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INTERNATIONAL R&D SPILLOVERS BETWEEN INDUSTRIES IN CANADA AND THE UNITED STATES

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INTERNATIONAL R&D SPILLOVERS BETWEEN INDUSTRIES IN CANADA AND THE UNITED STATES

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EXECUTIVE SUMMARY

This study has three objectives. Its primary purpose is to investigate the importance of international spillovers between Canadian and U.S. industries and to estimate the effects of both domestic and international spillovers on production cost, traditional input-output ratios (such as labour-output, and physical capital-output ratios), and research and development (R&D) intensity for eleven manufacturing industries in the United States and Canada. The second objective is to measure productivity growth rates for each of the eleven industries and to determine the productivity gains associated with international spillovers. The third objective is to estimate the private and social rates of return associated with R&D capital and to determine the extra-private returns arising from spillovers between Canada and the United States.

Investment in research and development (R&D) affects a country's standard of living. R&D activities provide both individuals and firms with new products which can be manufactured using relatively more efficient means of production. Consequently, the dynamic efficiency and competitiveness of an economy are both enhanced by R&D investment. It is a distinctive feature of R&D investment that firms undertaking such activity are unable to exclude others from obtaining the benefits of their R&D efforts. Hence, the benefits from R&D cannot be be completely appropriated and, inevitably, spillovers occur. R&D spillovers are ideas borrowed by one R&D performer from the knowledge of another performer.

In a world characterized by international trade, foreign direct investment and the international exchange of information, a country's stock of knowledge depends on its own R&D investment, and because R&D spillovers extend beyond national boundaries, on the R&D efforts of other countries as well.

The effects of domestic and international spillovers are estimated on average variable production cost, labour-output, intermediate input-output, physical capital-output, and R&D capital-output ratios for eleven Canadian and U.S. industries. These industries are: chemical products, electrical products, food and beverage, fabricated metals, nonelectrical machinery, non-metallic mineral products, paper and allied products, petroleum products, primary metals, rubber and plastics, and transportation equipment. In this context, the input-output ratios are referred to as *factor intensities*.

In this study international spillovers relate to R&D externalities between the corresponding industries in the two countries; spillovers that cross national boundaries but link the same industry in Canada and the United States. Domestic spillovers relate to the interindustry externalities that operate within a national boundary. Moreover, international/interindustry spillovers are indirectly captured through the domestic spillover effects.

One of the study's findings is that international spillovers generally exert greater influence on production cost and factor intensities relative to domestic spillovers. This result is not surprising since the international spillovers link the same industry in both countries. In addition, spillovers from the United States to Canada generate greater effects than spillovers from Canada to the United States. In Canada, spillovers from the United States are cost-reducing in all industries except rubber and plastics. The combination of domestic and international spillovers (i.e., the joint effect of both spillovers) are cost-reducing, but occasionally one type of spillover increases variable cost. The study therefore considers the interplay between domestic and international spillovers without unduly restricting the role of each type of spillover.

The direct variable cost reductions (that is, keeping capital intensities fixed) from a 1 percent increase in U.S. R&D capital are: 0.06 percent for chemical products, 0.69 percent for electrical products, 1.13 percent for food and beverage, 0.39 percent for fabricated metals, 0.18 percent for nonelectrical machinery, 0.44 percent for non-metallic mineral products, 0.05 percent for paper and allied products, 0.36 percent for petroleum products. 0.23 percent for primary metals, and 0.39 percent for transportation equipment.

Canadian R&D capital generates cost reductions in the United States in all industries except chemical products, primary metals, and transportation equipment. Moreover, in the paper and allied products industry, the effect of international spillovers from Canada to the United States were estimated to generate cost reductions that are four-and-one-half times greater than the corresponding reductions from the United States to Canada. In the remaining six industries, where we observed cost savings for both countries, the U.S. effect is from two to 20 times greater than the Canadian effect.

International spillovers tend to increase R&D intensities in both countries, i.e., international spillovers are complements to domestic R&D capital. This complementarity means that as producers in the corresponding U.S. industry increase their investment in R&D capital, Canadian producers increase the amount of R&D content in their output. The same result holds from Canada to the United States. Substitutes for international spillovers and R&D intensity are observed in the United States for only electrical products, rubber and plastics, and transportation equipment. In Canada, substitutes are found in the petroleum products, and rubber and plastics industries.

In the industries where complementary relationships exist, a 1 percent increase in U.S. R&D capital precipitates to an increase in Canadian R&D intensity from a low of approximately 0.14 percent in nonelectrical machinery to a high of 2.85 percent in fabricated metals. In the United States, a 1 percent increase in Canadian R&D capital causes R&D intensity to rise from a low of 0.01 percent in petroleum products to a high of 0.54 percent in paper and allied products. With respect to the other factor intensities, it was found that in both countries, the international spillovers generally lead to increases in physical capital intensities and decreases in labour and intermediate input intensities.

Total factor productivity growth (TFPG) rates are not much different between corresponding Canadian and U.S. industries. The differences that do occur, however, are clearly visible in the decomposition of TFPG rates. In the United States domestic spillovers generally contribute relatively more to productivity gains than international spillovers. In Canada the international spillover is the major contributor. Also in Canada, international spillovers are generally found to contribute positively to TFP growth. The percentage contributions range from a high of 100 percent in the food and beverage industry to a low of 26 percent in the chemical products industry.

In the United States R&D capital from Canada generally leads to productivity gains. In the electrical products industry, 33 percent of the 1.9 average annual growth rate is due to Canadian R&D capital expansion. In the food and beverage industry, virtually 100 percent of the 2.3 percent TFPG rate is due to international spillovers. In fabricated metals, 58 percent of the 0.3 percent growth rate arises from international spillovers. The percentage contribution is 5 percent of the 1 percent productivity growth rate in nonelectrical machinery, 8 percent of the 1 percent growth rate in non-metallic minerals, 1 percent of the 0.3 percent productivity growth rate in paper and allied products, 64 percent of the 1.1 percent productivity growth rate in petroleum products, and 47 percent of the 0.8 percent growth rate in rubber and plastics. Thus, Canadian R&D capital is found to account for a sizable portion of the productivity gains in a number of U.S. industries.

The real, after tax and net of depreciation, private rates of return are approximately 1.5 percent in Canada and 1.8 percent in the United States -- rates that are not materially different from each other. Moreover, in nominal terms, before tax and gross of depreciation, the private rates are close to 13 percent in Canada and 16 percent in the United States. Due to significant domestic and international spillovers, social rates of return to R&D capital are estimated to be substantially above the private rates in both Canada and the United States. In Canada, international spillovers generally account for a greater percentage of the social returns relative to the domestic spillovers; the reverse is true in the United States. Canadian social rates of return (nominal, before tax, gross of depreciation) range from a low of 32 percent in transportation equipment to a high of 162 percent in nonelectrical machinery. Social rates of return are from two-and-one-half to twelve times greater than private returns. In the United States social rates of return are from three-and-one-half to ten times greater than the private rates, which range from a low of 44 percent for rubber and plastics to a high of 183 percent for the food and beverage industry.

These high rates of social return mean that at current R&D levels, there is in Canada substantial underinvestment in R&D. This underinvestment arises from both intranational and international spillovers. Indeed, these returns can be interpreted to mean that for a $100 increase in industrial R&D capital, Canadian industrial output increases over a range of $32 to $162 (depending on the industry), and U.S. industrial output increases over a range of $44 to $183.

The benefits being derived from international R&D spillovers imply that the Canadian government should encourage international technology transfer. This can be accomplished in a number of ways. First, with respect to R&D activities, impediments to the rate of knowledge diffusion should be eliminated, along with restrictions on the importation of R&D related equipment and the inflow of scientists and engineers. Second, with respect to the channels of technology transfer, the government should continue to forge ahead on free trade, eliminate barriers to inward foreign investment, and encourage more firms to enter into licensing agreements and joint ventures. Third, the government should investigate the possibilities for international tax harmonization policies with respect to R&D activities.

INTRODUCTION

The purpose of this study is to investigate the extent to which international spillovers exist between Canadian and U.S. industries -- with a view to determining the productivity gains and the social rates of return associated with international spillovers. The reason for focusing on the Canadian and U.S. economies has to do with their integration through trade, investment and joint ventures. In addition, the study surveys the empirical literature on domestic and international spillovers.

Investment in research and development (R&D) affects a country's standard of living. R&D activities provide individuals and firms with new products produced by relatively more efficient means of production. Consequently, the degree of competitiveness and dynamic efficiency of an economy are enhanced by R&D investment. Until recently economic analysis paid little attention to the significance of R&D. Theories of growth, production, and investment treated technological change as an exogenous process, and focused on capital accumulation. The view has now shifted towards an emphasis on R&D investment and the resulting innovations that respond to incentives as sources of technological progress and productivity gains. Innovation results from the cumulative R&D investment, and hence productivity growth depends on past as well as current R&D efforts. There exists convincing empirical evidence that the stock of domestic R&D capital (cumulative R&D investment) is an important source of productivity gains (see Griliches 1988).

It is a distinctive feature of R&D investment that firms undertaking such activity are unable to exclude others from freely obtaining the benefits of their R&D efforts. Hence, there is a public good aspect to R&D capital accumulation. Moreover, the benefits from R&D cannot be completely appropriated and spillovers are therefore inevitable.

R&D spillovers are ideas borrowed by one R&D performer from the knowledge base of another performer. However, the recipients of such spillover (or externalities) benefits incur costs in order to incorporate those ideas into their own production processes or new products. Spillovers (positive ones, at least) imply that R&D performers are not being adequately compensated for their efforts. R&D spillovers spur the diffusion of new knowledge, while simultaneously creating disincentives to undertake R&D investment. A number of recent empirical papers show the importance of domestic R&D spillovers in generating productivity gains and in affecting R&D capital accumulation in the economy (see Bernstein, 1991 for a survey).

In a world characterized by international trade, foreign direct investment and the international exchange of information, a country's stock of knowledge depends on its own R&D investment -- and because R&D spillovers extend beyond national boundaries -- on the R&D efforts of other countries as well.

SURVEY OF THE EMPIRICAL LITERATURE ON DOMESTIC AND INTERNATIONAL SPILLOVERS

As a general rule, technological change has a positive effect on productivity growth; in turn, productivity growth acts as a stimulus to economic activity. Substantial amounts of technological change also derive from the R&D capital accumulated by firms. In this respect, R&D capital formation constitutes a major source of endogenous technological change that ultimately contributes to economic growth.

It is an important characteristic of R&D investment that it has the nature of a public good. Once such investment incurs, many firms in addition to the R & D performer, can make use of it. Thus, many firms tend to enjoy a free-ride on the R&D capital accumulation of a few other firms in the economy.

Economists also identify private/public commodities according to the degree to which they are rivalrous and the degree to which they are excludable. A commodity is purely rival if demand by one individual precludes demand by another. For a purely nonrival commodity, demand by one in no way limits the demand by another. A commodity is excludable if the owner can prevent others from using it. A commodity can be made excludable or partially excludable through legal means such as patent law or copyright protection.

R&D capital is nonrival, because its use does not limit the use by others in the economy. Also, R&D capital is not excludable (at least not entirely), because others cannot be entirely prevented from benefitting from the R&D capital stock of the performer. Thus, R&D capital involves an inherent appropriability problem. The returns to R&D capital can only be appropriated incompletely. Imperfect appropriation implies that some form of externality or spillover accompanies R&D capital accumulation. In fact, the cost of exclusion contributes to the existence of spillovers. For example, R&D performers may try to keep their inventions secret until they have reaped all the returns but in so doing, the costs incurred are usually so substantial as to be too high to prevent unauthorized use of the particular knowledge.

Spillovers constitute the knowledge transmitted from R&D investment as R&D capital accumulates. Indeed, they are ideas borrowed from the knowledge of others. Firms, for example, purchase machinery and equipment from each other. It is inherent that the transfer or exchange of such physical assets embodies the transfer of knowledge in making that machinery and equipment. Knowledge transfer can also occur through other channels -- such as the use of patented inventions, hiring labour from other firms, and joint ventures. Clearly R&D capital benefits users through knowledge transfers and spillovers. When R&D is performed, which leads to the introduction of new products, new processes, or the improvement of existing products, it is not only the performers who receive a stream of future benefits; benefits spill over to other users inside and outside the performing industry.

Domestic Spillovers

Models used to estimate the magnitude and extent of R&D spillovers vary. Studies of firms, industries and lines of business based on time series, cross-section or panel data have been used for estimation of spillovers. Most samples are drawn from manufacturing industries and range from a few industries to many hundreds of firms. The models exhibit a number of common features. Technology is specified by a production function or, its dual, a cost function. Production functions are generally of the Cobb-Douglas variety, while cost functions are translog or truncated translog. The models are specified in terms of short-run, long-run or temporary equilibrium -- the latter being based on a cost of adjustment framework. Adjustment costs are incurred as producers accumulate physical and R&D capital. The spillover variables are distinguished between interindustry and intraindustry. Finally, the effects of spillovers are generally estimated on rates of return, production costs, factor demand, product demand, and total factor productivity growth.

