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INTERNATIONAL R&D SPILLOVERS BETWEEN CANADIAN AND JAPANESE INDUSTRIES

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ABSTRACT

This paper estimates the effects of intranational and international R&D spillovers on the cost and production structure for ten Canadian and Japanese manufacturing industries. Domestic spillovers generate greater effects on average variable cost and factor intensities compared to international spillovers between the two countries.

Private and social rates of return to R&D are calculated for each industry in both countries. Social rates of return to R&D are one and one-half to twelve times the private returns. The Canadian social rates of return are generally two to three times higher than the Japanese rates.

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I. INTRODUCTION*

Research and development (R&D) investment has been an important source of technological change in North American economies (see the survey by Griliches (1988)). R&D investment is a cumulative process that has a public good characteristic. This characteristic arises because R&D performing firms can not completely appropriate the benefits from their R&D investment. Thus, there are externalities or spillovers associated with R&D capital accumulation (see Griliches (1991) and Nadiri (1993)).

There are numerous transmission channels associated with R&D spillovers. The knowledge of R&D investing firms can spill over through, for example, intermediate input purchases, the hiring of scientists and engineers, using patented inventions, running joint ventures, international trade and foreign direct investment. From the perspective of the spillover user or receiver, R&D spillovers affect the cost of production and factor intensities. From the perspective of spillover sources, spillovers create a wedge between private and social rates of return. Private rates of return measure the benefits accruing to the R&D investors, while social rates of return measure the benefits bestowed upon the users of the investment. In other words, social rates of return are inclusive of R&D spillovers.

Previous literature centres on domestic intraindustry and interindustry R&D spillovers. A few studies introduce international spillovers (see Bernstein and Mohnen (1995), and Coe and Helpman (1994)). However, they do not include international and intranational externalities in the same model in order to study their joint effects and relative importance. Bernstein (1995) investigates intranational and international spillovers between Canadian and U.S. manufacturing industries. In this paper we introduce both intranational and international R&D spillovers between Canada and Japan. The reason for the focus in this paper has to do with the relative importance of Japan as Canada's second largest trading partner.

The paper is organized in the following way. In section II, we develop the estimation model and

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discuss the test results relating to the existence of spillovers between Canada and Japan. Section III contains the discussion of the intranational and international spillover elasticities on average variable cost and factor intensities of each industry in Canada and Japan. We determine social rates of return to R&D capital for each industry in section IV. The last section is the summary and conclusion.

II. THE ESTIMATION MODEL AND THE TESTS FOR SPILLOVER EXISTENCE

Output is produced with a combination of non-capital inputs, capital inputs and R&D spillovers. The non-capital factors are labour and intermediate inputs or materials. The capital inputs are physical and R&D capital. R&D spillovers come from intranational (or domestic) sources and international (or foreign) sources. Intranational spillovers relate to interindustry R&D externalities within Canada or Japan. International spillovers relate to externalities that cross national boundaries and link the same industry in Canada and Japan.[1]

A production process is characterized by,

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

where y is output, v is the vector of non-capital inputs, K is the vector of capital inputs, S is the vector of spillover variables and F is the production function with the usual properties.[2]

Producers minimize cost. The optimization problem can be split into two stages. The first stage pertains to the determination of non-capital demands, while the second stage relates to the demands for the capital inputs. In the first stage, output quantity is given and capital stocks are fixed. The cost of non-capital inputs are minimized, subject to the production function. The solution to the first stage of the problem yields the variable cost function,

(2) $$c_t^v = C^v(w_t, y_t, K_t, S_{t-1}),$$

where c^v is variable cost, w is the vector of non-capital input prices, C^v is the variable cost function which is twice continuously differentiable, nondecreasing in w, y and nonincreasing in K, concave and homogeneous of degree one in w and convex in K. Applying Shephard's Lemma (see Diewert (1982)), we can retrieve the demands for non-capital factors of production,

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

The non-capital factor demands depend on the non-capital factor prices, output quantity, the capital inputs and the R&D spillovers. R&D spillovers affect non-capital input demands as well as variable cost.

Turning to the second stage, the demands for capital inputs are found by minimizing total cost, that is, variable cost plus capital cost. The equilibrium conditions relating to the capital input demands are,

$$-\omega_t = \nabla_k C^v (w_t, y_t, K_t, S_{t-1}), \tag{4}$$

where ω is the vector of capital input prices or rental rates. Capital input demands depend on non-capital input prices, output quantity, R&D spillovers and capital input prices. Equation sets (3) and (4) delineate the model that is to be estimated.[3]

In order to implement the model empirically, we need to specify a variable cost function. This function is given by,[4]

$$\begin{aligned} c_t^v / y_t = & \left(\sum_{i=1}^{2} \beta_i w_{it} + 0.5 \sum_{i=1}^{2} \sum_{j=1}^{2} \beta_{ij} w_{it} w_{jt} W_t^{1} \right) y_t^{\eta-1} + \left(\sum_{k=1}^{2} \psi_k k_{kt} \right. \\ & \left. + 0.5 \sum_{k=1}^{2} \sum_{j=1}^{2} \alpha_{kj} k_{kt} k_{jt} / y_t^{\eta-1} + \sum_{k=1}^{2} \sum_{j=1}^{2} \phi_{kj} k_{kt} S_{jt-1} \right) W_t, \end{aligned} \tag{5}$$

where $k_{kt} = K_{kt}/y_t$, $W_t = \sum_{i=1}^{2} a_i w_{it}$ is a Laspeyres non-capital input price index (a_i, $i = 1, 2$ are fixed coefficients). Defining W in this way avoids arbitrarily selecting one non-capital input price to normalize the cost function. The parameters are represented by the 2x1 vector of β_i, the 2x2 matrices of α_{kj} and

