovers from the communications equipment industry. Moreover, this contribution increased during the post-1973 period when the productivity slowdown occurred. Thus, the spillovers were a mitigating influence on the further erosion of productivity performance in Canadian manufacturing. However, it should be recognized that the spillovers from U.S. manufacturing were the major contributor in this regard – accounting for 76 percent of the average annual rate of productivity growth in Canadian manufacturing. Spillovers from Canadian manufacturing and the U.S. electrical products industry contributed to productivity growth in the Canadian communications equipment industry. The spillovers from Canadian manufacturing accounted for only about 6 percent of productivity growth, largely dominated by the spillovers from the United States. However, the main source of productivity in the Canadian communications equipment industry was the scale economies associated with output growth, which accounted for 65 percent of productivity growth.

Fifth, the fact that the Canadian communications equipment industry and manufacturing sector are sources of productivity gains implies that there are extra-private returns to their R&D capital. The before-tax, gross of depreciation private rate of return to R&D capital averaged 17 percent between 1966 and 1991. The social rate of return pertaining to Canadian communications equipment R&D capital is estimated at 55 percent, or 225 percent higher than the private rate of return. The social rate of return associated with Canadian manufacturing R&D capital is estimated at 21 percent, or 24 percent higher than the private rate of return. These differences point to an under-investment in R&D. However, this does not mean that governments should target the Canadian communications equipment industry for special status. Although its high annual rate of productivity growth and high social rate of return distinguish this industry, there are other manufacturing industries whose social rates of return to R&D capital exceed the private rate of return.

Finally, R&D investment should be encouraged through policy instruments that focus on R&D capital formation, but these policies should not be directed towards particular industries. There are several possibilities in this regard. The government could provide information to facilitate joint ventures aimed at new product development, and joint research or "laboratory" ventures. Legislation and regulation could be amended in order to reduce the transaction costs associated with these joint ventures. Reducing the legislative and regulatory burden would also help to encourage other more indirect means of internalizing the spillovers arising from R&D. Licensing agreements are one example that come to mind.

Tax expenditures and subsidies are other policy instruments that are — and can be — directed towards R&D capital formation. It is important to recognize that any analysis of the relative costs and benefits of government tax policies aimed at R&D investment must take into account R&D spillovers. Otherwise, the benefits associated with these policies will be underestimated, not only in the way they encourage R&D investment, but also in their contribution to improving living standards through higher rates of productivity growth.

1. INTRODUCTION

The factors of production and productivity are the two sources of output growth in an economy. Increased productivity generally results from technological improvements, scale economies and other sources of efficiency gains over time and is often referred to as a measure of dynamic production efficiency. Indeed, it is important for a society to have a stable and positive rate of productivity growth over the long term because these gains lead to improvements in living standards.

Advances in the state of knowledge through technological change tend to be the primary determinants of productivity growth over long periods of time; research and development (R&D) investments contribute directly to knowledge accumulation. Investment in R&D activities generates new products and production processes, and thereby productivity improvements. A distinctive feature of R&D investment is that its benefits spill over to other firms and organizations. Thus, the rate of growth of an industry's productivity depends on its own R&D activities, as well as on the R&D efforts of other knowledge-generating industries. This implies that joint cumulative R&D activity influences productivity growth.

Because R&D spillovers have had a significant effect in generating productivity growth, there is an increased interest in the sources of these spillovers. In fact, it has been observed that high-tech industries exhibit relatively high rates of productivity growth and are important sources of R&D spillovers.[1] Consequently, detailed industry studies are crucial to understanding whether knowledge-based industries exhibit unique features in generating productivity growth within their own industries and productivity gains throughout the economy.

Firms operating in the Canadian communications and other electronic equipment industries (Canadian Standard Industrial Classification [SIC] 335) are centres of knowledge-based activities. Firms like Northern Telecom, Mitel, and Newbridge Networks are all involved in producing goods that derive from intensive R&D efforts. This industry, therefore, provides an important example of the general role of R&D investment in improving productivity. This paper addresses three major issues.

The first is to estimate the effects of R&D spillovers from the communications equipment industry on the structure of production or factor intensities (i.e., the labour-output, intermediate input-output, physical capital-output, and R&D capital-output ratios) of the Canadian manufacturing sector (*net* of the communications equipment industry). Because spillovers from the United States generate significant effects on Canadian factor requirements, (Bernstein, 1995) those emanating from the U.S. manufacturing sector are also included.

In order to determine whether the production structure of the communications equipment industry differs from that of other manufacturing industries, the effects of R&D spillovers on factor intensities in the communications equipment industry are also estimated. In this case, R&D spillovers arise from the Canadian manufacturing sector and the U.S. electrical products industry.[2]

The second issue relates to the contribution of R&D spillovers to increased productivity. Productivity growth in Canadian manufacturing is measured and decomposed, so that the sources of growth — and especially the contribution of spillovers from the communications equipment industry and the U.S. manufacturing sector — can be determined. In addition, a similar analysis is conducted with respect to productivity growth in the communications equipment industry, where spillovers emanate from Canadian manufacturing, and U.S. electrical products. This issue enables us to consider the extent to which R&D capital accumulation by producers in one segment of the economy influences the productivity growth of producers in other industries or sectors.

While the first two issues address the effects of R&D spillovers from the viewpoint of its user or receiver, the third issue estimates the private and social rates of return to R&D capital of the communications equipment industry and the manufacturing sector. Private rates of return measure the benefits that accrue to the *performers* of R&D activities; social rates of return measure the benefits that accrue to the *users* of the investment.

Under most forms of investment (in plant and equipment, for example) the firm undertaking and the one using (i.e., deriving the benefit from) the investment are usually one and the same. However, in the case of R&D investments there are externalities or spillovers. This means that other individuals or groups in society can benefit from an R&D investment initiated and undertaken by another knowledge producer. Spillovers constitute the difference between social and private returns. It is the existence of these spillovers that provides the necessary, *but not sufficient*, conditions for government action in stimulating R&D activities. In general, there is under-investment in R&D when social returns exceed private returns. This deficiency can be overcome through various private- and public-sector actions.

This study is structured in six chapters and four appendices. Chapter 2, R&D Capital and Productivity Growth, presents a general discussion on productivity growth and R&D capital. In Chapter 3, R&D and the Productivity Slowdown, we examine the role, if any, of R&D capital accumulation in the productivity slowdown that occurred in the early 1970s. Chapter 4, Spillover Elasticities, describes the results of the econometric models used to estimate the effects of R&D spillovers on factor intensities in the Canadian manufacturing sector and the communications equipment industry. In Chapter 5, Productivity Growth and Social Rate of Return, we discuss the measurement and decomposition of productivity growth and provide an analysis of the private and social rates of return. In the Conclusion, we address some policy issues raised by our analysis. Appendix 1 sets out the Theoretical Model; Appendix 2 describes the Estimation Model; Appendix 3 gives the Estimation Results; and Appendix 4 provides the Data.

2. R&D CAPITAL AND PRODUCTIVITY GROWTH

In this chapter, we develop a simple framework that shows R&D capital as a factor of production and as a source of spillovers in determining output and productivity growth. The simplest way to understand the mechanism is to consider output determination and productivity growth in the absence of R&D spillovers.

In most empirical research, output is produced by combining three inputs: labour, capital, and intermediate inputs (i.e., materials), and an indicator of technology, usually measured as a time trend.[3] Thus, production can be represented as

$$Y = F(L,M,K,t) \tag{1}$$

where the amounts of output, labour, intermediate inputs, and capital are denoted by *Y*, *L*, *M*, and *K*; *t* is the time trend and *F* represents the production function.

In order to develop a measure of productivity growth, the production function can be written in terms of growth rates:

$$y - (\alpha l + \beta m + \gamma k) = (p_y - 1)(\alpha l + \beta m + \gamma k) + \phi_t \tag{2}$$

where lower case letters represent growth rates in output and inputs, α, β, and γ are the output elasticities with respect to the three factors of production, p_y is the degree of returns to scale, and ϕ_t is the rate of technological change. The left side of equation (2) represents the rate of growth of total factor productivity (TFP), that is output growth net of input growth. The right side of the equation shows that TFP growth can be decomposed into a scale term and a technological change term.

If there are constant returns to scale, then $p_y = 1$ and TFP growth represents technological change. If $\phi_t = 0$, there is no technological change and TFP growth represents deviations from constant returns to scale. It is important to note that the degree of returns to scale and the rate of technological change are not generally constant. These variables depend on the same elements that determine input demands, such as factor prices and technology indicators.

Next, consider the role of R&D capital and spillovers. The production function becomes:

$$Y = F(L,M,K,R,t,S) \tag{3}$$

where *R* denotes R&D capital, and *S* denotes R&D spillovers. From the viewpoint of a representative producer whose production process is specified by this equation, the R&D capital of this producer is a factor of production. Thus, decisions regarding its use and rate of change are governed by the same decision calculus as for other inputs. However, unlike other inputs, there are spillovers associated with R&D capital. It is, however, beyond the scope of this paper to enter into a detailed discussion of the measurement issues associated with R&D spillovers

(Bernstein, 1991; Griliches, 1991; and Nadiri, 1993). R&D spillovers used or received by a producer arise from the accumulated R&D investment of other producers. Spillovers consist of R&D capital stocks that are endogenously determined through the production decisions made by spillover sources or senders. However, spillovers are exogenous variables from the viewpoint of the user or receiver of the spillover.