Table 1 sets out the important studies that have been undertaken, with their results classified into four groups according to: spillover effects on productivity growth; spillover effects on profitability and supply of output; spillover effects on input demand; and social and private rates of return to R&D.

Spillover Effects on Productivity Growth

R&D spillovers have been found to reduce variable costs and hence, most studies report productivity gains. The magnitude of cost reduction varies among industries. The important findings are the following: Interindustry spillovers exert greater downward pressure on average cost of production relative to intraindustry spillovers. This is true for both Canadian and US industries, as found in Bernstein (1988), and Jaffe (1986); Unit costs decrease more in response to an increase in the intraindustry spillovers in industries with relatively large R&D cost shares, such as aircraft and parts, electrical products, and chemical products. However, unit costs decrease more in response to an increase in the interindustry spillovers in industries with relatively small R&D cost shares (Bernstein 1988); The contribution of R&D performance within an industry (own R&D) to total factor productivity growth is significant. However, interindustry R&D spillovers (outside R&D) contribute more than own R&D to total factor productivity growth. This is found in Terleckyj (1980), Scherer (1984), Griliches and Lichtenberg (1984). Furthermore, the privately financed component of outside R&D, is far more significant in contributing to productivity growth than its government financed counterpart. The latter was found to have a negligible influence (see Terleckyj, 1974, 1980), although the ability to distinguish the effects of private and public sector funding is somewhat clouded in these studies.

Spillover Effects on Profitability and Supply of Output

The supply of output is closely connected with profitability, which is, in turn, determined by production cost and product price. A recent study (Bernstein and Nadiri, 1991) shows that generally R&D spillovers cause output to expand and product price to fall. R&D spillovers also generate revenue growth and thus cause the size of the product market to expand. Jaffe (1986) estimates the elasticity of profit with respect to the spillover pool to be about 0.1 percent, based on a 1 percent increase in spillovers.

Table 1
Spillover Studies

Study	Sample	Model Specification		
		Technology Representation	**Equations Estimated & Equilibrium**	**Spillover Description**
Bernstein (1988)	680 Canadian firms in seven industries 1978-1981	translog cost function	cost function, labour, materials, physical capital and R&D capital cost shares long-run static model	interindustry and intraindustry effects on cost, production and rates of return
Bernstein (1989)	9 Canadian industries 1963-1983	truncated translog cost function	variable cost function, labour, materials and physical capital cost shares short-run static model	interindustry effects on cost, production and rates of return
Bernstein-Nadiri (1988)	5 U.S. industries 1958-1981	translog variable cost function	variable cost function, labour, materials and physical capital cost shares short-run static model	interindustry effects on production costs, factor demand and rates of return
Bernstein-Nadiri (1989b)	48 U.S. firms in four industries 1965-1978	generalized quadratic value function	value function, variable factor, physical and R&D capital demand functions temporary dynamic model	intraindustry effects on variable cost, production and rates of return

Study	Sample	Model Specification		
		Technology Representation	**Equations Estimated & Equilibrium**	**Spillover Description**
Bernstein-Nadiri (1991)	6 U.S. industries 1957-1986	truncated translog variable cost function	variable cost function, inverse product demand function, output supply, labour, materials, physical and R&D capital cost shares temporary dynamic model	interindustry effects on product demand, production costs and rates of returns
Griliches & Lichtenberg (1984)	193 manufacturing industries 1957-1978 subperiods	Cobb-Douglas TFP growth rate	TFP growth rate equation long-run static model	interindustry effects on TFP growth
Jaffe (1986)	432 firms 1973-1979	generalized Cobb-Douglas knowledge output function	patent equation, profit equation, market value equation long-run static model	intraindustry effects on productivity, profits and market value
Levin-Reiss (1988)	116 manufacturing line of business (FTC) in 1976	Cobb-Douglas unit variable cost function	output supply equation, process R&D equation, product R&D equation long-run static model	interindustry effects on output supply, process R&D intensity and product R&D intensity
Mohnen-Lepine (1988)	12 Canadian industries 1975, 1977, 1979, 1981-1983	translog variable cost function	variable cost function, variable inputs cost share equations for labour, materials and payments for technology short-run static model	interindustry effects on demand for R&D capital and production cost

Study	Sample	Model Specification		
		Technology Representation	**Equations Estimated & Equilibrium**	**Spillover Description**
Scherer (1982, 1984)	87 industries subgroups of industries 1964-1978 subperiods	generalized Cobb-Douglas production function	labour productivity growth rate equation long-run static model	interindustry effects on productivity growth
Sveikaus-kas (1981)	144 manufacturing industries 1959-1969	generalized Cobb-Douglas production function	TFP growth rate equation long-run static model	extra-industrial effects on factor productivity growth
Terleckyj (1974)	20 manufacturing and 13 non-manufacturing industries 1948-1966	generalized Cobb-Douglas production function	TFP growth rate equation short-run static model	interindustry effects on productivity growth and the magnitude of the effects
Terleckyj (1980)	20 manufacturing industries (1948-1966)	generalized Cobb-Douglas production function	TFP growth rate equation short-run static model	interindustry and intraindustry effects on TFP growth
Wolff-Nadiri (1987)	19 manufacturing industries 50 manufacturing and non-manufacturing sectors 1947, 1958, 1963, 1967, 1972	Leontief production function	TFP growth rate equation long-run static model	interindustry linkage effects on productivity growth, R&D intensity, and rate of return

Spillover Effects on Input Demand

R&D spillovers affect factor demands. Generally, demand for both labour and materials decreases in response to spillovers, while demand for physical capital increases. This suggests that R&D spillovers are at least partial substitutes for labour and materials, but complements to physical capital. These results were found in Bernstein (1988), and Bernstein and Nadiri (1991). Bernstein (1988) also found that physical capital is complementary to interindustry R&D spillovers, particularly in industries with high propensities to spend on R&D activities (Bernstein 1988).

The effect on the demand for R&D capital depends on the source of spillovers. Specifically, intraindustry spillovers are substitutes for R&D in industries with relatively small propensities to spend on R&D. However, they are complements in industries with relatively large R&D cost shares. This result means that industries that are relatively active as R&D performers also increase their own R&D investment as they obtain new knowledge from rival firms through intra-industry spillovers. Interindustry spillovers are generally a substitute for own R&D in all types of industries (Bernstein 1988).

Rates of Return to R&D

A distinction between private and social rates of return is necessary because of the existence of R&D spillovers. The private rate of return is the return from the performance of R&D activities. The social rate of return is the return from the use of R&D activities. Thus, the social rate is inclusive of spillovers and is equal to the private rate, plus the sum of marginal benefits bestowed upon rival firms within an industry (intra-industry spillovers), plus the sum of marginal benefits transmitted to all firms in other industries (interindustry spillovers).

Studies show that social rates of return on R&D generally exceed private rates. In the United States and Canada, industries such as nonelectrical machinery, rubber and plastics, petroleum products and chemical products record social rates that are at least twice the levels of private returns. (Bernstein, 1989, relates to two-digit industry data, while Bernstein, 1988, deals with firm- or enterprise-level data). Bernstein and Nadiri (1988) found that social rates exceed private rates from 10 percent to 1,000 percent. Tables 2 and 3 provide a summary of the social and private rates of return in selected industries in Canada and the United States respectively. Bernstein and Nadiri (1988) also found that social rates of return to R&D show a great deal of interindustry variation.

Although it is often difficult to distinguish between expenditures on process R&D and product R&D, Griliches and Lichtenberg (1984) show that the social rate of return is higher on process R&D -- between 38 percent and 76 percent on process R&D and between 21 percent and 29 percent on product R&D. Scherer (1982) also finds social returns to process R&D in the range of 37 percent to 93 percent. He does not, however, find any spillovers associated with product R&D. Privately financed R&D also experienced higher social rates of return compared to publicly financed R&D. The former exhibits social returns between 28 percent and 60 percent. In Terleckyj (1974, 1980) and Wolff & Nadiri (1987), again, no spillovers from government-financed R&D were found.

International Spillovers

Because most studies have been centered on domestic spillovers, there is limited empirical evidence about the production structure and productivity growth effects of international spillovers. Since R&D spillovers are a form of externality that derive from the nonrivalrous, but partially excludable character of R&D capital formation, they are not necessarily contained within national boundaries. International R&D spillovers occur in a number of ways. Some of these mechanisms include exports of goods and services, international alliances between firms (such as licensing agreements and joint ventures), foreign direct investment, international labour markets for scientists and engineers, and international communications (such as conferences).

Table 2
Social and Private Rates of Return
in Selected Canadian Industries (%)

	Rates of Return					
	Bernstein (1988)		Bernstein (1989)		Mohnen-Lepine (1988)	
Industry	pri	soca[a]	pri	soca[b]	pri	soca[b]
Aircraft and parts	12	23			8	11
Chemicals	12	26	25	81	15 51	17[c] 132
Electrical products	12	26	38	38	5 33	24[c] 47
Food and beverage	12	20				
Gas and oil wells			33	37		
Metal fabricating	12	20	29	29	274	314
Nonelectrical machinery	12	19	24	94	6 27	12[c] 117
Petroleum products			40	87		
Primary metal			26	42	17	51
Pulp and paper	12	20				
Rubber and plastics			47	89	143	157
Scientific instruments					49	75
Transportation equipment			28	29		

a = net of depreciation rates of return
b = gross of depreciation rates of return
c = depending on sub-aggregates within the industry
d = average rates of return of 1965, 1975 and 1985

Table 3
Social and Private Rates of Return
in Selected U.S. Industries (%)

	Rates of Return							
	Bernstein & Nadiri (1988)		Bernstein & Nadiri (1989a)		Bernstein & Nadiri (1989b)		Bernstein & Nadiri (1991)	
Industry	pri	soc[b]	pri	soc	pri	soc[b]	pri[d]	soc[d]
Chemical products	13	21	20		7	12	23	45
Electrical products	15	18			15	25		
Food and beverage			9					
Metal fabricating				21	21			
Nonelectrical machinery	27	58	16		7	9	22	28
Petroleum products					7	16		
Primary metals			10					
Scientific instruments	17	111			7	14	25	110
Transportation equipment	10	11					15	29

a = net of depreciation rates of return
b = gross of depreciation rates of return
c = depending on sub-aggregates within the industry
d = average rates of return of 1965, 1975 and 1985

It is important to emphasize that international transactions do not have to occur in order for spillovers to flow between nations. For example, Japanese automobile producers operating in the United States can perform reverse engineering on U.S. vehicles in the United States and transfer this information back to Japan. There are also the spillover links to upstream and downstream firms between nations in addition to the links between firms in the same industry but different countries. Input suppliers and intermediate input demanders are also part of the international spillover network. Indeed, as in the case of domestic spillovers, firms that are not connected through transactions can still be sources and recipients of international spillovers. Thus, the magnitude and extent of international spillovers can be quite pervasive.

A few studies estimate the effects of international spillovers. Mohnen (1990) looks at the effects of foreign R&D capital on Canadian manufacturing, measuring the international spillover variable as the sum of the R&D stocks in foreign countries, weighted by high-tech imports from the country of origin, expressed as percentages of total high-tech imports. Using high-tech imports for the weighting procedure implicitly assumes that the more a country imports high-tech products from a foreign country, the closer the two countries are, technologically. In addition, there is a tacit assumption that an importer benefits from exporters' R&D in proportion to its import share. This weighting approach also assumes that each unit of high-tech import is of equal value in terms of R&D externality, regardless of its country of origin. It is important to note the limitations of different weighting schemes in evaluating the results of the various empirical studies.

Countries are technologically linked through a number of channels and not only through international trade -- i.e., there are other forms of technology transfer. For example, both multinational firms and joint ventures can generate spillovers without purchase flows between host and foreign countries. The international mobility of scientists and engineers is another potential source of R&D spillovers not associated with trade. For these reasons, using high-tech imports as a criterion provides only a limited measure of spillovers.

Hartwich and Ewen (1983) measured international R&D spillovers by aggregating the R&D capital stocks of foreign countries by sectors, using the domestic country's sectoral purchase of intermediate inputs from foreign sectors as weights. The framework is similar to that used by Terleckyj (1974, 1980) in a domestic context. This approach assumes that spillovers follow input purchase flows. However, this measure accounts only for the forward linkage spillovers. In fact, R&D capital can be spilled over from downstream users to upstream suppliers -- as evidenced by the automobile industry. Improvements in motor vehicles generate technological advances in the steel, glass, machine tools, and electrical equipment industries.