Now, converting the extended production function into a growth equation by subtracting from output growth the same set of inputs as in the case where R&D and spillovers are absent, the growth equation becomes:

$$y - (\alpha l + \beta m + \gamma k) = (p_y - 1)(\alpha l + \beta m + \gamma k) + \phi_t + \mu r + \psi s \quad (4)$$

where r, and s are the growth rates of R&D capital and the spillover variable, and μ and ψ are the elasticities of output with respect to R&D capital and spillover, respectively. Thus, TFP growth is decomposed into a scale term and a technological change term. But the latter contains three elements which are linked to the time trend, R&D capital and spillovers.[4]

If the growth equation is considered in the two cases (with and without R&D capital), TFP growth appears to be defined in the same way. However, measured rates of TFP growth actually differ. In the TFP growth framework that does not explicitly account for R&D, shown in equation (2), 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 scientists and engineers, while the capital input includes laboratories and machinery used in the development of new products and processes. Next, when R&D is explicitly considered in the productivity framework, shown in equation (4), costs associated with the components of R&D are subtracted from the relevant traditional inputs in order to avoid double counting.[5] This raises the problem of different measured TFP growth rates in the two cases. The first measure implicitly contains R&D costs in the inputs, which are netted out from output growth to arrive at TFP growth. The second measure does not contain R&D costs in the inputs. With a positive R&D elasticity of output and growth rate for R&D capital (that is $\mu > 0$, and $r > 0$), TFP growth measured from equation (4) always exceeds productivity growth measured by equation (2).

Another problem with equation (4) occurs because a producer's own R&D capital is treated differently from other factors of production in the equation.[6] This gives the mistaken impression that the decision calculus regarding R&D capital differs from other factors of production. In fact, the demand for R&D capital depends on its own factor prices as well as the prices of labour, intermediate inputs, physical capital, and R&D spillovers (Bernstein, 1991; and Nadiri, 1993). Thus, although R&D capital generates spillovers to other producers, the demand for R&D capital by a producer depends on a set of variables similar to the one that governs the demands for other factors of production.[7]

In order to preserve the consistency of measured TFP growth rates in cases where R&D costs are either implicitly or explicitly considered, R&D capital can be included as part of the set of inputs whose growth rates are subtracted from output growth. The growth equation then becomes:

$$y - \alpha l + \beta m + \gamma k + \mu r) = (p_y - 1)(\alpha l + \beta m + \gamma k + \mu r) + \phi_t + \psi s \tag{5}$$

TFP growth is denoted by the left side of the equation, which is compatible with TFP growth when R&D capital is embedded in the other factors of production, denoted by equation (2). TFP growth is still decomposed into a scale term and a technology term. However, scale is now defined over all inputs, including R&D capital, while the technology term contains only two components: the time trend and the spillover variable.[8].

This presents a different view of the role of R&D capital. R&D capital generates output growth like other factors of production. In addition, R&D spillovers affect productivity growth. Thus, accumulation of R&D capital by a producer causes its own output to grow and, through spillovers, influences the productivity growth of other producers, and thereby their rates of growth of output.[9] This is the view adopted in this paper.

3. R&D AND THE PRODUCTIVITY SLOWDOWN

The inability of economies to recover fully from the productivity slowdown of the early 1970s has led to concerns that this trend reflects technological stagnation as exemplified by reductions in the accumulation of knowledge or R&D capital. Table 1 shows the TFP growth rates for the G7 countries up to 1973 and then from 1974 onward. In each case, TFP growth rates are declining. The decline was most pronounced in Japan and Italy, followed by France, Germany, then Canada, the United States, and the United Kingdom. Table 1 also shows the ranking of countries over the two periods. Their relative position remained virtually unchanged. Indeed, although Japan and Italy suffered the most severe downturn, they still led the other five countries throughout both periods.

Many reasons have been offered to explain the productivity slowdown, including rising energy and material prices, an increasing rate of physical capital depreciation, decreasing rates of capacity utilization, and declining rates of R&D capital accumulation (Griliches, 1988, 1994; Jorgenson, 1988; and Nadiri, 1993).[10] Although there is no consensus on any one cause, the culprit does not appear to be the exhaustion of technological progress.

Generally, analysis conducted on R&D and productivity growth suggests that R&D cannot explain the slowdown for a number of reasons. First, the elasticity of output with respect

Table 1
Aggregate average annual rates of TFP growth

Country	Period 1: to 1973[a]		Period 2: 1974-93	
	Percent	Rank	Percent	Rank
Canada	2.1	6	0.3	6
United States	1.6	7	0.1	7
Japan	5.5	1	1.4	2
United Kingdom	2.5	5	1.2	4
Germany	2.6	4	0.5	5
France	4.0	3	1.4	2
Italy	4.4	2	1.5	1

[a] TFP growth is for the non-farm business sector based on OECD data. The initial period begins in 1966 for Canada, 1960 for the United States, Germany and Italy, 1962 for Japan, and 1963 for the United Kingdom and France.

Source: Author's estimates.

to R&D capital, μ in equation (5), is too small to cause a sufficiently large reduction in output growth and thereby trigger a productivity slowdown. Moreover, the effect of this elasticity is of the second order. It affects TFP growth only when there are non-constant returns to scale. In this case, the elasticity is weighted by the deviation from constant returns to scale, which is generally a very small number. Second, there was no decline in the growth rate of R&D capital, r and s in equation (5), to lead to a deterioration in productivity performance. Lastly, attempts were made to see if the productivity effect of R&D had fallen over time (ψ in equation (5)). This yielded only mixed results at best.

Although R&D capital accumulation does not appear to be the cause of the productivity slowdown, as Griliches (1994) notes, it is difficult to overstate the significance of R&D capital accumulation for long-term economic growth. The significance of R&D capital arises from the relatively few firms that undertake R&D activities, and which, therefore, enhance their own output growth rates while also generating spillovers and productivity growth effects on other producers. Bernstein (1989) and Bernstein and Nadiri (1988) note that in both the United States and Canada, five two-digit SIC industries account for over 85 percent of manufacturing R&D expenditures in each country. Denny, Bernstein, Fuss, Nakamura & Waverman (1992) (hereafter DBFNW) compute productivity growth rates for these high-tech industries, as well as other two-digit manufacturing industries.[11] They find that although the aggregate slowdown was common across the United States, Japan and Canada, high-tech industries either did not exhibit any slowdown or the slowdown was not as pronounced as in other industries. This finding holds for all three countries.

Table 2 shows a comparison of TFP growth rates across countries and two-digit SIC industries. In each country, the electrical products industry (Canadian SIC 33) had the highest TFP growth rate before and after the 1973 turning point. More significantly, in all three countries, productivity growth in this industry actually increased during the post-1973 period. Following electrical products, were textiles, transportation equipment, chemical products, and non-electrical machinery. The lowest productivity performers were the food, paper, petroleum and primary metals industries.[12]

These figures confirm that the effects of R&D capital accumulation are not set on a declining trend. A relatively weak or non-existent productivity slowdown in the industries where the effects of R&D capital accumulation are generally the strongest suggests that technological stagnation cannot explain the productivity slowdown. Indeed, it appears that technological opportunities have improved. High-tech industries exhibit relatively better productivity performance and have been more successful in overcoming the range of contributing elements to the world-wide productivity slowdown.

Table 2
Two-digit SIC average annual rates of TFP growth

Industry	Canada		United States		Japan	
	1961-73	1974-85	1954-73	1974-86	1954-73	1974-86
Food	0.69	0.12	0.58	0.55	0.78	-0.32
Textiles	2.16	1.29	1.34	0.65	2.54	1.66
Paper	0.41	-0.01	0.68	0.78	1.95	0.18
Chemicals	1.37	0.37	1.85	0.03	2.29	1.26
Petroleum	0.39	0.37	0.81	-0.24	2.04	-2.95
Non-metallic mineral	1.81	0.03	0.59	-0.46	2.99	-0.91
Primary metals	0.88	0.36	-0.23	-0.64	1.39	0.83
Non-electrical machinery	1.17	0.12	0.91	2.00	2.08	1.45
Electrical products	1.95	2.53	1.58	1.70	3.01	3.69
Transportation equipment	2.43	0.67	0.61	0.39	2.94	0.93

Source: M. Denny, J. Bernstein, M. Fuss, S. Nakamura and L. Waverman. 1992. "Productivity in Manufacturing Industries, Canada, Japan, and the United States, 1953-1986: Was the 'Productivity Slowdown' Reversed?" *Canadian Journal of Economics*. 25(3).

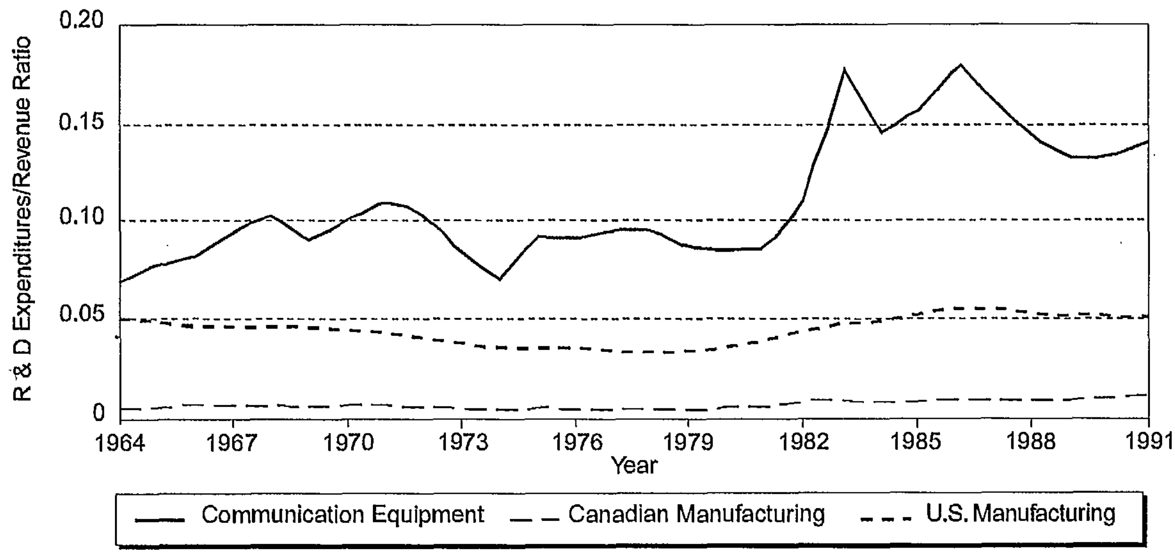
4. SPILLOVER ELASTICITIES

In this chapter, we examine a particular high-tech industry (communications equipment) as a source of R&D spillovers to the Canadian manufacturing sector. Naturally, because communications equipment is considered to be a source of spillovers, this three-digit SIC industry is netted out of the manufacturing sector.