A recent paper (Bernstein and Mohnen, 1994) looks at the effects of international spillovers between Japanese and U.S. R&D-intensive sectors. In this paper, the spillover effects from the United States to Japan, and from Japan to the United States are investigated simultaneously, using a bilateral model of production between the Japanese and U.S. economies. The significance of this approach is that the effects of international spillovers on production cost, productivity growth, and production structures (including decisions on domestic R&D capital) are considered simultaneously. The results from the U.S./Japanese study showed that a 1 percent increase in U.S. R&D capital caused Japanese average variable cost to decrease by 0.63 percent. However, a 1 percent increase in Japanese R&D capital generated only a 0.05 percent decrease in U.S. average variable cost. Thus, both countries benefit from international spillovers, but the effect in Japan is twelve times larger than the effect in the United States. It is important to note that declines in unit production costs associated with international spillovers imply that social returns to R&D capital exceed private returns.

Production structures -- i.e., input demands output supply or input-output ratios -- are also affected by international spillovers. In Japan and the United States, labour and physical capital intensities (i.e., the input-output ratios) decrease in response to the international spillover, but intermediate input intensity increases in the face of a growing spillover. In addition, R&D intensity increases for both countries as a result of an expanding spillover. Thus, own R&D intensity is complementary to new knowledge obtained from foreign sources.

International spillovers also affect the dynamic efficiency of an economy. Knowledge obtained from foreign countries tends to improve domestic productivity performance. Indeed, 52 percent of the total factor productivity growth in Japan can be attributed to U.S. R&D capital stock accumulation. The effect on U.S. productivity growth from the Japanese R&D spillover is about 15 percent. Thus, the paper by Bernstein and Mohnen (1994) finds that both countries exhibit productivity gains from international spillovers.

SPILLOVER ELASTICITIES

This section discusses the effects of domestic and foreign spillovers on average variable cost of production, and the structure of production. In this context, production structure refers to factor intensities (i.e., input/output ratios). The model and discussion of the data are presented in the Appendix. The formulae for the spillover elasticities are also derived in the Appendix, as equations (10), (11), and (12).

Domestic and intranational spillovers are measured as the sum of the R&D capital stocks (measured not as expenditures but as the deflated, undepreciated accumulation of R&D expenditures) of the domestic industries other than the industry under consideration. For example, (in this study) the intranational spillover for the Canadian chemical products industry is the sum of the R&D capital stocks of all Canadian manufacturing industries excluding the chemical products industry. The international spillover for the Canadian chemical products industry is the R&D capital stock for the U.S. chemical products industry. The spillover effects or elasticities show the percentage change in average variable cost and factor intensities when either a domestic or foreign spillover increases by 1 percent. The results are presented in Tables 4 through 14.

Consider first the chemical products industry. From Table 4 it can be seen that the international spillover from the United States to Canada exerts a direct negative effect on average variable cost. The direct effect (shown as the mean of "Direct Average Variable Cost"; the bottom line in both the intranational and international sections of Tables 4 through 14) reflects the percentage change in average variable cost when capital factor intensities are held fixed (-0.6106). It is possible for a spillover to result in direct average variable cost increases i.e., have a positive value. (This is explained in the paragraph following.) This result is obtained for the international spillover from Canada to the United States (0.24375).

It is possible for a spillover to have a direct positive effect on variable cost. Given the level of variable factor prices, output quantity and capital intensities (both physical and R&D), an increase in a spillover operates like a quality or characteristics change in output. changes in output characteristics can make existing labour and intermediate inputs more expensive to use thereby increasing variable cost. In a sense the technical efficiency of these inputs diminishes and so cost rises. Thus, output produced by existing labour and intermediate inputs becomes less profitable.

The effect on average variable cost (second to last row in both the intranational and international sections of Tables 4 through 14) measures the sum of the direct effects, and the effect on average variable cost resulting from the percentage changes in variable factor intensities. It is important to note here that although the combined direct and indirect effects of spillovers (both individually or jointly) are usually negative, they can also be positive, because these effects include changes in factor intensities -- as, for example, when a spillover directly reduces average variable cost but also precipitates substantial increases in variable factor intensities. Increases in factor intensities are cost increasing and since more inputs are used per unit of output, the indirect effect of these positive factors can offset the negative direct effect such that the average variable cost increases.

Table 4
Chemical Products

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.00589	0.00114	0.01879	0.00878
Intermediate/Output	-0.01676	0.00495	0.03384	0.01389
Physical Capital/Output	0.00147	0.00017	-0.01362	0.00154
R&D Capital/Output	0.00057	0.00007	-0.21594	0.02255
Average Variable Cost	-0.01156	0.00215	0.03028	0.01261
Direct Average Variable Cost	-0.01096	0.00195	0.02663	0.01293

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.14461	0.02720	-0.04337	0.02518
Intermediate/Output	0.39942	0.04589	-0.07780	0.04152
Physical Capital/Output	-0.11756	0.01987	0.02662	0.00468
R&D Capital/Output	0.01563	0.00244	0.53853	0.05251
Average Variable Cost	0.27897	0.00777	-0.06963	0.03750
Direct Average Variable Cost	0.24375	0.01453	-0.06106	0.03758

There is a complementary relationship between R&D intensity and the international spillover in each country. Thus, R&D capital expansion in the U.S. chemical industry leads to an increase in the R&D intensity in the Canadian chemical products industry. A 1 percent increase in U.S chemical products R&D causes Canadian chemical products R&D intensity to increase by 0.54 percent. The converse is also true. However, the effects in Canada are substantially greater than than the corresponding effects in the U.S.

In terms of the non-R&D capital intensities, in Canada labour and intermediate input intensities are substitutes for the international spillover, while physical capital intensity is complementary to it. These results are the opposite to those found in the United States.

Table 5
Electrical Products

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.11067 0.03899	-0.02723	0.01595	
Intermediate/Output	0.22378 0.01518	-0.03780	0.01102	
Physical Capital/Output	-0.25830 0.05373	0.12199	0.03209	
R&D Capital/Output	0.22210 0.01721	-0.35236	0.18433	
Average Variable Cost	0.15970 0.02973	-0.03356	0.00897	
Direct Average Variable Cost	0.16808 0.03484	-0.04104	0.01040	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.07975 0.07065	-0.66398	0.55930	
Intermediate/Output	-0.14004 0.08300	-0.79874	0.20500	
Physical Capital/Output	0.13645 0.05122	0.35762	0.05676	
R&D Capital/Output	-0.12656 0.07207	0.62644	0.02420	
Average Variable Cost	-0.10723 0.07817	-0.73513	0.27414	
Direct Average Variable Cost	-0.11316 0.08424	-0.68744	0.26225	

The effects of intranational spillovers (between industries) generates results that are quite different from the international externality. In Canada, the intranational spillover leads to a reduction of R&D intensity. For example, as borrowed knowledge from other Canadian industries expands, the Canadian chemical products industry substitutes this knowledge for its own R&D per unit of output. In the United States the relationship between own R&D intensity and intranational spillovers is very small. With respect to Canadian non-R&D capital intensities, intranational spillovers, lead to increases in labour and intermediate input intensities while physical capital intensity decreases. In the United States the opposite results.

In the electrical products industry (see Table 5) the effects of international spillovers on Canadian production structure and costs exceed the effects of intranational spillovers. In the United States, however, the effects of intranational or domestic spillover are dominant. Also, R&D intensity in Canada increases as a result of R&D undertaken in the U.S. electrical products industry. A 1 percent increase in U.S. R&D in the electrical products industry leads to a 0.63 percent increase in Canadian R&D intensity. In the United States, R&D intensity decreases as a result of R&D undertaken in the U.S. electrical products industry. Canadian R&D expansion also causes the United States to decrease its R&D intensity. It can also be observed from Table 5 that domestic spillovers reduce R&D intensity in Canada, but that they increase R&D intensity in the United States. Thus, the electrical products industries in the two countries respond quite differently to both domestic and international spillovers. For the other factor intensities, however, we observe that although international and intranational spillovers generate the same directional influences in Canada, in the United States the results differ between the intranational and international spillovers.

Table 6
Food & Beverage

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.05190.00527	-0.00103	0.00037	
Intermediate/Output	0.11922.01758	-0.00170	0.00071	
Physical Capital/Output	-0.01060.00147	-0.01253	0.00203	
R&D Capital/Output	-0.03100.00398	0.24255	0.01987	
Average Variable Cost	0.10042.01170	-0.00156	0.00061	
Direct Average Variable Cost	0.09929.01167	-0.00138	0.00061	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.28281.23178	-0.75403	0.40347	
Intermediate/Output	-0.66709.95261	-1.25666	0.74248	
Physical Capital/Output	0.05160.01571	0.96805	0.00776	
R&D Capital/Output	0.24630.407994	0.31532	0.02964	
Average Variable Cost	-0.55492.27310	-1.14886	0.65294	
Direct Average Variable Cost	-0.54872.27040	-1.13207	0.64861	

Table 6 shows the results for the food and beverage industry -- which are similar to those for the electrical products industry. In Canada, both intranational and international spillovers reduce average variable cost, although the effects of intranational spillovers are quite small. In terms of the international spillovers, a 1 percent increase causes average variable cost to decrease by slightly more than 1 percent, which is approximately double the magnitude found in the United States. Once more, the influence of U.S. R&D capital in Canada exceeds the effect generated by Canadian R&D in the United States.

In both countries, R&D intensity is complementary to the international spillovers, and the elasticities are not much different. In Canada, a 1 percent increase in international spillovers increases R&D intensity by 0.32 percent; in the United States the magnitude is 0.25 percent. With respect to the other factor intensities, both countries behave similarly in response to the international spillovers. Labour and intermediate input intensities are substitutes, and physical capital intensity is complementary. The effects of the United States on Canada exceed those of Canada on the United States. The elasticities associated with intranational spillovers are smaller (in terms of absolute value) to those emanating from international spillovers.

Table 7
Fabricated Metals

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.01169 0.01257	0.02273	0.00619	
Intermediate/Output	0.01801 0.01955	0.02049	0.00320	
Physical Capital/Output	-0.26310 0.05767	-0.05788	0.00938	
R&D Capital/Output	0.36905 0.03793	0.48809	0.21809	
Average Variable Cost	0.01501 0.01622	0.02124	0.00415	
Direct Average Variable Cost	-0.01023 0.02521	0.01950	0.00412	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.03160 0.01805	-0.48104	0.18788	
Intermediate/Output	-0.04823 0.02725	-0.42754	0.12731	
Physical Capital/Output	0.05385 0.02444	1.26277	0.06510	
R&D Capital/Output	0.02883 0.01521	2.85225	0.95321	
Average Variable Cost	-0.04037 0.02283	-0.44548	0.14686	
Direct Average Variable Cost	-0.03448 0.02076	-0.39285	0.14427	

Table 7 shows the results for the fabricated metals industry. Here, the effects of international spillovers dominate the elasticities associated with the intranational spillovers. In addition, Canada is relatively more elastic in response to spillovers from the United States compared to the effects on the United States from Canada. A 1 percent increase in international spillovers directly reduces average variable cost by 0.40 percent in Canada, and by only 0.03 percent in the United States. R&D intensity is complementary to international spillovers, but the difference between the two countries is striking. A 1 percent increase in international spillovers increases Canadian R&D intensity by 2.85 percent, an effect that is 100 times greater than the corresponding effect in the United States. As for other industries, international spillovers reduce labour and intermediate input intensities and increase physical capital intensity.

Table 8
Nonelectrical Machinery

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.0016	0.0013	0.0539	0.0828
Intermediate/Output	-0.0028	0.0017	0.0701	0.1198
Physical Capital/Output	0.0039	0.0008	0.0694	0.0170
R&D Capital/Output	0.0009	0.0002	0.7311	0.0262
Average Variable Cost	-0.0022	0.0015	0.0647	0.1068
Direct Average Variable Cost	-0.0016	0.0014	0.0655	0.1069

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.1432	0.1859	-0.1426	0.0756
Intermediate/Output	-0.2145	0.2761	-0.2123	0.0904
Physical Capital/Output	0.7234	0.0936	0.1320	0.0428
R&D Capital/Output	0.2263	0.0899	0.1399	0.0169
Average Variable Cost	-0.1807	0.2299	-0.1879	0.0857
Direct Average Variable Cost	-0.0640	0.1843	-0.1774	0.0837

The findings for the nonelectrical machinery industry are presented in Table 8. Generally, the effects of international spillovers dominate the intranational effects. This is not the case for R&D intensity in Canada, however. Here, a 1 percent increase in intranational spillovers causes R&D intensity to increase by 0.73 percent, compared to a 0.14 percent increase attributable to international spillovers. In this industry, the international spillover elasticities in Canada are, generally, not more elastic. Although it is true that a 1 percent increase in U.S. R&D capital directly reduces Canadian average variable cost by 0.18 percent (which is three times greater than Canada's influence on the United States), a 1 percent increase in Canadian R&D capital increases U.S. R&D intensity by 0.23 percent (50 percent more than the influence of U.S. R&D capital on the Canadian R&D intensity). International spillovers exert the usual effects on non-R&D capital intensities; labour and intermediate input intensities fall, while physical capital intensities rise. Indeed, a 1 percent increase in Canadian R&D capital generates a 0.72 percent expansion in the physical capital intensity in the U.S. nonelectrical machinery industry.