The Canadian communications equipment industry is heavily involved in R&D activities. This can be observed by comparing the ratio of R&D expenditures to revenue (or sales) in communications equipment to that of the Canadian and U.S. manufacturing sectors. This ratio is referred to here as the "R&D propensity", since it measures the average propensity to spend on R&D activities in relation to the income of a producer. The ratios of R&D capital stock to output are for the communications equipment industry, and the Canadian and U.S. manufacturing sectors.[13] This ratio is referred to as the "R&D intensity".

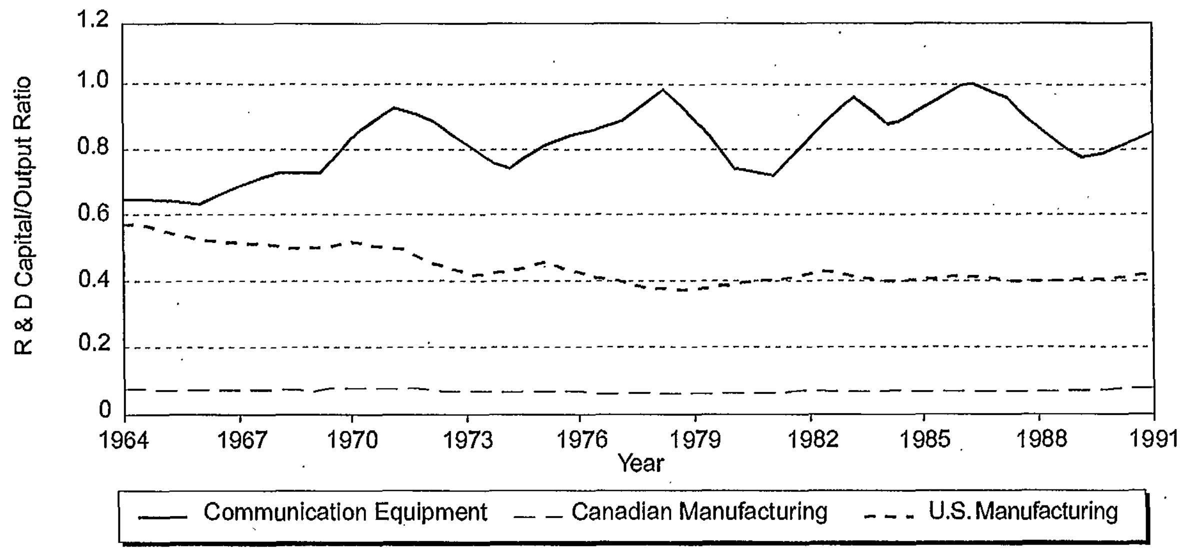
Figure 1 shows the R&D propensity of the Canadian communications equipment industry, and the Canadian and U.S. manufacturing sectors. It can be seen that R&D propensity in communications equipment is substantially higher than in the manufacturing sector, in both Canada and the United States. In addition, U.S. manufacturing has a higher spending propensity than Canadian manufacturing. It is interesting to note that, although there was a dip in the R&D-to-sales ratio in the communications equipment industry in 1974— when productivity growth slowed in North America (Griliches, 1994) —, the R&D propensity recovered (at least partially) in the two subsequent years.

Figure 1



Source: Author's calculations.

Figure 2



Source: Author's calculations.

Figure 2 shows the R&D intensity in the communications equipment industry and the Canadian and U.S. manufacturing sectors. This ratio is more significant than the R&D propensity in an analysis of productivity and output growth. Knowledge does not depreciate during a single time period. The stock of existing R&D capital should be considered in addition to current expenditures, since accumulated and undepreciated R&D capital affects output. Moreover, since output and R&D capital prices do not change at the same rate, ratios denominated in current dollars convolve the underlying trend in R&D intensity with price changes.

Figure 2 also shows that the R&D intensity in the Canadian communications equipment industry was higher and grew faster than in the Canadian and U.S. manufacturing sectors. Although the R&D intensity in the communications equipment industry fell over the periods 1971-1974 and 1978-1981, which were periods of general decline in productivity growth, in each case R&D intensity recovered within a couple of years. The R&D intensity in the Canadian manufacturing sector was lower than in the U.S. manufacturing sector. However, the R&D intensity in Canada was constant over the 28-year period, while in the U.S., it fell from 1964 to 1988, at which point it began to increase.

There are enormous measurement problems associated with the construction of R&D capital data. R&D expenditures must be deflated by a price index. Deflated R&D expenditures must then be accumulated and depreciated at some rate. Both R&D capital price indexes and depreciation rates are needed. Unfortunately, these data are not produced by government agencies or departments.[14] In constructing R&D capital data, a 10 percent depreciation rate is assumed (recent work by Nadiri & Prucha, 1993, has estimated rates close to 10 percent). In addition, for Canadian R&D price indexes, data from Bernstein (1992) was used for the period

1964-1987, and extrapolated from 1988 to 1991 using the percentage change in the gross domestic product deflator.

The U.S. R&D price index was obtained from Jankowski (1993) for the period 1969 to 1988; extrapolations were made back to 1964 and forward to 1991 using the percentage change in the U.S. gross domestic product deflator. The model used to analyse spillover effects is presented in Appendix 1. In the model, manufacturing output is based on four factors of production: labour, intermediate inputs, physical capital and R&D capital. There are also two sources of technological change: the R&D spillovers from the communications equipment industry, and the R&D spillovers from the U.S. manufacturing sector. Bernstein (1995) has shown that there are significant international spillovers between Canadian and U.S. two-digit manufacturing industries. These results imply that international trade, foreign direct investment, and the migration of scientists and engineers are all important channels of knowledge transmission. This is especially true of Canadian industries, where spillovers from the United States can generate important structural changes in production. In light of these results, R&D spillovers from U.S. manufacturing to Canadian manufacturing are included.

It is beyond the scope of this paper to enter into a detailed discussion of alternative ways to measure R&D spillovers (Bernstein, 1991; Griliches, 1991; Nadiri, 1993). In this case, R&D spillovers are measured by one-period lagged R&D capital stocks. Since R&D does not depreciate in a single year, R&D expenditures (or deflated R&D expenditures) is not the appropriate variable to use in a time series context for analysing R&D spillovers. R&D capital is a source of externalities. The benefits from R&D investment cannot be completely appropriated in the present or in the near future, and therefore spillovers occur. These spillovers have an intertemporal dimension: R&D investment undertaken in the present period provides a source of spillovers in future periods for as long as the R&D capital arising from this investment has not fully depreciated.

In the manufacturing sector, production is assumed to be carried out according to the principle of minimization of production costs. This means that a cost function contains all the available information about production in the sector. In order to determine the effects of spillovers on input-output ratios or factor intensities, a function representing variable cost-per-unit of output or average variable cost is specified for estimation purposes. This function represents the costs of labour and intermediate inputs per unit of output and depends on non-capital input prices, output, physical and R&D capital intensities, and R&D spillovers. From the average variable cost function, factor intensities of labour, intermediate inputs, physical capital, and R&D capital are obtained. The intensities associated with labour and intermediate inputs depend on their factor prices, output, physical and R&D capital intensities and R&D spillovers. In turn, physical and R&D capital intensities depend on the labour and intermediate input prices, the input prices of physical capital and R&D capital, output, and R&D spillovers.

An average variable cost function is estimated, since R&D spillovers and the capital intensities affect the average variable cost. Spillovers have two effects on the average variable cost: directly, and indirectly through capital intensities. Physical and R&D capital intensities depend on spillovers, and they also affect variable cost.

Another feature of the average variable cost function is that the non-capital input intensities depend on spillovers and physical and R&D capital intensities. Thus, spillovers have both a direct effect on non-capital intensities, and an indirect effect through capital intensities.[15]

This chapter focuses on the effects of R&D spillovers on factor intensities and the average variable cost in the Canadian manufacturing sector and the Canadian communications equipment industry. The results for manufacturing are shown in Table 3.

The direct effect of spillovers on the average variable cost results from the interaction of R&D spillovers and the factor prices of labour and intermediate inputs. Thus, the direct effect is synonymous with changes in non-capital input intensities arising from the spillovers. R&D spillovers can lead to either increases or decreases in non-capital input intensities. Therefore, spillovers can be unit-variable cost increasing or decreasing. For example, if the spillovers are process-oriented, then at existing output levels efficiency improvements can reduce labour and intermediate input requirements, thereby reducing the average variable cost. However, if the spillovers are product-oriented, then it is possible that the average variable cost will increase as a result of the spillovers. In this case, an increase in the product price would be

Table 3
Spillover elasticities: Canadian manufacturing

	Spillovers from the communications equipment industry		Spillovers from the U.S. manufacturing sector	
	Mean[1]	Standard deviation	Mean	Standard deviation
Labour intensity	0.0103	0.0085	-0.3310	0.1244
Intermediate input intensity	-0.0112	0.0066	-0.3920	0.0534
Physical capital intensity	-0.0223	0.0127	0.2022	0.0215
R&D capital intensity	0.1490	0.0934	-0.5164	0.0842
Average variable cost	-0.0109	0.0070	-0.3759	0.0699
Direct average variable cost	-0.0060	0.0037	-0.2140	0.0399

1 The elasticities are percentages based on a 1 percent increase in R&D spillovers. The mean value of the vector of each elasticity is presented along with the sample standard deviation.

expected at existing output levels, or an increase in output at existing product price levels. The revenue gain would then outweigh the higher cost.[16]

The effects of R&D spillovers become more complicated when there are multiple spillover sources (such as in models with domestic and foreign spillovers). Suppose there are two process-oriented spillovers and that both are jointly utilized in the production process. In this case, it is possible for one of the spillovers to generate cost increases, but cost decreases associated with the other spillover can simultaneously lead to joint cost reductions. This can occur, for example, with spillovers that relate simultaneously to hardware and software developments. Clearly, using existing software along with upgraded hardware based on new information obtained through R&D spillovers may be more costly than using old hardware. However, by using new software with the hardware upgrade, the effect of the joint spillover can become cost-reducing.[17]

The direct effects of spillovers on the average variable cost are shown in the last row of Table 3. It can be seen that a 1 percent increase in R&D capital in the communications equipment industry leads to a 0.006 percent direct reduction in the unit variable cost of manufacturing. There are several channels through which this cost reduction operates. Spillovers occur directly through intermediate input or physical capital input purchases of firms in the communications equipment industry, and indirectly through input purchases from telecommunication carriers who purchase inputs from the communications equipment industry; through joint ventures between firms in the communications equipment and other manufacturing industries; through the mobility of scientists and engineers; and through the diffusion of information (at conferences and in scientific and engineering publications).[18]

A 1 percent increase in R&D spillovers from the communications equipment industry reduces the average variable cost of the Canadian manufacturing sector by 0.011 percent. This includes both the direct effect and the indirect effect that operates through capital intensities. These results imply that the indirect effect of the spillovers reduces the average variable cost, since the combined direct and indirect effects outweigh the direct effect. Although in this case average variable cost declined, it could also increase. For example, even if the direct effect is cost-reducing, both capital intensities may decline as a result of the spillover, thereby increasing the average variable cost. In other words, physical and R&D capital act as substitutes for the spillovers. If the indirect effect through capital intensities dominates the direct effect then, in this example, the average variable cost rises.

The second set of effects is related to factor intensities. Table 3 shows that the spillovers from the communications equipment industry reduce labour, intermediate input, and physical capital intensities, while increasing R&D capital intensity. Thus, the spillovers make manufacturing production techniques more knowledge-intensive, although in all cases the elasticities are highly inelastic. Moreover, since the indirect effect of the spillovers reduces the average variable cost, and because increases in capital intensities also reduce average variable cost, then the cost reductions caused by increases in R&D capital intensity dominate the cost increase that derive from decreases in physical capital intensity.

The spillovers from the U.S. manufacturing sector also generate direct cost reductions. Not surprisingly, these cost reductions are substantially greater than those arising from the communications equipment industry spillovers. A 1 percent increase in U.S. manufacturing R&D capital leads to a direct unit variable cost reduction of 0.21 percent. The spillovers from the United States also reduce the labour and intermediate input intensities, but increase the physical capital intensity. Moreover, R&D capital from the United States is a substitute for Canadian manufacturing R&D capital. As a result of the spillovers from the United States, Canadian manufacturing production becomes more physical-capital intensive.

We now turn to the effects of R&D spillovers on factor intensities and average variable costs in the communications equipment industry. The results are presented in Table 4. Again, the analysis begins by examining the effects of the spillovers on the average variable cost. The direct effects on average variable cost are shown in the last row of Table 4. It can be seen that a 1 percent increase in R&D capital in Canadian manufacturing leads to a direct reduction of 0.050 percent in the unit variable cost of the communications equipment industry. As might be expected, Tables 3 and 4 show that the direct effect of manufacturing R&D capital on the average variable cost in the communications equipment industry is substantially greater than the effect of communications equipment R&D on manufacturing. This finding also carries over to the combined direct and indirect effects on the average variable cost. Table 4 shows that the average variable cost declines by 0.056 percent.

Factor intensities in the communications equipment industry are also affected by R&D capital in the manufacturing sector. As for capital intensities, Table 4 shows that the

Table 4
Spillover elasticities: communications equipment

	Spillovers from the Canadian manufacturing sector		**Spillovers from the U.S. electrical products industry**	
	Mean[1]	**Standard deviation**	**Mean**	**Standard deviation**
Labour intensity	-0.0301	0.0194	-0.8800	0.5995
Intermediate input intensity	-0.0497	0.0179	-0.8515	0.4326
Physical capital intensity	0.1322	0.0450	0.5062	0.0472
R&D capital intensity	-0.3813	0.2186	0.6439	0.0889
Average variable cost	-0.0560	0.0031	-0.6376	0.2318
Direct average variable cost	-0.0503	0.0033	-0.5862	0.2222

1 The elasticities are percentages based on a 1 percent increase in R&D spillovers. The mean value of the vector of each elasticity is presented along with the sample standard deviation.

communications equipment industry becomes more physical-capital intensive and less R&D-capital intensive in the face of growing domestic spillovers. A comparison of Tables 3 and 4 shows that this high-tech industry behaves differently from the manufacturing sector. In the latter case, domestic spillovers from the communications equipment industry cause manufacturing production to become more R&D intensive and less physical-capital intensive. The converse is true with respect to domestic spillovers in the communications equipment industry.

Table 4 also shows that both labour and intermediate input intensities decline as the spillovers from manufacturing increase. It is interesting to note from Tables 3 and 4 that domestic spillovers in the manufacturing sector and in the communications equipment industry reduce both labour and intermediate input intensities; that is, the non-capital input intensities. Thus, in response to domestic spillovers, production becomes more capital intensive in both the communications equipment industry and in manufacturing.

International R&D spillovers from the U.S. electrical products industry also affect the Canadian communications equipment industry.[19] The international spillovers reduce the average variable cost, and the effect is ten times greater (in absolute terms) than that of the domestic spillovers. In addition, the international spillovers increase both capital intensities. Hence, R&D intensity in communications equipment industry is complementary to the spillovers from the U.S. electrical products industry. Table 4 also shows that both non-capital input intensities decline as the international spillovers expand. Thus, production becomes more capital intensive.

5. PRODUCTIVITY GROWTH AND SOCIAL RATE OF RETURN

In this chapter, growth in total factor productivity (TFP) is measured and decomposed for the Canadian manufacturing sector and the communications equipment industry. The contribution of spillovers to productivity growth is of particular interest. In terms of measuring productivity growth, recall from Chapter 3 that the productivity slowdown of the early 1970s was common across the United States, Japan and Canada. However, high-tech industries either did not exhibit a slowdown or the slowdown was not as pronounced as in other industries. In each country, the electrical products industry had the highest TFP growth rates before and after the 1973 turning point. More significantly, productivity growth in this industry actually increased during the post-1973 period in all three countries.

The productivity gains of the electrical products industry at the two-digit level is reflected in the communications equipment industry at the three-digit level. Table 5 shows the TFP growth rates for the communications equipment industry and for the manufacturing sector (excluding the communications equipment industry).[20] It can be seen from this table that over the period 1966-1991, the average annual rate of productivity growth in the communications equipment industry was 1.24 percent, while in the manufacturing sector, it was 0.5 percent. The communications equipment industry outperforms the manufacturing sector by 150 percent on an average annual basis. In addition, except for the first five years of the sample, the communications equipment industry outperformed the manufacturing sector in each sub-period. The rates in the pre- and post-1973 period, when the worldwide productivity slowdown is said to have occurred, show that there was a slowdown in the Canadian manufacturing sector but not in the communications equipment industry. Indeed, productivity growth in that industry actually increased during the post-1973 period by about 46 percent on an average annual basis.

Table 5
Average annual TFP growth rates

	Canadian manufacturing (percent)	Communications equipment (percent)
Five-year periods		
1966-1970	0.660	-1.594
1971-1975	0.842	3.931
1976-1980	0.523	2.451
1981-1985	0.866	1.156
1986-1991	-0.267	0.412
Pre- and post-slowdown periods		
1966-1973	1.083	0.940
1974-1991	0.233	1.371
Overall sample period		
1966-1991	0.495	1.238

In decomposing productivity growth in the Canadian manufacturing sector,[21] TFP growth is split into two general components: a returns to scale component and a technological change component. Within technological change, two variables affect productivity growth: the R&D spillovers from the communications equipment industry, and the spillovers from the U.S. manufacturing sector. Since a decomposition of TFP growth from the econometric model is compared to a measured rate of productivity growth, there is also a residual element associated with measured productivity that is not captured by the model. The two spillover variables, deviations from constant returns to scale and the residual term, exhaust the decomposition of measured productivity growth.

Table 6 shows that R&D spillovers from the communications equipment industry leads to productivity gains in the Canadian manufacturing sector. Over the sample period (1966 to 1991), about 8.5 percent of the annual TFP growth in manufacturing is accounted for by R&D spillovers from the communications equipment industry. Moreover, the importance of the communications equipment industry grew during the post-slowdown era. From 1966 to 1973, around 2 percent of the annual TFP growth is attributed to spillovers from the communications equipment industry. That contribution increased to about 22 percent between 1974 and 1991.