From Table 9 it can be seen that the results for non-metallic mineral products are much the same as those emerging for other industries. International spillover effects dominate intranational effects. U.S. R&D capital has a greater impact in Canada than Canadian R&D capital has in the United States. R&D intensity is complementary to international spillovers, as is physical capital intensity, while labour and intermediate input intensities are substitutes. A 1 percent increase in international spillovesr reduces direct average variable cost in Canada by 0.44 percent, and in the United States the elasticity is 0.02 percent. The elasticities for the R&D intensities are much closer together. A 1 percent increase in the international spillover causes R&D intensity to expand by approximately 0.21 percent in both countries.

Table 9
Non-Metallic Mineral Products

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.06728	0.00634	0.03787	0.01312
Intermediate/Output	0.10862	0.01090	0.04373	0.01087
Physical Capital/Output	0.19472	0.04577	0.05560	0.00602
R&D Capital/Output	0.13955	0.08587	0.15188	0.04784
Average Variable Cost	0.08741	0.00733	0.04176	0.01156
Direct Average Variable Cost	0.02319	0.00782	0.03629	0.01118

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.02186	0.01073	-0.467[illegible]	0.[illegible]0352
Intermediate/Output	-0.03533	0.01829	-0.533[illegible]	0.[illegible]8639
Physical Capital/Output	0.04065	0.01404	0.58311	0.05047
R&D Capital/Output	0.20850	0.03104	0.21054	0.04679
Average Variable Cost	-0.02841	0.01431	-0.511[illegible]	0.[illegible]9163
Direct Average Variable Cost	-0.01976	0.01151	-0.437[illegible]	0.[illegible]7987

The results for the paper and allied products industry do not follow the usual pattern. It can be seen from Table 10 that a 1 percent expansion in Canadian R&D capital directly reduces U.S. average variable cost by 0.20 percent. However, a 1 percent increase in U.S. R&D capital reduces average variable cost in Canada by only 0.05 percent. In the paper and allied products industry Canadian R&D capital generates greater benefits for the U.S. industry. In both countries R&D intensity responds positively to the international spillover. A 1 percent increase in international spillovers increases Canadian R&D capital per unit of output by 0.87 percent and for the United States, the effect is 0.54 percent. As in other industries, labour and intermediate input intensities are substitutes for the international spillover, while physical capital is a complement.

Table 10
Paper & Allied Products

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.02610.20457	0.04091	0.03180	
Intermediate/Output	-0.05570.61245	0.06121	0.03580	
Physical Capital/Output	-0.02330.50387	-0.32142	0.03995	
R&D Capital/Output	-0.34320.48887	0.11641	0.03705	
Average Variable Cost	-0.04270.80753	0.05541	0.03459	
Direct Average Variable Cost	-0.05090.40931	0.04216	0.03540	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.14960.82301	-0.04204	0.06771	
Intermediate/Output	-0.31490.33826	-0.05236	0.08787	
Physical Capital/Output	0.25840.62761	0.22284	0.06050	
R&D Capital/Output	0.53660.10286	0.86844	0.49254	
Average Variable Cost	-0.24290.22195	-0.04953	0.08182	
Direct Average Variable Cost	-0.19770.91327	-0.04483	0.08060	

In this industry domestic spillovers generate effects that are quite different from those obtained for international spillovers. In Canada domestic spillovers produce effects that are the converse of the international spillovers, except for R&D intensity. For both types of spillover, R&D intensity is complementary to the spillover. In the United States, all factor intensities, including R&D capital, are substitutes for the domestic spillover.

Petroleum products is another interesting case. Table 11 shows that, although average variable cost decreases as a result of the growth in international spillovers between Canada and the United States, these spillovers have very little effect on R&D intensity in the United States, whereas, in Canada, R&D intensity is a substitute for the international spillover. Thus, a 1 percent increase in U.S. R&D capital leads to a decrease in Canadian R&D capital per unit of output by about 0.43 percent. This is not the case for the domestic spillover affecting the Canadian petroleum products industry, however. Here, R&D capital is complementary to the domestic spillover. In the United States the domestic spillover reduces R&D capital intensity. In contrast, the domestic spillover effects in Canada and the United States are opposite to each other. In the United States, all non-R&D capital intensities increase in the face of a growing spillover. However, as can be seen, the opposite is true for Canada -- although the effects are quite small in both countries. In terms of international spillovers, the non-R&D capital intensities follow the usual pattern.

Table 11
Petroleum Products

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.01730.00152	-0.00926	0.00146	
Intermediate/Output	0.02420.00160	-0.01162	0.00219	
Physical Capital/Output	0.01380.00353	-0.01365	0.00253	
R&D Capital/Output	-0.27710.14533	0.32172	0.04125	
Average Variable Cost	0.02360.00155	-0.01150	0.00216	
Direct Average Variable Cost	0.01750.00185	-0.00860	0.00296	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.15207.05718	-0.32198	0.10975	
Intermediate/Output	-0.21810.29371	-0.40773	0.15780	
Physical Capital/Output	0.17911.02661	1.07858	0.07437	
R&D Capital/Output	0.00660.80246	-0.43254	0.05415	
Average Variable Cost	-0.21250.19148	-0.40375	0.15619	
Direct Average Variable Cost	-0.18850.49866	-0.35877	0.16623	

Table 12 sets out the results for primary metals. Here, a 1 percent increase in international spillovers directly reduces average variable cost in Canada by 0.24 percent. In the United States, Canadian R&D capital generates increases in average variable cost by about 0.06 percent. As has already been discussed, it is possible for any one type of spillover to cause average variable cost increases directly. R&D capital intensity increases as a result of international spillovers. An interesting feature of the results obtained for this industry is that, although non-R&D capital intensities in Canada appear to follow the general pattern, the effect of Canadian R&D capital expansion is that it leads to increases in labour and intermediate input intensities and a reduction in physical capital intensity in the United States. This result is the opposite of the domestic spillover situation. In both countries, in the primary metals industry, international and domestic spillovers generate opposite effects on factor intensities.

Table 12
Primary Metals

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.157904839	0.02663	0.00826	
Intermediate/Output	-0.301092344	0.03468	0.00519	
Physical Capital/Output	0.011400181	-0.06809	0.00718	
R&D Capital/Output	-0.397649336	-0.04922	0.00447	
Average Variable Cost	-0.243409107	0.03282	0.00582	
Direct Average Variable Cost	-0.246609093	0.03060	0.00579	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.038000698	-0.19799	0.07602	
Intermediate/Output	0.069200865	-0.25557	0.05903	
Physical Capital/Output	-0.008200157	0.27570	0.02659	
R&D Capital/Output	0.078501025	0.29396	0.03186	
Average Variable Cost	0.056700734	-0.24224	0.06210	
Direct Average Variable Cost	0.056500737	-0.23263	0.06154	

An interesting result can be observed in the rubber and plastics industry, as shown in Table 13. Canada incurs rather large cost increases from international spillovers. The Table shows that a 1 percent increase in the U.S. R&D capital leads to a 1.20 percent increase in Canadian direct average variable cost. Conversely, Canadian R&D capital reduces direct average variable cost in the United States by 0.09 percent. This effect is not particularly great. However, domestic spillovers reduce average variable cost directly. In this industry R&D capital per unit of output is generally found to be a substitute for both domestic and international spillovers. Only U.S. R&D intensity (compared to Canada) increases with growing domestic spillovers, but the effect is relatively small. It also appears that domestic and international spillovers affect non-capital factor intensities in the same direction, although the directional changes are not identical in the two countries.

Table 13
Rubber & Plastics

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.01720.30505	1.16765	0.97986	
Intermediate/Output	-0.03306.61619	0.19523	0.15878	
Physical Capital/Output	0.24491.94014	-0.15570	0.02750	
R&D Capital/Output	0.09589.90749	-0.29961	0.04530	
Average Variable Cost	-0.02600.81047	-1.77431	1.12728	
Direct Average Variable Cost	-0.01890.01025	-1.73295	1.09633	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.04658.08295	1.00776	0.87687	
Intermediate/Output	-0.06007.12182	0.70864	0.51395	
Physical Capital/Output	-1.55446.40980	-0.30750	0.10278	
R&D Capital/Output	-0.08447.03737	-0.55072	0.17972	
Average Variable Cost	-0.05602.10582	1.27928	0.49284	
Direct Average Variable Cost	-0.09106.12316	1.19924	0.45463	

The last industry considered in this study is transportation equipment. Table 14 shows that Canada obtains an overall cost reduction as foreign R&D capital expands. A 1 percent increase in international spillovers causes direct average variable cost to decrease by 0.39 percent. However, Canadian R&D capital generates average variable cost increases in the United States. This increase (0.34 percent) is roughly the same as the cost reduction (-0.39 percent) found for the Canadian industry. Canadian R&D capital has relatively little effect on U.S. capital intensities, both in terms of R&D and physical capital. This is not the case in Canada, however. Here, there are substantial capital intensity effects associated with international spillovers. In fact, these effects are elastic (that is greater than one in absolute value).

Table 14
Transportation Equipment

Elasticities of Intranational Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	-0.4552314395	-0.05997	0.03638	
Intermediate/Output	-0.8696432248	-0.08193	0.03371	
Physical Capital/Output	-0.5340151279	-0.18250	0.02251	
R&D Capital/Output	0.3355402302	-1.86780	0.55418	
Average Variable Cost	-0.6923276342	-0.07689	0.03464	
Direct Average Variable Cost	-0.6868357208	-0.05970	0.03394	

Elasticities of International Spillovers

	United States		Canada	
	Mean	Std.Dev.	Mean	Std.Dev.
Labour/Output	0.2450104982	-0.34349	0.12620	
Intermediate/Output	0.4346209380	-0.49474	0.08466	
Physical Capital/Output	0.0784000864	2.42493	0.21265	
R&D Capital/Output	-0.1120702738	1.76953	0.67274	
Average Variable Cost	0.3555703623	-0.07689	0.03464	
Direct Average Variable Cost	0.3430193686	-0.38867	0.09469	

In the United States, domestic spillovers are much more important in the transportation equipment industry than international spillovers. This is not the case in Canada. Here, international spillovers play a more significant role. For example, a 1 percent increase in international spillovers precipitates an increase of 1.8 percent in R&D intensity.

Productivity Growth

Total factor productivity (TFP) growth is a measure of the dynamic efficiency of a producer. In this section of the paper we want to measure and decompose TFPG for the Canadian and U.S. industries. In particular, we want to determine the contribution of domestic and foreign R&D spillovers to TFPG rates.

By definition the traditional measure of TFPG is the difference between output and input growth rates. In our context, inputs are defined by labour, physical capital, intermediate inputs, and R&D capital. Hence TFPG can be measured in discrete time as,

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

where:
subscript t represents the current period,
subscript s represents the past period,
subscript m designates the mean value of a variable (for example,
$y_m = (y_t + y_s)/2)$
s_v is the vector of noncapital cost shares,
s_k is the vector of capital cost shares
and cost shares are defined in terms of the cost of all factors of production.

TFPG rates can be decomposed by using the estimated variable cost function. Since the variable cost function is in the family of second order quadratic forms in which second order parameters do not change over time, then variable cost differences over time can be decomposed into

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

This equation identifies the difference in variable cost between two time periods. The difference is attributable to the variable factor prices, output quantity, capital stocks, and R&D spillovers. Variable cost depends on these variables. Also (by definition of variable cost), the change over two periods is given by

$$c^v_t - c^v_s = \Sigma_{i=1}^n (w_{is} (v_{it} - v_{is}) + v_{it} (w_{it} - w_{is})).$$

Using the previous three equations yields

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

The decomposition of TFPG, as shown by the right side of the previous equation, consists of two elements. The first is the scale effect. If there are constant returns to scale then the term inside the square brackets is zero. The second element describes the R&D spillover effects and can be further decomposed into two elements. There are both direct and indirect effects associated with spillovers on variable cost. The direct spillover effect (defined as the impact effect or direct effect on variable cost) is essentially the effect(s) of traditional technological change on TFPG -- of which there are two. One traditional technological change effect is due to the domestic spillover; the other occurs as a result of the international spillover between Canadian and U.S. industries. The indirect spillover effect on productivity growth represents the impact on capital intensities of the new knowledge obtained from other industries in the home country and from the same industry in the foreign country.