Generally, the major component of TFP growth derives from U.S. R&D spillovers. This result is consistent with Bernstein (1995). For the sample period, U.S. spillovers accounted for about 76 percent of TFP growth in Canadian manufacturing.[22] Table 6 also shows that R&D

Table 6
Decomposition of average annual TFP growth rates

	Canadian manufacturing (percent)				
	TFP growth rate	**Scale**	**Spillovers from communications equipment**	**Spillovers from U.S. manufacturing**	**Residual element**
Five-year periods					
1966-1970	0.660	0.222	0.025	0.420	0.007
1971-1975	0.842	0.211	0.021	-0.034	0.644
1976-1980	0.523	0.188	0.016	0.073	0.246
1981-1985	0.866	0.109	0.063	0.503	0.191
1986-1991	-0.267	0.051	0.077	0.822	-1.217
Pre- and post-slowdown periods					
1966-1973	1.083	0.286	0.024	0.242	0.531
1974-1991	0.233	0.093	0.050	0.433	-0.343
Overall sample period 1966-1991	0.495	0.152	0.042	0.375	-0.074

spillovers from both the communications equipment industry and the U.S. manufacturing sector mitigated the productivity slowdown in Canadian manufacturing. The slowdown was not caused by a decrease in R&D spillovers.

In examining the decomposition of productivity growth in the communications equipment industry, TFP growth is broken down into the same components as for Canadian manufacturing. In this case, the spillovers derive from the R&D capital stocks of the Canadian manufacturing sector and of the U.S. electrical products industry.

Table 7 shows that scale economies coming from output growth and spillovers from the U.S. electrical products industry are the major sources of productivity gains in the communications equipment industry. For the period 1966-1991, scale economies accounted for 65 percent of productivity gains, while U.S. spillovers contributed 52 percent.[23] During the pre-slowdown period of manufacturing productivity — 1966 to 1973 — scale economies and international spillovers contributed 95 percent and 75 percent of productivity gains respectively. These percentages declined in the post- productivity slowdown period to 59 percent and 43 percent, respectively. Table 7 also shows that R&D spillovers from the Canadian manufacturing sector contributed only about 6 percent of productivity growth over the entire period. Clearly, productivity growth did not decline during the post-1973 period due to the degree of scale economies in the industry and to the spillovers emanating from the United States.

Table 7
Decomposition of average annual TFP growth rates

	Communications equipment (percent)				
	TFP growth rate	**Scale**	**Spillovers from manufacturing**	**Spillovers from electrical products**	**Residual element**
Five-year periods	-1.594	0.413	0.019	0.343	-2.369
1966-1970	3.931	1.898	0.059	1.684	0.290
1971-1975	2.451	1.602	0.173	1.331	-0.655
1976-1980	1.156	0.827	0.165	0.671	-0.507
1981-1985	0.412	0.279	0.013	0.058	0.062
1986-1991					
Pre- and post-slowdown periods					
1966-1973	0.940	0.891	0.028	0.703	-0.682
1974-1991	1.371	0.802	0.097	0.588	-0.116
Overall sample period	1.238	0.807	0.069	0.641	-0.279
1966-1991					

In this part of the study, we provide an analysis of R&D spillovers from the vantage point of the spillover source; in other words, we consider the social rate of return. Productivity gains associated with spillovers imply that there are extra-private returns to the R&D capital of industries that are sources of spillovers. The social rate of return to R&D capital consists of the private return and the extra-private return attributable to the spillovers.

High-tech industries are important sources of R&D spillovers. For U.S. high-tech industries, Bernstein & Nadiri (1988) estimated the social rate of return at between two and ten times the private rate of return. For Canada, Bernstein (1988, 1989) estimated a similar range of magnitude.[24] These high social rates of return imply that high-tech industries are important sources of productivity gains for other producers.

In the long run, the private return is the marginal product of R&D capital per dollar of R&D investment. Thus, the private return is the before tax rental rate of R&D capital divided by the R&D deflator. The private return is taken to be the gross of depreciation, before tax rate of return. Over the sample period (1966-1991), the mean value of the private rate of return in both manufacturing and communications equipment is estimated at 17 percent.[25]

The extra-private return to R&D capital from the communications equipment industry is the direct cost reduction in Canadian manufacturing caused by the spillovers from the communications equipment industry per dollar of R&D investment.[26] It is estimated that the extra-private return to R&D capital over the sample period averages 38 percent.[27] Thus, the mean value of the social rate of return is 55 percent.

The extra-private return to R&D capital from Canadian manufacturing is the direct cost reduction in the communications equipment industry caused by the spillovers from the Canadian manufacturing sector per dollar of R&D investment. It is estimated that the extra-private return to R&D capital over the sample period averages 4 percent.[28] Thus, the mean value of the social rate of return is 21 percent.

The magnitude of the social rate of return is consistent with the literature on spillovers (Griliches, 1991; and Nadiri, 1993). Generally, intra-industry spillovers generate smaller returns relative to inter-industry spillovers (where industries are defined at the same SIC level). In this study, we consider spillovers between a three-digit industry and a sector (single-digit level industry). These spillover effects are greater than those obtained in intra-industry cases, but less than the magnitudes for two-digit inter-industry spillovers. There are substantial extra-private returns to R&D capital in the communications equipment industry, such that the social rate of return is more than three times the private rate of return.

6. CONCLUSION

High-tech industries are important sources of spillovers that generate productivity gains in other industries. In addition, these industries tend to exhibit superior productivity performance. Indeed, in some cases (notably electrical equipment), there is no evidence of the productivity slowdown that affected most industries in North America, Japan and other G7 countries during the 1970s.

In this study, productivity growth rates are measured for the Canadian communications equipment industry (which is comprised of important high-tech firms such as Northern Telecom), and the Canadian manufacturing sector. Over the period 1966-1991, average annual productivity growth in the communications equipment industry was 150 percent greater than in the manufacturing sector. Moreover, unlike the manufacturing sector, which suffered a productivity slowdown during the post-1973 period, average annual productivity growth in the communications equipment industry increased by 46 percent.

The communications equipment industry and the manufacturing sector are both sources of spillovers. As such, the communications equipment industry affects the production structure (i.e., factor intensities) of the manufacturing sector. Indeed, an expansion of R&D capital in the communications equipment industry leads to an increase in knowledge intensity in manufacturing. In addition, spillovers from the communications equipment industry reduce factor intensities for physical capital, labour and intermediate inputs (such as materials).

In terms of relative importance, R&D spillovers from U.S. manufacturing generate greater effects on Canadian manufacturing factor intensities than spillovers from the communications equipment industry. It is interesting to note that the R&D capital inputs in the two North American manufacturing sectors are substitutes. An increase in U.S. manufacturing R&D capital leads to a reduction in the domestic knowledge intensity in Canadian manufacturing.

Factor intensities in the Canadian communications equipment industry are affected by spillovers from both the Canadian manufacturing sector and the U.S. electrical products industry. Both sources of spillovers reduce labour and intermediate input intensities, and increase the intensity of physical capital. However, spillovers from the Canadian manufacturing sector reduce the R&D intensity in the communications equipment industry. Combining the results of spillovers between the communications equipment industry and the manufacturing sector shows that expanding R&D capital in communications equipment increases R&D intensity in manufacturing production. This result then mitigates the need (all other elements being held constant) for further R&D expansion in the communications equipment industry, with the final result that R&D intensity declines.

The spillovers from the U.S. electrical products industry increase the R&D intensity in the Canadian communications equipment industry. Thus, between these two industries R&D capital stocks are complementary. In addition, R&D capital from the U.S. electrical products industry has a greater effect on the production structure of the Canadian communications equipment industry than R&D capital from the Canadian manufacturing sector.

The communications equipment industry is a source of productivity gains for Canadian manufacturing. Between 1966 and 1991, about 8.5 percent of the average annual rate of productivity growth in manufacturing was accounted for by spillovers from the communications equipment industry. Moreover, this contribution increased during the post-1973 period when the productivity slowdown occurred. Thus, the spillovers were a mitigating influence in the further erosion of manufacturing productivity. However, it should be recognized that the spillovers from the U.S. manufacturing sector (which accounted for 76 percent of the average annual rate of productivity growth) were the major contributor to productivity growth in Canada.

Spillovers from the Canadian manufacturing sector and U.S. electrical products industry contributed to productivity growth in the communications equipment industry. The spillovers from Canadian manufacturing accounted for only about 6 percent of productivity growth, while the spillovers from the United States dominated the Canadian spillover source. However, the main element governing productivity growth in the communications equipment industry was scale economies through output growth. They accounted for 65 percent of productivity growth.

The fact that the Canadian communications equipment industry and the manufacturing sector are sources of productivity gains implies that there are extra-private returns to their R&D capital. It is estimated that the social rate of return pertaining to Canadian communications equipment R&D capital is 55 percent, or 225 percent greater than the private rate of return. The social rate of return associated with Canadian manufacturing R&D capital is estimated to be 21 percen,t or 24 percent greater than the private rate of return. These differences point to an under-investment in R&D in both the communications equipment industry and the manufacturing sector in Canada. However, this does not mean that governments should target the communications equipment industry for special status. Although high annual productivity growth rates and high social rates of return distinguish this industry, there are other manufacturing industries whose social rates of return to R&D capital exceed their private rates of return.

R&D investment should be encouraged through policy instruments that focus on R&D capital formation, but those policies should not target particular industries. There are several possibilities. The government could provide information to facilitate joint ventures towards the development of new products, and joint research or "laboratory" ventures. Legislation and regulation could be amended in order to reduce the transaction costs associated with those joint ventures. Moreover, reducing the legislative/regulatory burden would also help to encourage other more indirect means of internalizing the spillovers arising from R&D. Licensing agreements are one example that comes to mind.

Tax expenditures or subsidies are further policy instruments that are — and can be — directed towards R&D capital formation. It is important to recognize that any analysis of the relative costs and benefits of government tax policies aimed at R&D investment must take into account R&D spillovers. Otherwise, the benefits associated with these policies will be underestimated, not only in the way they encourage R&D investment, but also in their contribution to improving living standards through higher rates of productivity growth.

ENDNOTES

1. For the Standard Industrial Classification (SIC) two-digit manufacturing industries, Denny, Bernstein, Fuss, Nakamura & Waverman (1992) found that the electrical products industry in Canada, the United States and Japan had the highest productivity growth rates from the mid-1960s to the mid-1980s. The average annual growth rates were in excess of 2 percent in Canada and the United States, and 3 percent in Japan. Bernstein & Nadiri (1988) estimated that the social returns to R&D in U.S. high-tech industries greatly exceeded the private returns.

2. Detailed data for the U.S. communications equipment industry, especially with respect to R&D expenditures and price indexes, were unavailable. Therefore, we used R&D data for the electrical products industry. This industry is defined at the two-digit SIC level.

3. More outputs and inputs can be added, but this framework is used only for illustrative purposes.

4. It is important to note that ϕ, μ, and ψ could be zero in particular empirical applications. The three components of the technology term do not have to be present. In addition, the time trend represents technological efficiency changes that are not attributable to R&D capital or spillovers.

5. This problem arises for other inputs as well. In the case of the explicit treatment of energy as a distinct factor of production, all related energy costs must be subtracted form the set of traditional inputs. Intermediate inputs would be one such factor of production.

6. It should also be noted that the definition of returns to scale differs in the two models. In the first case, given by equation (2), returns to scale are defined over all inputs — in other words, capital, labour and intermediate inputs, each of which includes the relevant components of R&D capital. In the second case, given by equation (4), where R&D cost is subtracted from the cost of the traditional factors, returns to scale are defined over capital, labour and intermediate inputs net of the R&D capital components.

7. Although the demand for R&D capital could depend on an array of elements that are unique to this input, it is important to note that R&D demand is not exogenous and does depend on prices and spillovers.

8. In most analyses of TFP growth, technological change is only represented by a time trend. This variable is a catch-all that can reflect both productivity gains and losses. Indeed, it seems more appropriate to view changes in the trend variable as an indicator of dynamic production efficiency gains or losses, as opposed to a strict measure of the rate of technological change. The reason is that under constant returns to scale, long-run equilibrium, and no spillovers, productivity growth is synonymous with the effect of changes in the trend variable. Since it is difficult to imagine technological regression occurring from

a variable that is costless to change, then productivity slowdowns should not be observed in this context. Intuitively, one should accept a more circumspect role for the trend variable.

9. If there are deviations from long-run equilibrium due to costs adjustment associated with some factors of production, but the appropriate shadow values are used to construct measured TFP growth rates, this analysis stands. If market prices are used to compute measured rates, then the deviation between market price and shadow value appears as a component of TFP growth. This deviation operates in a similar fashion to returns to scale and rates of technological change. In this case, predetermined input quantities affect the components of TFP growth, along with factor prices and other exogenous variables.

10. In addition, it has been emphasized (especially by Griliches, 1994) that measurement errors in the prices of outputs and inputs affect measured TFP growth rates. Nevertheless, there is agreement that productivity growth did in fact decline.

11. Economy-wide TFP growth rates (as opposed to industry rates) can point to general trends, but they cannot identify the industries that buttress the trend and those which run counter to it.

12. The high-tech/low-tech distinction is not without exception, as petroleum and paper were poor productivity performers, while textiles showed relatively higher productivity growth. The low ranking of petroleum products provides evidence of the severity of the energy crisis, as manifested by higher prices, and the ensuing decrease in capacity utilization.

13. R&D intensity is often defined by the ratio of R&D expenditures to sales. However, this terminology is inconsistent with the usual definition of intensity that refers to an input-output ratio. Since it is R&D capital, and not R&D expenditures, that appears in a production function showing the link between inputs and outputs, then the R&D capital-to-output ratio is the appropriate measure of R&D intensity.

14. Given the importance of R&D capital formation for technological progress, productivity and output growth, a proper accounting of inflation and depreciation of R&D capital is needed in order to formulate, conduct and evaluate policies aimed at encouraging long-term growth.

15. Because our interest lies in the measurement and decomposition of long-run TFP growth, along with the determination of long-run social rates of return to R&D capital, we abstract from the dynamics linked with adjustment costs.

16. This paper does not model the product demand side, but is conditioning on output, so the estimates capture output increases over time from the spillovers. These effects are also accounted for in the measure of TFP growth that reflects output growth net of input growth. In addition, the formula for the social rate of return does not include the revenue gain explicitly, and thus may actually be biased downward. However, the social rate of

return reflects cost changes due to the spillovers, and since these changes depend on output, then implicitly the actual measure of the return includes output changes.

17. Another way that process oriented (and also product oriented) spillovers can be cost increasing is if they lead to future cost reductions. Thus, in present value terms, the spillovers are cost-reducing. To the extent that future cost reductions are omitted from the calculation of the social rate of return, there is a possible downward bias in the magnitude. However, since social rates of return are cost dependent then, implicitly, these future reductions are reflected first in the time path of cost and then in the measure of the social rates of return.

18. It is important to note that spillover networks do not have to coincide with the flows of intermediate inputs, as represented by input-output tables. For example, in the United States, industries purchase little from the scientific instruments industry, in a relative sense, but this industry is an important source of R&D spillovers (Bernstein & Nadiri, 1988).

19. The U.S. electrical products industry is a two-digit industry, while the Canadian communications equipment industry is defined at the three-digit level. Thus, the international spillover is not defined at exactly the same level of aggregation as for the Canadian industry. Appropriate data for the U.S. communications equipment industry could not be obtained. However, the electrical products industry is defined at the two-digit level and encompasses communications equipment.

20. The calculation of TFP growth is based on equation (7) in the Appendix 2.

21. The decomposition of productivity growth is based on equation (9) in the Appendix 2.

22. There was only one period (1971-1975) where the spillovers from the United States caused productivity growth to decline. As Figure 1 shows, this was due to the decline in R&D expenditures during this period. Our econometric results show that the direct effect on the average variable cost from an increase in U.S. spillovers is cost-reducing at every point in the sample.

23. Recall that productivity contributions can exceed 100 percent due to the fact that some elements in the decomposition can cause productivity losses.

24. These results and others are summarized in Griliches (1991) and Nadiri (1993).

25. With a depreciation rate of 10 percent and a corporate tax rate of 46 percent, the net of depreciation, after-tax rate of return is about 4 percent. Also, based on a mean value of 0.17 for the rate of return, the sample standard deviation is 0.015.

26. The derivation of the extra-private return to R&D capital is presented in the Appendix 2 as equation (11).

27. The sample standard deviation based on extra-private returns of 0.38 is 0.08.

28. The sample standard deviation based on extra-private returns of 0.04 is 0.01.

APPENDIX 1

Theoretical model

Two models of production and investment, (including R&D activities) have been developed and estimated. One model relates to the Canadian communications equipment industry; the other relates to the Canadian manufacturing sector. The models enable us to determine spillover effects on production cost, factor intensities, and productivity growth for the Canadian communications equipment industry specifically, and the Canadian manufacturing industry as a whole.

Two source of spillovers affect production. For the communications equipment industry, one source of spillovers emanates from the aggregate manufacturing industry, net of communications equipment; the other source of spillovers arises from the U.S. electrical products industry. For Canadian manufacturing (net of communications equipment), one source of spillovers pertains to the R&D capital of the communications equipment industry; the other source of spillovers arises from the R&D capital associated with U.S. manufacturing.

In this model, producers use labour, intermediate inputs, physical and R&D capital, and two spillovers to produce output. Producers minimize costs subject to a production function given by

$$y_t = F(v_t, K_t, S_{t-1}, t) \tag{1}$$

where y is output, v is the vector of labour and intermediate input demands, K is the vector of physical and R&D capital demands, S is the vector of R&D spillovers, S_{1t} is the domestic spillover either from communications equipment or from manufacturing and S_{2t} is the foreign spillover from either U.S. manufacturing or U.S. electrical products. Lagged R&D capital stocks are used as a measure of the spillovers because borrowed knowledge emanates from the undepreciated and existing stocks of R&D capital; t represents production-efficiency effects that do not arise from R&D spillovers. F is the production function, which has the usual properties.

The problem of minimizing costs subject to the production function can be handled in two stages. In the first stage, given output and the capital inputs, the costs of labour and intermediate inputs can be minimized. Thus,

$$\min_{V} w_t^T v_t \tag{2}$$

subject to the production function, in equation (1). Now, w is the vector of exogenous labour and intermediate input prices. If the solution to (2) is substituted into non capital cost or variable factor cost (that is, $w^T v$) then,

$$c^v_t = C^v (w_t, y_t, K_t, S_{t-1}, t) \tag{3}$$

where c^v is variable cost and C^v is the variable cost function. By applying Shephard's Lemma, (that is, $\delta c^v / \delta w_i = v_i$) the demands for the variable factors can be retrieved from the variable cost function. Thus,

$$v_t = \nabla_w C^v (w_t, y_t, K_t, S_{t-1}, t). \quad (4)$$

The variable factor demands depend on the variable factor prices, output, the capital inputs, and the R&D spillovers, and exogenous efficiency effects. To determine the demands for the capital inputs, proceed to the second stage of the problem. With the variable cost function, cost is minimized. Thus,

$$\min_K C^v (w_t, y_t, K_t, S_{t-1}, t) + \varpi^T{}_t K_t \quad (5)$$

where ϖ is the vector of capital input prices (or in other words capital rental rates). The solution to (5) is given by the equation

$$\nabla C^v{}_K (w_t, y_t, K_t, S_{t-1}, t) + \varpi_t = 0. \quad (6)$$

The solution to equation (6) shows that capital demands depend on non capital input prices, R&D spillovers, exogenous efficiency effects and the capital input prices. Equations (4) and (6) describe the model that is to be estimated.