Table 15
Decomposition of the Average Annual TFP Growth Rates
in the Chemical Products Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	1.700	2.293	0.232	-0.243	-0.980	0.368
1969-1974	1.008	1.459	0.240	-0.249	-0.352	-0.090
1975-1980	0.633	0.545	0.215	-0.225	0.056	0.042
1981-1986	-0.126	0.405	-0.083	0.088	-0.323	-0.213
1964-1986	0.725	1.126	0.148	-0.153	-0.377	0.024
Canada						
1964-1968	1.472	0.990	0.018	0.122	0.072	0.270
1969-1974	0.755	0.597	-0.014	-0.020	0.088	0.104
1975-1980	0.469	0.331	0.022	-0.030	0.118	0.028
1981-1986	0.085	0.069	-0.170	0.204	0.398	-0.416
1964-1986	0.676	0.478	-0.038	0.067	0.173	-0.004

Tables 15 through 25 show the productivity growth rates and decompositions for the eleven industry under review, and for both the United States and Canada. In Table 15 pertaining to the chemical products industry, three components to TFPG are identified; returns to scale effect, domestic spillover effect, and international spillover effect. These effects occur because TFPG captures the shift in the production function due to technological change, in other words, the spillover effects and the "movement along the production function due to non-constant returns to scale" -- i.e., the scale effect. The spillover components are also subdivided into direct and indirect components. The TFPG rate (the TFPG column in the tables) is calculated as the net sum of the components for each time period (row).

TFPG in the chemical products industry does not differ significantly between the United States and Canada. In both countries productivity growth in this industry declined over the sample period. Overall, the average annual productivity growth rate is 0.73 (0.725 rounded) percent in the United States, and 0.68 (0.676 rounded) percent in Canada.

Spillovers play an interesting role in both countries. U.S. R&D capital directly contributes around 25 percent to Canadian productivity growth. However, Canada's R&D capital expansion generates cost increases and thereby contributes directly to productivity losses in the United States. These losses occur because the direct effect of international spillovers to the United States is to increase variable cost. In both countries, however, domestic spillovers play a smaller (positive) role than international spillovers.

Table 16
Decomposition of the Average Annual TFP Growth Rates in the Electrical Products Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	2.162	1.783	0.195	-0.049	0.265	-0.032
1969-1974	1.170	0.457	0.367	-0.051	0.394	0.004
1975-1980	1.858	1.377	0.270	-0.073	0.300	-0.016
1981-1986	2.605	1.302	-0.187	-0.033	1.567	-0.044
1964-1986	1.940	1.206	0.160	-0.052	0.647	-0.021
Canada						
1964-1968	2.652	0.439	-0.331	-0.010	2.278	0.276
1969-1974	2.479	0.764	-0.193	-0.031	1.868	0.071
1975-1980	0.907	0.385	-0.026	0.006	0.591	-0.049
1981-1986	3.393	0.532	0.108	0.069	3.009	-0.325
1964-1986	2.357	0.534	-0.101	0.009	1.922	-0.007

Productivity growth rates for electrical products are presented in Table 16. In this industry average annual TFPG rates were relatively high for both countries, with Canada recording a somewhat higher rate than the United States. The average rates are respectively 2.4 percent and

1.9 percent. The U.S. productivity growth rate was very stable over the sample period, whereas the Canadian rate dropped during the last half of the 1970s, but then recovered in the 1980s. International spillovers contributed the majority of the productivity gains in Canada, accounting for over 80 percent of the average annual growth rate of TFP. In the United States, Canadian R&D capital expansion accounted for only 33 percent of the TFPG in this industry. Domestic spillovers also played a smaller role than international spillovers.

Table 17
Decomposition of the Average Annual TFP Growth Rates in the Food and Beverage Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	1.707	-0.880	0.205	0.009	2.324	0.049
1969-1974	2.617	-0.571	0.276	-0.006	2.900	0.018
1975-1980	2.052	0.226	0.154	-0.003	1.674	0.001
1981-1986	2.756	0.847	-0.078	-0.003	2.038	-0.048
1964-1986	2.308	-0.060	0.136	-0.001	2.230	0.003
Canada						
1964-1968	1.549	-0.787	-0.002	0	2.006	0.332
1969-1974	2.701	-0.266	0.001	0	2.579	0.387
1975-1980	2.673	0.112	0	0	3.060	-0.499
1981-1986	3.439	0.244	0.007	0	3.187	0.001
1964-1986	2.635	-0.148	0.001	0	2.739	0.043

TFPG rates for the food and beverage industry are given in Table 17. This industry performed well in both countries. The average annual TFPG rates were quite similar across the two countries, with Canada slightly outpacing the United States 2.6 percent to 2.3 percent. In this industry international spillovers contributed virtually 100 percent to TFPG and, over the sample period, the rates of productivity growth were very stable. Similarly, the contribution of intranational spillovers to productivity gains were quite stable.

TFPG in the Canadian fabricated metals industry exceeded the rate in the United States, as shown in Table 18; the Canadian average annual rate was 0.66 percent, while the average rate in the United States was 0.33 percent. These rates were both relatively stable over time, although they declined in both countries. Also, in both the United States and Canada international R&D spillovers were the main contributing element to productivity growth. In the United States 58 percent of TFPG resulted from international spillovers; in Canada, international spillovers are the major force behind productivity growth; virtually 100 percent of TFPG was attributable to international spillovers.

Table 18
Decomposition of the Average Annual TFP Growth Rates in the Fabricated Metals Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	0.550	0.455	-0.056	0.037	0.101	0.013
1969-1974	0.361	0.013	-0.008	0.031	0.338	-0.013
1975-1980	0.333	0.131	0.047	0.008	0.144	0.003
1981-1986	0.171	-0.033	-0.016	0.012	0.211	-0.003
1964-1986	0.333	0.128	-0.008	0.019	-0.194	0
Canada						
1964-1968	0.913	0.273	0.032	-0.002	0.554	0.056
1969-1974	0.875	0.099	-0.014	-0.017	0.765	0.042
1975-1980	0.522	0.047	0.012	-0.007	0.613	-0.143
1981-1986	0.378	-0.043	-0.098	-0.043	0.543	0.019
1964-1986	0.662	0.086	-0.019	-0.018	0.622	-0.009

In the nonelectrical machinery industry, TFPG rates were quite similar across nations. In Canada the average annual TFPG rate was 1.12 percent; in the United States the rate was 1 percent. These data are presented in Table 19. The movement of the rates over time differs. In Canada the rate remained stable from the mid-1960s to the mid-1970s, then dropped for the remainder of the sample period. In the United States productivity growth declined during the early 1970s, rebounded in the late 1970s, then fell again in the 1980s. U.S. R&D capital contributed 76 percent of Canadian TFPG. This is not the case for Canadian R&D capital in the United States, however. The impact of international spillover on productivity growth was only about 5 percent.

Table 19
Decomposition of the Average Annual TFP Growth Rates in the Non-electrical Machinery Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	1.452	1.295	0	-1.219	0	1.376
1969-1974	0.690	0.377	0.004	-0.003	-0.868	1.180
1975-1980	1.173	1.115	0.001	-0.001	0.233	-0.175
1981-1986	0.773	0.874	0.009	-0.009	0.691	0.792
1964-1986	1.004	0.899	0.003	-0.300	0.047	0.355
Canada						
1964-1968	1.400	0.709	0.170	0.081	0.454	-0.014
1969-1974	1.419	0.654	-0.004	0.164	0.583	0.022
1975-1980	0.836	0.318	-0.044	-0.090	0.876	-0.224
1981-1986	0.883	-0.399	-0.534	0.145	1.436	0.235
1964-1986	1.124	0.304	-0.115	0.075	0.854	0.006

Table 20 shows the productivity growth rates and the decompositions for the non-metallic minerals industry. Average annual TFPG rates were approximately 1.1 percent in both counties. The U.S. rate was more stable than the Canadian rate over time. Initially, productivity growth in Canada exceeded the rate in the United States, but since the mid 1970s the trend has reversed. In Canada, the international spillover emanating from the United States accounts for 88 percent of the productivity gains. In the United States, Canadian R&D capital contributes approximately 10 percent to TFPG. In both instances, these relative contributions have remained fairly stable over the entire period.

Table 20
Decomposition of the Average Annual TFP Growth Rates in the Non-Metallic Minerals Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	1.185	1.069	0.032	0.004	0.065	0.015
1969-1974	1.191	1.022	0.057	-0.020	0.113	0.019
1975-1980	1.041	1.136	-0.162	-0.023	0.100	0.010
1981-1986	1.108	1.035	-0.040	0.019	0.080	0.014
1964-1986	1.098	1.024	-0.027	-0.005	0.091	0.015
Canada						
1964-1968	1.362	0.453	0.052	-0.014	0.844	0.027
1969-1974	1.510	0.495	-0.021	-0.020	0.998	0.058
1975-1980	0.899	-0.072	0.024	0.010	1.219	-0.282
1981-1986	0.455	-0.080	-0.162	-0.072	0.702	0.067
1964-1986	1.080	0.230	-0.030	-0.030	0.945	-0.035

Table 21
Decomposition of the Average Annual TFP Growth Rates in the Paper and Allied Products Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	0.766	0.316	-0.098	-0.002	0.551	-0.001
1969-1974	-0.089	0.207	-0.100	0.025	-0.238	0.017
1975-1980	-0.181	0.201	-0.086	-0.007	-0.289	0
1981-1986	0.785	0.743	0.034	0.019	-0.015	0.004
1964-1986	0.324	0.369	-0.061	0.009	-0.002	0.005
Canada						
1964-1968	0.031	0.309	-0.020	-0.057	-0.206	0.005
1969-1974	0.090	0.133	0.003	-0.045	-0.073	0.072
1975-1980	0.198	0.067	0.068	-0.039	0.218	-0.116
1981-1986	0.339	0.058	-0.321	-0.127	0.669	0.060
1964-1986	0.171	0.134	-0.069	-0.067	0.168	0.005

Table 21 points up the fact that productivity growth rates are relatively low in the paper and allied products industry. In addition, these rates have fluctuated wildly throughout the period; the U.S. rate dropped substantially during the 1970s, then rebounded in the 1980s to its earlier level. The contribution of international spillovers to productivity growth in both countries also varied over the period. At the beginning of the sample period, the contribution in the United States was 72 percent, but later international spillovers generated productivity losses, with the result that on average international spillovers had little influence. In Canada, however, since the mid 1970s, international spillovers have taken on a more important role in accounting for productivity gains.

In the petroleum products industry international R&D spillovers are the main element accounting for productivity growth. Table 22 shows that U.S. productivity growth averaged 1.1 percent per year, and 64 percent of that was due to Canadian R&D capital. TFPG was lower in Canada, averaging 0.75 percent annually, with 95 percent of this rate attributable to international spillovers. Although the United States and Canada exhibit markedly different productivity trends in this industry, it is clearly observable that international spillovers have been playing a more prominent role in both countries since the mid 1970s.

As Table 23 highlights, there is considerable disparity in TFPG rates between Canada and the United States in the primary metals industry. In Canada, the TFPG averages 0.63 percent annually, while in the United States the rate has been consistently negative since 1969. The average annual rate of U.S. productivity loss is 0.71 percent. Although Canada's R&D capital contributes to the U.S. productivity loss, a more important culprit is the direct effect associated with domestic spillovers. Such spillovers can lead to productivity losses if they generate variable cost increases, or if R&D capital growth rates fall. Individual spillovers may be cost increasing. In Canada, international spillovers again account for the major element contributing to TFP gains. Indeed, over 95 percent of productivity has been due to international spillovers; equally important, this contribution has been very stable over the sample period.

In the rubber and plastics industry, U.S. R&D capital negatively affects TFPG in Canada. This result can be clearly seen in Table 24. Indeed, the direct effect of international spillovers is the main cause of productivity losses because of the variable cost increases associated with the spillovers. TFPG for Canada begins at a respectable 1.3 percent during the mid-1960s then declines over the 1970s. The growth rate moved back up in the 1980s, but the overall annual rate averaged only 0.43 percent. TFPG in the United States also started high, then fell over the first half of the 1970s. The gain in productivity began earlier in the United States than in Canada, but by the end of the sample period the Canadian industry had a higher growth rate. In the United States, the direct effect of Canadian R&D capital was to contribute 47 percent to TFPG. In recent years international spillovers in both countries accounted for substantial productivity growth.