APPENDIX 2

Estimation model

Estimation Equations

In order to estimate the theoretical model, a variable cost function, or more precisely an average variable cost function, is specified:

$$
\begin{aligned}
c^v_t/y_t = {} & (\Sigma_{i=i}^2 \beta_i w_{it} + 0.5\Sigma_{i=i}^2\Sigma_{j=i}^2\beta_{ij} w_{it} w_{jt} W_t^{-1} + \Sigma_{i=1}^2\Sigma_{j=1}^2 \phi_{ij} w_{it} S_{jt-1} \\
& + \Sigma_{i=1}^2 \phi_i w_{it} t) y_t^{\vartheta-1} + [\Sigma_{i=1}^2 \alpha_i k_{it} + 0.5\Sigma_{i=1}^2 \Sigma_{j=1}^2 \alpha_{ij} k_{it} k_{jt}/y_t^{\vartheta-1} \\
& + \Sigma_{i=1}^2\Sigma_{j=1}^2 \eta_{ij} k_{it} S_{jt-1} + \Sigma_{i=1}^2 \eta_i k_{it} t] W_t \qquad (1)
\end{aligned}
$$

where the parameters to be estimated are given by β_i, β_{ij}, ϕ_{ij}, ϕ_i, α_i, α_{ij}, η_{ij}, η_i, i, j = 1, 2, and ϑ is the inverse of the degree of returns to scale. The non capital factor prices are denoted as w_i, i=1 is the labour price, and i=2 is the price of intermediate inputs. Also capital intensities are $k_i = K_i/y$, where K_i is the capital input i=1 is physical capital, i=2 is R&D capital, *y* is output, and *t* is the time trend. $W = \Sigma_{i=1}^2 a_i w_i$, where a_i, i = 1,2 are fixed coefficients. *W* can be defined as a Laspeyres index of non capital input prices. By defining *W* in this manner the cost function need not be normalized by any non capital input price, but rather by a weighted average of both prices. The attractive feature of this average variable cost function is that the curvature conditions may be imposed on the function. R&D spillovers are denoted by S_{1t} for the domestic spillover, and S_{2t} for the spillover from the United States.

Using the average variable cost function under cost minimization conditions, non capital input equilibrium is given by

$$
\begin{aligned}
\vartheta_{it} = {} & (\beta_i + \Sigma_{j-1}^2 \beta_{ij} w_{jt} W_t^{-1} - 0.5\Sigma_{h-1}^2\Sigma_{j=1}^2 \beta_{hj} w_{ht} w_{jt} W_t^{-2} a_i \\
& + \Sigma_{j-1}^2 \phi_{ij} S_{jt-1} + \phi_i t) y_t^{\vartheta-i} + [\Sigma_{j=1}^2 \alpha_j k_{jt} \\
& + 0.5\Sigma_{h=1}^2\Sigma_{j=1}^2 \alpha_{hj} k_{ht} k_{jt} / y_t^{\vartheta-1} \\
& + \Sigma_{h=1}^2\Sigma_{j=1}^2 \eta_{hj} k_{ht} S_{jt-1} + \Sigma_{i-1}^2 \eta_i k_{it} t] a_i, \ i = 1,2, \qquad (2)
\end{aligned}
$$

where non capital input intensities are $\vartheta_i = v_i/y$, i = 1,2, and v_1, is labour input, and v_2 is intermediate input. Based on the average variable cost function, and cost minimization, the demands for the physical and R&D capital inputs are

$$k_{it} = (\alpha_{jj} A_{it} - \alpha_{ij} A_{jt})/A, \ i \neq j, \ i,j = 1,2,$$

where $A_{it} = (-\alpha_i - \Sigma_{j=1}^2 \eta_{ij} S_{jt-1} - \eta_i t - \omega_{it} W_t^{-1}) y_t^{\theta-1}$, i = 1,2, (3)

and $A = (\alpha_{11}\alpha_{22} - \alpha_{12}^2)$, ω_i is the factor price of the ith capital input. Equations (2) and (3) define the model that is to be estimated.

This framework allows for the investigation of the impact of R&D spillovers on input-output ratios, or factor intensities, the decomposition of productivity growth, and measurement of the private and social rates of return to R&D capital.

Spillover Elasticities

The effects of spillovers on the average variable cost and factor intensities can be determined by differentiating equations (1), (2), and (3) with respect to S_1, and S_2. First, in terms of the capital intensities

$$ek_cS_j = S_j y^{\vartheta-1}(\alpha_{12}\eta_{dj} - \alpha_{dd}\eta_{cj})/Ak_c,\ j = 1,2,\ c \neq d,\ c,d = 1,2, \tag{4}$$

where ek_cS_j is the *j*th spillover elasticity of the *c*th capital intensity.

Second, turning to the non capital input demands,

$$\begin{aligned} e\vartheta_i S_h = [&\phi_{ih} y^{\vartheta-1} + (\eta_{hh}k_h + \eta_{gh}k_g)a_i + (\partial k_1/\partial S_h)(\alpha_1 + \Sigma_{j=1}{}^2\alpha_{1j}k_j y^{\vartheta-1} \\ &+ \Sigma_{j=1}{}^2\eta_{1j}S_j + \eta_1 t)a_i + (\partial k_2/\partial S_h)(\alpha_2 + \Sigma_{j=1}{}^2\alpha_{j2}k_j y^{\vartheta-1} \\ &+ \Sigma_{j=1}{}^2\eta_{2j}S_j + \eta_2 t)a_i]S_h/\vartheta_i,\ i=1,2,\ g \neq h,\ g,h=1,2, \end{aligned} \tag{5}$$

where $e\vartheta_i S_h$ is the *h*th spillover elasticity of the *i*th non capital input demand. There are two effects of the spillovers on the non capital intensities: the first is the direct effect arising from the fact that the non capital input price interacts with the spillovers; the second is the indirect effect that arises because the non capital input intensities are affected by the capital intensities. The last set of elasticities shows the effects of the spillovers on the average variable cost. They are

$$\begin{aligned} ec_y{}^v S_h = [&\phi_{1h}w_1 + \phi_{2h}w_2 + [\eta_{hh}k_h + \eta_{gh}k_g + (\partial k_1/\partial S_h)(\alpha_1 \\ &+ \Sigma_{j=1}{}^2\ \alpha_{1j}k_j y^{\vartheta-1} + \Sigma_{j=1}{}^2\eta_{1j}S_j + \eta_1 t) \\ &+ (\partial k_2/\partial S_h)(\alpha_2 + \Sigma_{j=1}{}^2\alpha_{j2}k_j y^{\vartheta-1} \\ &+ \Sigma_{j=1}{}^2\ \eta_{2j}S_j + \eta_2 t)]W]S_h/(c^v/y),\ g \neq h\ g,h = 1,2, \end{aligned} \tag{6}$$

where $ec_y{}^v S_h$ is the *h*th spillover elasticity of the average variable cost. There are also two effects of the spillovers on the average variable cost. The first is the direct effect and the second is the indirect effect which operates through the capital intensities.

Productivity Growth and Social Rate of Return

TFP growth can be measured as

$$TFPG(t,s) = (y_t - y_s)/y_m - s_{vm}{}^T(v_t - v_s)/v_m - s_{km}{}^T\ (K_t - K_s)/K_m, \tag{7}$$

where the subscript t represents the current period, and s represents the past period, the subscript m designates the mean value of a variable (for example $y_m = (y_t + y_s)/2$), s_v is the vector of non capital cost shares, s_k is the vector of capital cost shares, and the mean values of the cost shares for the non-capital inputs are defined as $s_{im} = (w_{im}v_{im})/((c/y)_m y_m)$ where c is the sum of variable and capital costs. The mean values of the cost shares of the capital inputs are defined in a similar fashion.

TFP growth rates may be decomposed by using the estimated variable cost function. The difference in cost between time periods is

$$\begin{aligned} c_v^t - c_s^v = .5[&\Sigma_{i=1}^n(v_{it} + v_{is})(w_{it} - w_{is}) \\ &+ ((\partial c^v/\partial y)_t + (\partial c^v/\partial y)_s)(y_t - y_s) \\ &+ \Sigma_{k=1}^m((\partial c^v/\partial K_k)_t + (\partial c^v/\partial K_k)_s)(K_{kt} - K_{ks}) \\ &+ \Sigma_{j=1}^o((\partial c^v/\partial S_j)_t + (\partial c^v/\partial S_j)_s)(S_{jt} - S_{js}) \\ &+ ((\partial c^v/\partial t)_t + (\partial c^v/\partial t)_s)(t - s)]. \end{aligned} \quad (8)$$

Cost differences are attributable to the variable factor prices, output quantity, capital stocks, R&D spillovers, and time trend. In addition, by the definition of variable cost, the change over two periods is given by $c_t^v - c_s^v = \Sigma_{i=1}^n (w_{is}(v_{it} - v_{is}) + v_{it}(w_{it} - w_{is}))$. Using this result with (7) and (8) yields

$$\begin{aligned} TFPG(t,s) = ((y_t - y_s)/y_m)[&1 - (\partial c^v/\partial y)_m(y/c)_m] \\ &- \Sigma_{j=1}^o(\partial c^v/\partial S_j)_m(S_{jm}/y_m)(y/c)_m)(S_{jt} - S_{js})/S_{jm}, \\ &- (\partial c^v/\partial t)_m(t - s)(y/c)_m/y_m \end{aligned} \quad (9)$$

The decomposition of TFP growth, as shown by the right side of equation (9), consists of three elements. The first element is the scale effect. If there are constant returns to scale in long-run equilibrium then the term inside the square brackets is zero. The second element relates to the R&D spillover effects. There are two spillover effects. The third element is the one associated with the time trend.