Table 22
Decomposition of the Average Annual TFP Growth Rates in the Petroleum Products Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	0.619	0.173	0.028	0.002	0.382	0.034
1969-1974	0.447	0.311	0.039	-0.007	0.092	0.012
1975-1980	1.110	0.394	0.026	-0.006	0.806	-0.110
1981-1986	1.998	0.608	-0.031	0.005	1.369	0.047
1964-1986	1.062	0.380	0.015	-0.002	0.675	-0.006
Canada						
1964-1968	0.793	-0.012	-0.019	-0.001	0.654	0.171
1969-1974	1.129	0.471	0.004	0.005	0.505	0.144
1975-1980	0.688	0.118	-0.003	0	0.848	-0.275
1981-1986	0.409	-0.401	0.047	0.003	0.854	-0.094
1964-1986	0.753	0.046	0.008	0.002	0.718	-0.021

Table 23
Decomposition of the Average Annual TFP Growth Rates in the Primary Metals Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	0.017	0.483	-0.576	0.271	-0.237	0.076
1969-1974	-0.466	0.188	-0.466	0.053	-0.241	0
1975-1980	-0.780	-0.141	-0.249	-0.212	-0.130	-0.048
1981-1986	-1.482	-1.780	0.114	0.298	-0.076	-0.038
1964-1986	-0.708	-0.347	-0.286	0.095	-0.168	-0.002
Canada						
1964-1968	0.700	0.121	0.063	0.004	0.525	-0.013
1969-1974	0.337	0.051	-0.023	0.002	0.337	-0.030
1975-1980	0.746	0.076	0.019	-0.002	0.577	0.076
1981-1986	0.749	-0.007	-0.139	-0.020	0.906	0.009
1964-1986	0.630	0.057	-0.023	-0.004	0.589	0.011

Table 24
Decomposition of the Average Annual TFP Growth Rates in the Rubber & Plastics Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	2.147	1.943	-0.043	0.018	-0.169	0.398
1969-1974	-0.416	-0.714	-0.044	0.017	0.099	0.226
1975-1980	0.574	0.225	-0.028	0.004	0.368	0.005
1981-1986	0.663	0.201	0.017	0.005	1.095	-0.655
1964-1986	0.786	0.437	-0.024	0.010	0.371	-0.007
Canada						
1964-1968	1.294	1.704	1.883	0.748	-2.085	-0.956
1969-1974	-0.236	4.846	-0.723	-0.904	-3.391	-0.064
1975-1980	-1.791	0.079	0.686	-0.652	-2.568	0.664
1981-1986	1.283	0.951	-0.859	0.003	1.745	0.299
1964-1986	0.431	1.883	-0.271	-0.243	-1.463	0.017

Table 25
Decomposition of the Average Annual TFP Growth Rates in the Transportation Equipment Industry (%)

Period	TFPG Rate	Scale	Domestic Spillover		International Spillover	
			Direct	Indirect	Direct	Indirect
United States						
1964-1968	0.192	1.602	-1.081	-0.005	-0.334	0.010
1969-1974	-0.183	0.150	-0.629	0.288	0.004	0.004
1975-1980	-0.448	0.545	-1.066	0.364	-0.345	0.054
1981-1986	-0.170	0.927	0.372	0.060	-1.485	-0.054
1964-1986	-0.180	0.771	-0.580	0.185	-0.549	0.003
Canada						
1964-1968	2.621	1.256	0.047	0.015	0.778	0.525
1969-1974	0.823	0.477	0.093	0.036	0.167	0.050
1975-1980	-0.144	-0.029	-0.043	0.007	-0.095	0.016
1981-1986	1.058	0.139	0.411	-0.096	0.735	-0.131
1964-1986	1.023	0.426	0.131	-0.011	0.380	0.097

The last industry to be considered is the transportation equipment industry. From Table 25 it can be seen that the average annual productivity growth rates in the United States have generally been negative. Productivity losses have stemmed from the direct effects of domestic and international spillovers. The average TFP rate of loss has been 0.17 percent annually. In Canada the picture has been quite different. The TFPG has averaged 1 percent annually, and except for the period during the second half of the 1970s, the growth rate has been consistently positive. Approximately 37 percent of the TFPG has been due to international spillovers.

Rates of Return

The social rates of return to R&D capital equal the private rates of return plus the returns associated with domestic and international spillovers. These latter returns can be calculated by considering joint U.S. and Canadian cost of production. The joint U.S.-Canadian expected discounted flow of funds can be defined as

$$\Omega_\tau = \Sigma_{j=1}^{2}\Sigma_{i=1}^{11}(C^{vij}\,(w^{ij}_{\tau},y^{ij}_{\tau},K^{ij}_{\tau},S^{ij}_{\tau-1}) + \varpi^{ij}_{\tau}K^{ij}_{\tau})$$

The superscript i denotes the industry; j denotes the country.

Consider the right side of the equation to be evaluated at the equilibrium input-output ratios for each industry and country. The joint expected discounted cost is not minimized because of the existence of domestic and international spillovers. The reason is that the internalization of R&D spillovers generates additional profit that derives from the joint use of the R&D capital stocks. The additional profit is the reduction in joint cost. The reduction in joint domestic cost in equilibrium in period t from an increase in the fth industry R&D capital in the jth country is (using equation (7) in the Appendix) per dollar of R&D capital is

$$d^{fj}_{rt} = \Sigma_{i=1 i\neq f}^{11}\Sigma_{h=1}^{2}\,(K_{ht}/y_t)^{ij}\eta^{ij}_{h1}W^{ij}_{t}y^{ij}_{t} / q^{fj}_{rt}.$$

where q_r is the acquisition or purchase price of R&D capital.

There is also the international spillover effect on joint cost. This is expressed as

$$i^{fj}_{rt} = \Sigma_{h=1}^{2}\,(K_{ht}/y_t)^{fk}\,\eta^{fk}_{h2}W^{fk}_{t}y^{fk}_{t} / q^{fj}_{rt},\ j\neq k,\ j,k = 1,2.$$

These two equations show the domestic and foreign wedges between the social and private rates of return per dollar of R&D capital evaluated in equilibrium that arises from the R&D capital of the fth industry in the jth country.

Next, consider the private rate of return to R&D capital for each industry in each country. The private return is the rental rate divided by the acquisition price. (This return is obtained from the first order condition for R&D capital, given as equation (6.2) in the Appendix). Thus, the private return is the before tax gross of depreciation rate of return; it equals the marginal cost reduction due to the expansion of R&D capital per dollar of R&D capital. Defining ρ^{fj}_{rt} to be the private rate of return of R&D capital in period t for industry f in country j, we have

$$\rho^{fj}_{rt} = (\partial c^{vfj}_{t} / \partial K^{fj}_{rt})/q^{fj}_{rt}$$

Thus, the social rate of return to R&D capital in industry f for country j is

$$\gamma^{fj}_{rj} = \rho^{fj}_{rt} + d^{fj}_{rt} + i^{fj}_{rt},\ j \neq k,\ j,k = 1,2.$$

Each social rate of return consists of three components: the private rate of return, the return due to the domestic spillovers and the return due to international spillovers.

Table 26
Rates of Return

United States
(mean percent)

Industry	Private Rate of Return	Spillover Return Domestic	Intern.	Social Rate of Return
Chemical Products	16.059	80.550	1.635	98.244
Electrical Products	13.297	75.723	6.535	95.555
Food & Beverages	17.845	80.625	84.663	183.134
Fabricated Metals	16.366	63.047	77.854	157.266
Non-electrical Machinery	19.071	63.759	2.504	85.334
Non-Metallic Minerals	17.322	63.981	50.841	132.144
Paper & Allied Products	18.518	66.470	14.236	99.223
Petroleum Products	17.977	103.837	52.703	174.518
Primary Metals	16.629	39.495	54.738	111.212
Rubber & Plastics	12.042	34.495	-2.661	43.876
Transportation Equipment	14.673	15.784	58.002	88.459

The rates of return to R&D capital are presented in tables 26 and 27. The first column in the tables shows the private rates of return. In Canada, the same inflation rate assumption was used across industries. (this assumption makes little difference in the results) and since the private rate is the rental rate deflated by the purchase price, the private rates are the same across industries. The private rate of return in table 27 is the before tax, gross of depreciation, purchasing power parity return; it is 12.7 percent. This means that with a 10 percent depreciation rate and a corporate tax rate of 46 percent, the net after tax purchasing power parity return is approximately 1.5 percent in real terms.

Table 27
Rates of Return

Canada
(mean percent)

Industry	Private Rate of Return	Spillover Return Domestic	Spillover Return Intern.	Social Rate of Return
Chemical Products	12.729	43.204	-7.450	48.483
Electrical Products	12.729	57.012	101.357	158.369
Food & Beverages	12.729	20.961	110.936	144.626
Fabricated Metals	12.729	40.052	101.024	153.805
Non-electrical Machinery	12.729	38.317	110.848	161.895
Non-Metallic Minerals	12.729	20.753	77.812	111.294
Paper & Allied Products	12.729	21.630	92.060	126.419
Petroleum Products	12.729	18.908	94.421	126.059
Primary Metals	12.729	45.768	-6.350	52.151
Rubber & Plastics	12.729	49.479	92.517	154.879
Transportation Equipment	12.729	30.079	-11.136	31.673

It can be discerned from Table 21 that in the United States, the before tax gross of depreciation nominal rate of return is approximately 16 percent across the eleven industries. Net of depreciation (10 percent), net of inflation (averaging 3 percent across industries), and with a corporate income tax rate of 40 percent, the net after tax return is 1.8 percent in real terms. (In the United States private returns differ across industries because the data used includes differential inflation rates.) Thus, on a purchasing power parity basis, after tax net real private returns in the United States are about the same as the Canadian rates of return on R&D capital.

The returns from domestic and international spillovers are presented in the second and third columns of Tables 26 and 27. In the United States the extra-private returns that accrue from domestic spillovers are generally more important than the returns obtained from the externalities sent to Canada. In three U.S. industries (fabricated metals, primary metals and transportation equipment) it was found that the international spillover returns substantially exceed the domestic-based returns. In one industry (food and beverage) the returns from domestic and international spillovers are about the same. In the remaining seven industries the domestic spillover returns are vastly greater than the international returns, and in one industry (rubber and plastics) the return from international spillovers is negative. Such a result occurs when the direct effect of the spillover is cost increasing. This condition is necessary, but not sufficient because the spillover effects on TFPG are weighted by the growth rates of R&D capital that constitute the intranational and international spillovers. However, the joint domestic and international spillover return for the U.S. rubber and plastics industry is positive.

The spillover returns for Canadian industries are presented in Table 27. For eight of the eleven industries, the returns from international spillovers dominate the returns from the domestic externalities. In fact, in the three industries where domestic returns are most important (chemical products, primary metals, and transportation equipment) the returns from international spillovers are negative. Nevertheless, these negative returns are more than offset by the domestic-based returns.

The social rates of return are calculated by summing the first three columns in Tables 26 and 27. It is noteworthy that these returns are purchasing power parity-based returns. Canadian data is purchasing power parity adjusted to the U.S. data. Hence, these returns are comparable across countries and in both countries the social returns greatly exceed the private rates of return. In Canada the social returns are from two-and-one-half to twelve-and-one-half times the private rates of return. In the United States the social returns are from three-and-one-half to ten times the private rates of return. The ordering of the industries between the two countries also differs. The ranking differs because of the role of international spillovers. Five of the eleven industries are roughly in (or close to) the same position in Canada as in the United States. These industries are chemical products, food and beverage, fabricated metals, paper and allied products, and transportation equipment. However, three industries near the top of the Canadian ranking are near the bottom of the U.S ranking. These industries are nonelectrical machinery, electrical products, and rubber and plastics. In addition, three industries ranked near the bottom in Canada are near the top in the United States. The three are: petroleum products, non-metallic minerals and primary metals. The rates of return to R&D capital in Canada vary from around 32 percent to 162 percent; in the United States the returns range from 44 percent to 183 percent.

Clearly, there are high social returns that derive from investing in R&D capital and a major portion of those returns are international in nature. Such high social returns imply that at existing levels of R&D capital, there is substantial underinvestment in R&D. Moreover, that underinvestment arises from both intranational and international R&D spillovers.

CONCLUSION AND POLICY IMPLICATIONS

In this study the effects of domestic and international spillovers have been estimated on average variable production cost, labour-output, intermediate input-output, physical capital-output, and R&D capital-output ratios for eleven Canadian and U.S. industries. These industries are: chemical products, electrical products, food and beverage, fabricated metals, nonelectrical machinery, non-metallic mineral products, paper and allied products, petroleum products, primary metals, rubber and plastics, and transportation equipment. The input-output ratios are also referred to as factor intensities.

International spillovers have been generally found to exert greater influences on production cost, and factor intensities relative to domestic spillovers. This not a surprising result since international spillovers link the same industry in both countries. In addition, spillovers emanating from the United States generate greater effects than spillovers emanating from Canada. However, in the paper and allied products industry it has been estimated that the international spillover from Canada to the United States precipitates cost reductions (in Canada) that are four-and-one- half times greater than the cost reductions resulting from spillovers from the United States to Canada. In other industries, where cost savings for both countries can be observed the U.S. effect, generally, is from two to 20 times greater than the Canadian effect.

International spillovers tend to increase R&D intensities in both countries -- i.e., international spillovers are complements to domestic R&D capital. This complementarity means that as producers in the U.S. industry increase their investment in R&D capital, Canadian producers in the corresponding industry increase the R&D content of their output. The same result holds from Canada to the United States. Substitutes for international spillovers and R&D intensity are observed in only a few industries. With respect to non-R&D capital factor intensities, in both countries it was found that international spillovers generally lead to increases in physical capital intensities and decreases in labour and intermediate input intensities.

This study also measures total factor productivity (TFP) growth rates, and finds that there is not much difference between the corresponding Canadian and U.S. industries. The differences lie rather in the decomposition of TFPG rates. In the United States international spillovers from Canada generally do not contribute substantially to productivity gains. In Canada, the international spillover is the major contributor. TFPG in most industries is positively affected by international spillovers. These are the results obtained in a bilateral model of production linking the U.S. and Canadian industries. The percentage contributions in Canada range from a high of 100 percent in the food and beverage industry to a low of 26 percent in the chemical products industry. In the United States, contributions range from a low of 1 percent in the paper and allied products industry to a high of 100 percent in the food and beverage industry.

The real, after tax, net of depreciation, private rates of return are around 1.5 percent in Canada, and 1.8 percent in the United States -- rates that are not materially different from each other. Moreover, in nominal, before tax, gross of depreciation terms, the private rates are approximately 13 percent in Canada and 16 percent in the United States. We also estimate that due to significant domestic and international spillovers, social rates of return to R&D capital are substantially above the private rates in both Canada and the United States. In Canada, international spillovers generally account for a higher percentage of the social returns relative to domestic spillovers. In the United States the converse is true. Canadian social rates of return (nominal, before tax, gross of depreciation) range from a low of 32 percent in transportation equipment to a high of 162 percent in nonelectrical machinery. Social rates are from two-and-one-half to twelve-and-one-half times greater than private returns. In the U.S. social returns are from three-and-one-half to ten times greater than the private rates, which range from a low of 44 percent for rubber and plastics to a high of 183 percent for the food and beverage industry. The implication of these high social returns is that at current R&D levels there is substantial underinvestment in R&D. This underinvestment relates to both intranational and international spillovers. Indeed, these returns can be interpreted so that for a $100 increase in industrial R&D capital, increases in Canadian industrial output range from $32 to $162, and increases in U.S. industrial output range from $44 to $183.

A notable finding of this study points to the fact that there is an important set of relationships between the Canadian and U.S. economies that are not reflected in international trade, but that are nonetheless well entrenched in international knowledge diffusion.

A number of policy implications can be derived from this study. The first is that the benefits of international spillovers between Canada and the United States imply that barriers preventing the international transmission of technology should be eliminated. Such barriers pertain to the level of R&D investment and its rate of diffusion (such as unduly restrictive patent terms). In addition, Canada should eliminate barriers associated with the flow of existing R&D capital. This policy should not focus only on the physical components of R&D capital (such as high tech equipment and the elimination of restrictions on their importation), but on the human components as well. As a percentage of R&D expenditures, wages, salaries and benefits to scientists, engineers and technicians account for approximately 50 percent. Hence, as part of the elimination of barriers to knowledge diffusion, Canada should not prevent or otherwise restrict the flow of scientists, engineers and technicians.

There are also other ways for the Canadian government to facilitate international technology transfer directly. It can assist by providing and disseminating information concerning new products and processes (through conferences and trade shows, for example). Licensing agreements are another potentially important way for firms to obtain new technologies. The government should also ensure that no impediments exist that prevent or otherwise discourage firms from entering into such agreements. Tax policy is another instrument used by Canada and the United States to encourage R&D investment. In light of the significant international R&D spillovers both countries should investigate the possibilities for tax harmonization with respect to knowledge-generating activities.

Numerous channels exist through which international technology transfer occurs. These include international trade, foreign direct investment and joint ventures. In this regard Canada should continue to push hard for multilateral free trade and the removal of all barriers to foreign direct investment flows, and facilitate international joint ventures involving Canadian firms.

APPENDIX
AN ECONOMETRIC MODEL OF PRODUCTION AND INTERNATIONAL SPILLOVERS

This section develops a model of international spillovers and production for Canadian and U.S. industries which can be used to estimate and determine the effects of international spillovers on production costs, factor intensities and productivity growth for eleven industries in Canada and the United States. The spillovers associated with R&D capital cause social rates of return to differ from the private returns; in this study both the private and social rates of return to R&D capital are computed.

Theoretical Model

In this model labour, intermediate inputs, physical capital and R&D capital are used to produce output. There are two R&D spillovers: domestic and international. Producers maximize profit subject to a production function given by

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

where:
y is output
v is the vector of labour and intermediate inputs
K is the vector of physical and R&D capital
S is the vector of R&D spillovers with
S_{1t} is the domestic spillover and
S_{2t} is the international spillover.
F is the production function which is quasiconcave and has positive and diminishing marginal products.

The domestic spillover is the sum of one period lagged R&D capital stocks of all industries other than the one under consideration. The international spillover is the lagged R&D stock of the corresponding industry in the foreign country. Domestic spillovers are interindustry; international spillovers are intra-industry. Spillovers that operate across national boundaries and between industries are assumed to be indirectly captured through the domestic spillovers, which are themselves influenced by lagged foreign R&D capital stocks. Lagged R&D capital stocks are used as the spillovers because borrowed knowledge emanates from the undepreciated and existing stocks of R&D capital.

The problem of maximizing profit subject to the production function is handled in two stages. In the first stage, given output and capital inputs, the costs of labour and intermediate inputs can be minimized, subject to the production function as shown in equation (1). Thus,

(2) $$\min_{v} w^T_t v_t$$

where superscript T represents vector transposition, and w is the vector of exogenous labour and intermediate input prices. If the solution to equation (2) is substituted into noncapital cost or variable factor cost (that is $w^T v$) we obtain

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

where c^v is the variable cost and C^v is the variable cost function, which is increasing in w and y, decreasing in K, concave and homogeneous of degree one in w, and convex in K. By applying Shephard's Lemma ($\partial c^v / \partial w_i = v_i$) the demands for the variable factors can be retrieved from the variable cost function. Thus,

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

The variable factor demands depend on the variable factor prices, output, the capital inputs, and the R&D spillovers.

In order to determine the demands for the capital inputs and the supply of output, we proceed to the second stage of the problem.

With the variable cost function, profit is maximized. Thus

(5) $$\max_{y,K} p_t y_t - C^v(w_t, y_t, K_t, S_{t-1}) - \omega_t^T K_t$$

where p is the product price and ω is the vector of capital input prices (i.e., capital rental rates). The solution to (5) is given by the equations

(6.1) $$p_t - C^v_y(w_t, y_t, K_t, S_{t-1}) = 0$$

(6.2) $$-\nabla C^v_k(w_t, y_t, K_t, S_{t-1}) - \omega_t = 0.$$

The solution to equation set (6) demonstrates that capital demand and output supply depends on noncapital input prices, R&D spillovers, product price, and capital input prices. Equation sets (4) and (6) describe the model that is to be estimated.

Empirical Specification and Estimation Results

Let us now specify the variable cost function, or more precisely, the average variable cost function, which is $C^v(w_t, K_t/y_t, S_{t-1})$, as

(7) $$c^v_t/y_t = (\Sigma^2_{i=1}\beta_i w_{it} + 0.5\Sigma^2_{i=1}\Sigma^2_{j=1}\beta_{ij} w_{it} w_{jt} W_t^{-1}) y_t^{\vartheta-1}$$
$$+ [\Sigma^2_{i=1}\psi_i k_{it} + 0.5\Sigma^2_{i=1}\Sigma^2_{j=1}\alpha_{ij} k_{it} k_{jt}/y_t^{\vartheta-1}$$
$$+ \Sigma^2_{i=1}\Sigma^2_{j=1}\eta_{ij} k_{it} S_{jt-1}]W_t$$

where the parameters to be estimated are given by β_i ,β_{ij} ,γ_i ,α_{ij} ,ηij , i,j = 1,2, and ϑ is the inverse of the degree of returns to scale. Also, let $k_t = K_t / y_t$ and $W_t = \Sigma_{i=1}^{2} \gamma_i w_{it}$, where γ_i, i = 1,2 are fixed coefficients. W is defined as a Laspeyres index of noncapital input prices. By defining W in this manner it is not necessary to normalize the cost function arbitrarily by any one noncapital 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 can be imposed on the function for all values of the variables.

Using (7), the noncapital equilibrium conditions (i.e., equation set (4)), can be written as

$$
\begin{aligned}
(8) \qquad \upsilon_{it} = (\beta_i + \Sigma^2_{j=}\beta_{ij} w_{jt} W^1_t \\
- 0.5 \Sigma^2_{h=1} \Sigma^2_{j=1} \beta_{hj} w_{ht} w_{jt} W^{-2}_t \gamma_i) y^{\vartheta-1} \\
+ [\Sigma^2_{j=1} \psi_j k_{jt} + 0.5 \Sigma^2_{h=1} \Sigma^2_{j=1} \alpha_{hj} k_{ht} k_{jt} / y^{\vartheta-1} \\
+ \Sigma^2_{h=1} \Sigma^2_{j=1} \eta_{hj} k_{ht} S_{jt-1}] \gamma_i, \ i = 1,2,
\end{aligned}
$$

where $\upsilon_{it} = v_{it}/y_t$, i = 1,2. In addition, by fixing the degree of returns to scale, equations (6.1) and (6.2) are not independent of each other, since $\vartheta^{-1} = (1 - \Sigma_{h=1}{}^{2} \partial 1nc^{v}/\partial 1nK)/\partial 1nc^{v}/\partial 1ny$ is the degree of returns to scale. This means that only one of equations (6.1) and (6.2) must be considered. We choose to consider set (6.2), and so, the capital demands are

$$(9) \qquad k_{it} = (\alpha_{jj} A_{it} - \alpha_{ij} A_{jt}) / A \quad i \neq j, \ i, j = 1,2,$$

where $A_{it} = (-\psi_i - \Sigma_{j=1}^{2} \eta_{ij} s_{jt-1} - \omega_{it} W_t^{1}) y^{\vartheta-1}$, i = 1,2, and $A = (\alpha_{11} \alpha_{22} - \alpha_{12}^{2})$.

Equation sets (8) and (9) define the model to be estimated. There is, however, a further technical point to be noted. If we let the matrix of β_{ij} parameters be B, the vector of β_i parameters be β, and the vector of γ_i parameters be γ, we then determine from the average variable cost function that $(B + 2\gamma\beta^T)$ parameters are identified. Thus, for identification we introduce the two restrictions

$\beta_{ii} + \beta_{ij} = 0$ and $i \neq j$, i,j = 1,2.

The emphasis in this study is on the effects that international R&D spillovers have on production structure, productivity growth and social rates of return. This framework enables us to investigate the impact of both domestic and international R&D spillovers on input-output ratios (or factor intensities) on the decomposition of productivity growth and to measure the private and social rates of return to R&D capital.

The effects of domestic and international spillovers on average variable cost and factor intensities can be determined by differentiating equations (7), (8) and (9) with respect to S_1 , the domestic spillover and S_2 , the international spillover. First, in terms of the capital intensities, we have

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

where ek_cS_j is the jth spillover elasticity of the cth capital intensity.
Second, turning to the noncapital input demands we have

$$(11)\ e\upsilon_iS_h = S_h[\eta_{hh}k_h + \eta_{gh}k_g + (\partial k_1/\partial S_h)(\psi_1 + \Sigma^2_{j=1}\alpha_{1j}k_jy_j^{\vartheta-1} + \Sigma^2_{j=1}\eta_{1j}S_j) + (\partial k_2/\partial S_h)(\psi_2 + \Sigma^2_{j=1}\alpha_{j2}k_jy_j^{\vartheta-1} + \Sigma^2_{j=1}\eta_{2j}S_j)]\gamma_i/\upsilon_i \quad i = 1,2,\ g\neq h,\ g,h = 1,2,$$

where $e\upsilon_iS_h$ is the hth spillover elasticity of the ith noncapital input demand. There are two effects of the spillovers on the noncapital intensities. The first is the direct effect arising from the fact that the noncapital input price index interacts with the spillovers. The second is the indirect effect that arises because the noncapital input intensities are affected by the capital intensities. The last set of elasticities shows the effects of the spillovers on average variable cost. These are

$$(12)\quad ec^v_yS_h = S_h[\eta_{hh}k_h + \eta_{gh}k_g + (\partial k_1/\partial S_h)(\psi_1 + \Sigma^2_{j=1}\alpha_{1j}k_jy_j^{\vartheta-1} + \Sigma^2_{j=1}\eta_{1j}S_j) + (\partial k_2/\partial S_h)(\psi_2 + \Sigma^2_{j=1}\alpha_{j2}k_jy_j^{\vartheta-1} + \Sigma^2_{j=1}\eta_{2j}S_j)]W/(c^v/y) \quad i = 1,2,\ g\neq h,\ g,h = 1,2,$$

where $ec^v_yS_h$ is the hth spillover elasticity of average variable cost.