The social rates of return to R&D capital equal the private rates of return plus the returns associated with the spillovers. These latter returns can be calculated by considering a situation where the spillovers have been internalized. In this regard, joint costs are defined as

$$\Omega_\tau = \Sigma_{j-1}^2(C^{vj}(w_\tau^j, y_\tau^j, K_\tau^j, S_{\tau-1}^j, t^j) + \omega_\tau^j K_\tau^j) \quad (10)$$

The superscript j refers to the producer; j=1 is manufacturing, and j=2 is communications equipment.

Consider the right side of equation (10) to be evaluated at the equilibrium input-output ratios. In equilibrium, the cost for each producer is at a minimum. However, joint cost is not minimized relative to the case where the spillovers are internalized. With the internalization of R&D spillovers, there is additional profit (through cost reductions) to be earned from each of the

R&D capital stocks. The additional profit is the reduction in joint cost. Using the average variable cost function, the reduction in joint cost in equilibrium from an increase in the R&D capital from communications equipment is

$$\partial\Omega_t/\partial K_{2t-1}^{2} = \Sigma_{i=1}^{2}\ \phi_{i1}^{1} w_{it}^{1} (y_t^{1})^{\vartheta^1} + \Sigma_{h=1}^{2} k_{ht}^{1} \eta_{h1}^{1} W_t^{1} y_t^{1}. \qquad (11)$$

Equation (11) shows the spillover wedge between the social and private rates of return, evaluated in equilibrium, that arises from R&D capital from the communications equipment industry. The private rate of return to R&D capital in long-run equilibrium is the marginal product of R&D capital per dollar of R&D investment. This return is defined gross of depreciation and before tax. The private return is the before tax rental rate deflated by the R&D capital price index.

Let us define ρ_{2t}^{2} to be the private rate of return to R&D capital in period *t* for the communications equipment industry. Let the extra-private return to R&D capital for this industry be $\iota_{2t}2$, which is the right side of (11) divided by the R&D price deflator in the communications equipment industry. Thus, the social rate of return to R&D capital is

$$\gamma_{2t}^{2} = \rho_{2t}^{2} + \iota_{2t}^{2}. \qquad (12)$$

APPENDIX 3

Estimation results

Table A3.1
Canadian manufacturing sector

Parameter	Estimate	Standard Error
β_1	0.947	0.241
β_2	2:949	0.755
β_{11}	0.712	0.102
$\dot{\vartheta}$	0.945	0.021
α_1	-8.192	2.424
α_2	-5.155	1.671
α_{11}	20.281	8.502
α_{22}	10.470	4.497
λ	0.051	0.018
η_{12}	-0.176E-05	0.317E-06
η_{22}	-0.449E-06	0.281E-06
η_{21}	-0.276E-04	0.103E-04

Note: $a_{12} = a_{21} = (\lambda a_{11} a_{22})^{0.5}$
Squared correlation of actual and fitted labour intensity: 0.838
Intermediate input intensity: 0.995
Physical capital intensity : 0.860
R&D capital intensity: 0.871

Table A3.2
Communications equipment industry

Parameter	Estimate	Standard error
β_1	0.886	0.370
β_2	0.988	0.457
β_{11}	3.237	0.328
ϑ	0.892	0.027
α_1	-1.029	0.209
α_2	-0.318	0.121
α_{11}	0.077	0.016
α_{22}	0.769	0.248
λ	0.975E-03	0.533E-03
η_{12}	0.844E-05	0.182E-05
η_{22}	-0.198E-05	0.149E-05
η_{21}	-0.398E-04	0.943E-05

Note: $a_{12} = a_{21} = (\lambda\ a_{11}\ a_{22})^{0.5}$
Squared correlation of actual and fitted labour intensity: 0.958
Intermediate input intensity: 0.975
Physical capital intensity: 0.939
R&D capital intensity: 0.992

APPENDIX 4

Data

The sample period for the estimation models is 1966-1991. The variables used in the estimation of the models are defined as follows. The quantity of output is measured in millions of 1986 dollars. The price of output is a price index obtained by dividing current dollar gross output by 1986 dollar gross output with 1986 = 1.00. The quantity of labour is labour compensation in millions of 1986 dollars. The price of labour is current dollar labour compensation divided by 1986 dollar labour compensation, and is indexed to 1.00 in 1986. The quantity of intermediate inputs is obtained by netting value added from gross output, and its price is obtained in the same manner as the price of output with 1986 = 1.00. Both physical and R&D capital stocks are measured in millions of 1986 dollars.

The rental rates are obtained as follows. The rental rate of physical capital is before-tax, defined as

$$w_k = p_k(r + \delta_k)(1 - itc_k - u_c z)/(1 - u_c),$$

where p_k is the acquisition price of capital, r is the interest rate on long-term government bonds, δ_k is physical capital depreciation rate, itc_k is the investment tax credit rate, u_c is the corporate income tax rate and z is the present value of capital cost allowances.

The present value of capital cost allowances is calculated using the declining balance method. The sum is calculated under two regimes, distinguished by whether the half-year rule is in effect or not. In addition, capital cost allowances are different for buildings and engineering constructions and for machinery and equipment. For buildings and engineering constructions, the discounted sum of capital cost allowances, z_b, outside the half-year rule, is

$$z_b = cca_b\,(1 - itc_b)(1 + r)/(r + cca_b),$$

where cca_b is capital cost allowances and the subscript b refers to building and engineering constructions. Inside the half-year rule, the present value of capital cost allowances is

$$z_b = cca_b\,(1 - itc_b)/2 + (1 - cca_b/2)(cca_b(1 - itc_b)/(r + cca_b)).$$

The present value of capital cost allowances for machinery and equipment, zm, outside the half-year rule, is

$$z_m = \Sigma_{t=0}^{T} cca_m(1 - itc_m)/(1 + r)^t,$$

where t represents time, T represents the number of years and the subscript m stands for machinery and equipment. Inside the half-year rule, the discounted sum is

$$z_m = \Sigma_{t=0}^{T-1}\, cca_m(1 - itc_m)/(1 + r)^t + (cca_m(1 - itc_m)(1 + 1/(1 + r)^T)/2.$$

The aggregate *z* is an index of z_b and z_m, where the weights are the shares of the acquisition values of the capital stocks.

The before-tax rental rate on R&D capital is defined as

$$w_r = p_r\,(r + \delta_r)((1 - u_c)(1 - itc_r) - u_c d)/(1 - u_c),$$

where p_r is the R&D investment price, $\delta_r = 0.1$ is the R&D capital depreciation rate, itc_r is the R&D investment tax credit, and *d* is the present value of incremental R&D investment allowance.

The present value of incremental investment allowance at time *t* is

$$d = iia_r(1 - \Sigma_{t=1}^{3} 1/(3(1 + r)^t)),$$

where iia_r is the incremental investment allowance rate. If the current R&D investment expenditures exceed an average of R&D expenditures in the past three years, then a tax reduction is allowed on the R&D expenditures in period *t* at the rate iia_r.

The spillover variables are expressed in millions of 1986 dollars.

Table A4.1 gives the mean, standard deviation, minimum and maximum value for the data used in the Canadian manufacturing model, and Table A4.2 gives the mean, standard deviation, minimum and maximum value for the data used in the communications equipment model.

Table A4.1
Data for the Canadian manufacturing sector

Variables	Mean	Standard deviation	Minimum	Maximum
Output quantity	211531.213	47051.527	129581.820	289522.156
Output price	0.663	0.323	0.274	1.119
Labour quantity	53946.820	2450.947	50004.148	59070.188
Labour price	0.611	0.369	0.163	1.289
Intermediate input quantity	141854.941	32621.629	85606.672	196522.500
Intermediate input price	0.662	0.325	0.263	1.083
Physical capital stock	41117.447	9939.198	23910.189	63823.320
Physical capital rental rate	0.126	0.0584	0.0423	0.213
R&D capital stock	11952.332	2126.900	8096.431	16065.187
R&D capital rental rate	0. 104	0.0648	0.0257	0.203
Spillovers from communications equipment	2822.314	1686.547	830.352	6296.646
Spillovers from U.S. manufacturing	530158.148	69438.803	441080.000	689200.000

Table A4.2
Data for the communications equipment industry

Variables	Mean	Standard deviation	Minimum	Maximum
Output quantity	3567.033	2001.444	1440.500	7750.300
Output price	0.705	0.263	0.361	1.083
Labour quantity	1346.011	148.079	1126.600	1657.500
Labour price	0.588	0.368	0.162	1.284
Intermediate input quantity	1527.350	1128.144	462.950	4101.000
Intermediate input price	0.731	0.213	0.440	1.000
Physical capital stock	2927.644	885.012	1706.100	5011.400
Physical capital rental rate	0.143	0.0673	0.0502	0.250
R&D capital stock	3034.128	1783.115	931.699	6549.354
R&D capital rental rate	0.117	0.0594	0.0407	0.230
Spillovers from Canadian manufacturing	11637.660	2123.501	7569.022	15656.976
Spillovers from U.S. electrical products	110188.556	12147.914	89126.000	134060.000

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