There are also two effects of the spillovers on average variable cost. The first is the direct effect; the second is the indirect effect, which operates through the capital intensities.

The data for this study were obtained from a number of sources. The non-R&D data for the empirical model are described in the paper by Denny, Bernstein, Fuss, Waverman and Nakamura, "Productivity in manufacturing industries, Canada, Japan, and the United States, 1953-1986: was the 'productivity slowdown' reversed?", *Canadian Journal of Economics*, 25, 3, 1992, 584-603. The Canadian R&D expenditure data were obtained from the Statistics Canada publication on industrial R&D statistics; the R&D price indexes are obtained form Bernstein, "Price Indexes for Canadian Industrial Research and Development Expenditures", Statistics Canada, ST-92-01. This latter study also contains the R&D expenditure data.

In order to construct R&D capital stocks series, R&D expenditures were deflated by their price indexes to compute R&D investment. The benchmark stock was calculated as R&D investment in the initial period deflated by the depreciation rate for R&D capital (assumed to be 10 percent), plus the average growth rate for physical capital. Using the initial R&D capital stock, we developed a time series by applying the perpetual inventory formula. To avoid double counting the relevant labour, intermediate input, and physical capital R&D expenditure components were subtracted from these inputs. For example, the wages and salaries of scientists and engineers were subtracted from labour costs.

The U.S. R&D data was obtained from the National Science Foundation. The procedures adopted with respect to these were the same as for the Canadian R&D data. For a description of the U.S. R&D data see Bernstein and Nadiri, "Product Demand, Cost of Production, and the Social Rate of Return to R&D", NBER Working Paper 3625. In addition, we fixed the degree of returns to scale for each industry by that implied in Bernstein (1989). (See the references associated with the spillover survey.)

The estimation results are presented in tables A1 to A11. Likelihood ratio tests were performed to determine if the set of spillover parameters should be included in the industry models. In each case the hypothesis of no spillovers could be rejected. In each model the restriction was that the variable cost function must be concave in the noncapital input prices. Thus, we set $\beta_{11} = -b_{11}^2$. In addition, the condition was imposed that the cost function must also be convex in the capital inputs. Hence we set $\alpha_{12} = \lambda(\alpha_{11}\ \alpha_{22})^{.5}$, where $-1 < \lambda < 1$, $\alpha_{11} > 0$, i = 1,2. In each case the absolute value of λ was between 0 and 1 and $\alpha_{11,}\ \alpha_{22}$ were positive. It was therefore unnecessary to impose the latter restrictions. Table A12 shows the correlation coefficients between the actual and fitted values of the endogenous variables to be quite high. The model appears to fit the data well.

Table A1
Estimates for the Chemical Industry

LOG OF LIKELIHOOD FUNCTION = 353.285

Parameters	Estimate	Standard Error
β1U	0.87363	0.33668
β1C	0.41123	0.08014
b11	0.50882	0.12281
ϕ1U	-2.46153	0.93500
ϕ1C	-2.84468	0.58564
ϕ2U	-8.67920	5.27393
ϕ2C	1.08297	0.98331
α11	6.34656	3.87388
α22	40.47540	20.11290
λ	-0.03327	0.01750
η11U	-0.00795	0.22475
η11C	-0.98673	0.28411
η22U	-0.00106	0.63116
η22C	-0.00005	0.00005
η12U	0.00065	0.00003
η12C	0.00001	0.00002
η21U		
η21C	0.53309	0.28380
β2U	2.33949	0.94535
β2C	1.51681	0.37057

Table A2
Estimates for the Electrical Products Industry

LOG OF LIKELIHOOD FUNCTION = 327.878

Parameters	Estimate	Standard Error
β1U	1.00900	0.49803
β1C	0.69339	0.24266
b11	0.67579	0.04278
ϕ1U	-3.17410	0.71181
ϕ1C	-1.46271	0.75241
ϕ2U	-1.50722	0.60594
ϕ2C	-0.67147	1.04174
α11	3.82083	0.14507
α22	1.04886	0.30917
λ	0.21512	0.49914
η11U	0.61223	1.18047
η11C	-1.61387	0.66973
η22U	0.00001	0.00005
η22C	-0.00004	0.000003
η12U	-0.00006	0.00007
η12C	-0.00001	0.000007
η21U	-0.15515	0.43834
η21C	0.91369	0.93690
β2U	1.30880	0.70022
β2C	1.47590	0.56923

Table A3
Estimates for the Food & Beverage Industry

LOG OF LIKELIHOOD FUNCTION = 575.431

Parameters	Estimate	Standard Error
β1U	0.57370	0.13576
β1C	0.34616	0.05040
b11	0.23359	0.13548
ϕ1U	-10.98930	2.62227
ϕ1C		
ϕ2U	-6.64269	3.44588
ϕ2C	-0.41577	0.20149
α11	27.87620	6.78697
α22		
λ	0.56750	0.26635
η11U	0.19378	0.91193
η11C		
η22U	-0.00137	0.00116
η22C	-0.00051	0.00023
η12U	-0.00188	0.00201
η12C	-0.00088	0.00024
η21U	0.13074	0.21376
η21C	-0.39792	0.16447
β2U	2.37383	0.57650
β2C	1.19124	0.29169

Table A4
Estimates for the Fabricated Metals Industry

LOG OF LIKELIHOOD FUNCTION = 503.336

Parameters	Estimate	Standard Error
β1U	0.45617	0.20637
β1C	0.46461	0.02472
b11	0.53095	0.05789
ϕ1U	-0.92699	0.90580
ϕ1C	-0.04840	0.44242
ϕ2U	-1.50230	0.58400
ϕ2C	2.81320	0.95710
α11	1.40769	1.16809
α22	2.61900	0.14600
λ	-0.02185	0.06359
η11U	0.40213	0.96114
η11C	0.34706	0.02605
η22U	-0.00061	0.00832
η22C	-0.00027	0.00230
η12U	-0.00033	0.00107
η12C	-0.00012	0.00005
η21U	-4.49163	0.26140
η21C	-4.60825	0.43660
β2U	0.58859	0.33221
β2C	0.87005	0.19583

Table A5
Estimates for the Machinery Industry

LOG OF LIKELIHOOD FUNCTION = 311.370

Parameters	Estimate	Standard Error
β1U	0.2601	0.5696
β1C	0.6692	0.1155
b11	0.8104	0.0681
ϕ1U	2.1437	0.8143
ϕ1C	-1.0311	0.8892
ϕ2U	14.0182	11.4010
ϕ2C	-5.8516	5.5131
α11	0.9299	0.3447
α22	-59.9233	44.8193
λ	0.1289	0.2412
η11U		
η11C	-0.9830	0.9551
η22U	0.0049	0.0014
η22C	0.1184E-05	0.1577E-03
η12U		
η12C	-0.5118E-05	0.1540E-04
η21U		
η21C	10.2888	8.0147
β2U	-0.5459	0.8955
β2C	1.5751	0.1702

Table A6
Estimates for the Non-Metallic Mineral Products Industry

LOG OF LIKELIHOOD FUNCTION = 318.163

Parameters	Estimate	Standard Error
β1U	0.42483	0.05876
β1C	0.52694	0.06742
b11	0.50121	0.10675
ϕ1U		
ϕ1C	-0.47515	0.23323
ϕ2U	-0.53451	0.18204
ϕ2C	-0.29714	0.15908
α11	0.66158	0.36393
α22		
λ	0.30948	0.40292
η11U		
η11C	0.19093	0.25027
η22U	-0.00004	0.00018
η22C	-0.00003	0.00006
η12U	-0.00005	0.00028
η12C	-0.00010	0.00006
η21U	0.31785	0.13070
η21C	0.01133	0.68072
β2U	0.45704	0.09388
β2C	1.05830	0.24590

Table A7
Estimates for the Paper and Allied Products Industry

LOG OF LIKELIHOOD FUNCTION = 483.572

Parameters	Estimate	Standard Error
β1U	0.35130	0.08694
β1C	0.25256	0.05512
b11	0.62521	0.07973
ϕ1U	-0.89284	0.97235
ϕ1C	-0.18464	0.62287
ϕ2U	1.87758	0.04667
ϕ2C	-1.98453	0.74183
α11	1.90684	0.02540
α22	8.66510	3.96580
λ	-0.07787	0.07097
η11U	-0.13766	0.34177
η11C	1.53340	0.21583
η22U	0.00008	0.00329
η22C	0.00076	0.00127
η12U	-0.00025	0.00070
η12C	-0.00013	0.00019
η21U	1.07165	0.07158
η21C	-6.57301	3.01860
β2U	0.66922	0.18680
β2C	0.81774	0.10868

Table A8
Estimates for the Petroleum Products Industry

LOG OF LIKELIHOOD FUNCTION = 502.178

Parameters	Estimate	Standard Error
β1U	0.07886	0.01510
β1C	0.05401	0.00396
b11	0.06718	0.02322
ϕ1U		
ϕ1C	-0.17791	0.27100
ϕ2U	-1.47822	0.84206
ϕ2C	-0.80420	0.21714
α11	3.05956	1.92805
α22	8.94753	2.25528
λ	0.03402	0.04419
η11U		
η11C	-0.01415	0.52350
η22U	-0.00010	0.00026
η22C	-0.00001	0.00004
η12U	-0.00030	0.00030
η12C	-0.00009	0.00005
η21U	0.25856	0.18290
η21C	-0.83129	0.21118
β2U	1.16308	0.31578
β2C	1.46244	0.21845

Table A9
Estimates for the Primary Metals Industry

LOG OF LIKELIHOOD FUNCTION = 404.989

Parameters	Estimate	Standard Error
β1U	0.38553	0.14651
β1C	0.38064	0.20144
b11	0.47063	0.11775
ϕ1U		
ϕ1C	0.69024	1.53380
ϕ2U	-0.72679	0.91111
ϕ2C	-11.94870	9.75360
α11	3.18935	4.30659
α22	9.51800	5.09700
λ	-0.02597	0.03408
η11U	-1.06911	0.49612
η11C	-0.16846	0.47785
η22U	-0.00224	0.01527
η22C	-0.00064	0.00181
η12U	0.00019	0.00095
η12C	0.00004	0.00019
η21U	12.77170	7.77980
η21C	3.14768	1.28770
β2U	0.73008	0.30880
β2C	1.18870	0.56659

Table A10
Estimates for the Rubber & Plastics Industry

LOG OF LIKELIHOOD FUNCTION = 147.718

Parameters	Estimate	Standard Error
β1U	1.55316	0.26148
β1C	0.12314	0.71732
b11	1.60736	0.37594
ϕ1U		
ϕ1C	-8.72347	6.77116
ϕ2U	-1.82184	0.77116
ϕ2C	21.39080	9.85060
α11	9.04695	6.24265
α22	5.46000	4.26300
λ	-0.02418	0.01987
η11U	-0.31506	0.70600
η11C	0.43460	0.07840
η22U	-0.06150	0.10872
η22C	-0.00021	0.00239
η12U	0.02166	0.02428
η12C	0.00016	0.00069
η21U		
η21C	-7.45420	3.31100
β2U	2.78612	0.48748
β2C	2.68006	1.11995

Table A11
Estimates for the Transportation Equipment Industry

LOG OF LIKELIHOOD FUNCTION = 347.860

Parameters	Estimate	Standard Error
β1U	0.71473	0.19876
β1C	0.20525	0.02713
b11	0.73693	0.06069
ϕ1U		
ϕ1C		
ϕ2U	-2.56448	1.06565
ϕ2C	0.76912	0.52646
α11	3.10403	2.29268
α22		
λ	0.16496	1.04097
η11U	1.13589	0.36665
η11C	0.08893	0.83346
η22U	0.00012	0.00018
η22C	-0.000004	0.000007
η12U	-0.00003	0.00018
η12C	-0.000008	0.000004
η21U	-1.47071	0.80115
η21C	-2.87758	0.84249
β2U	1.81319	0.52908
β2C	0.97973	0.04545

Table A12
Correlation of Actual and Fitted Values

Industry	Labour Demand	Interm. Demand	Phys. Cap. Demand	R&D Cap. Demand	Variable Cost
Chemical Products	0.96	0.91	0.99	0.99	0.99
Electrical Products	0.99	0.96	0.99	0.99	0.99
Food & Beverages	0.99	0.96	0.99	0.99	0.93
Fabricated Metals	0.99	0.90	0.99	0.99	0.99
Non-electrical Machinery	0.99	0.97	0.93	0.99	0.99
Non-metallic Minerals	0.99	0.85	0.99	0.85	0.99
Paper & Allied Products	0.97	0.91	0.99	0.99	0.99
Petroleum Products	0.99	0.87	0.99	0.98	0.95
Primary Metals	0.99	0.86	0.96	0.93	0.97
Rubber & Plastics	0.96	0.97	0.76	0.99	0.99
Transportation Equipment	0.98	0.97	0.98	0.98	0.99

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