β_{ij}, the 2x1 vectors of ψ_k, the 2x2 matrix of ϕ_{kj} and the scalar η. The scale parameter is η^{-1}.[5]

The functional form of the variable cost function is a simple extension of the one developed by Diewert and Wales (1988, 1987). The extension involves the possibility of non-constant returns to scale. The attractiveness of this functional form is that the concavity and convexity properties of the variable cost function can be imposed without restricting the flexibility of the form.

Using equation (5), the non-capital input demand equations (that is equation set (3)) can be written as,

$$
\begin{aligned}
\upsilon_{it} &= (\beta_i + \sum_{j=1}^{2} \beta_{ij} w_{jt} W_t^{1} - 0.5 \sum_{l=1}^{2} \sum_{j=1}^{2} \beta_{lj} w_{lt} w_{jt} W_t^{2} a_i) y_t^{\eta \, 1} \\
(6) \qquad & + (\sum_{k=1}^{2} \psi_k k_{kt} + 0.5 \sum_{k=1}^{2} \sum_{j=1}^{2} \alpha_{kj} k_{kt} k_{jt} / y_t^{\eta-1} \\
& + \sum_{k=1}^{2} \sum_{j=1}^{2} \phi_{kj} k_{kt} S_{jt-1}) a_i \qquad i = 1, 2,
\end{aligned}
$$

where $\upsilon_{it} = v_{it} / y_t$, $i = 1, 2$. From the equilibrium conditions for the capital inputs (that is equation (4)), and using (5) the demands for the capital inputs are,

$$(7) \qquad k_{kt} = (\alpha_{jj} A_{kt} - \alpha_{kj} A_{jt}) / \Lambda \qquad k \neq j, \quad k, j = 1, 2,$$

where $A_{kt} = (-\psi_k - \sum_{j=1}^{2} \phi_{kj} S_{jt-1} - \omega_{kt} W_t^{1}) y_t^{\eta-1}$ and $\Lambda = \alpha_{11}\alpha_{22} - \alpha_{12}^2$. From equation set (7), spillovers affect the capital intensities through the ϕ_{kj} and α_{kj} parameters. In addition, spillovers affect the non-capital input intensities (equation set (6)) directly through the ϕ_{kj} parameters and indirectly through the capital intensities. Equation sets (6) and (7) constitute the estimation model.

The sample consists of ten manufacturing industries; chemical products, electrical products, food and beverage, fabricated metals, non-electrical machinery, non-metallic mineral products, paper and allied products, petroleum products, primary metals, and transportation equipment. The data are annual observations from 1962 to 1988.

For Canada, the quantity of output is gross output in millions of 1985 dollars. The price of output is obtained by dividing 1985 dollar gross output into current dollar gross output. The quantity of labour is labour compensation in 1985 millions of dollars. The price of labour is current dollar labour compensation divided by 1985 dollar labour compensation. The quantity of materials are intermediate goods measured by taking the difference between gross output and value-added in 1985 dollars. The price of materials is obtained by taking the ratio of intermediate goods in current and 1985 dollars. The quantity of physical capital is the geometric net stock in 1985 millions of dollars. The before-tax rental rate of physical capital is based on the investment price index (1985=1.00).[6] R&D capital stock is defined by the perpetual inventory method based on deflated R&D expenditures. Initial constant dollar R&D expenditures are grossed up by the average annual growth rate of physical capital for the period 1954 to 1961 plus the depreciation rate for R&D capital which is assumed to be 10 percent.[7] The before-tax rental rate for R&D capital is based on R&D investment price index (1985=1.00). Intranational spillovers are the sum of R&D stocks lagged one period of all domestic industries other than the representative one. International spillovers are the R&D stock lagged one period of the corresponding foreign industry.[8] The variables for Japanese industries are defined in a similar way and are purchasing power parity adjusted to the Canadian data.[9]

For each industry, the Canadian and Japanese data are pooled, so that we deal with a bilateral model of production (see Jorgenson and Kuroda (1990), Jorgenson and Nishimizu (1981)). The model is estimated for each industry separately. Each model contains four equations and the estimator is full information maximum likelihood.[10] In order to determine the existence of spillovers between Canada and Japan, we conduct likelihood ratio tests. We first test whether there are spillovers from Japan to Canada by setting the Canadian international spillover parameters ϕ_{22c} and ϕ_{12c} (see equation (6) and (7)) equal to zero. We reject the null hypothesis of no spillovers in Canada, if the likelihood ratio test statistic is larger than the value of $\chi^2_{0.05,2} = 5.99$. Table 1 summarizes the results. The test statistics are shown in brackets. The null hypothesis of no R&D spillovers from Japan to Canada is rejected for all industries except electrical products, food and beverage and primary metals.

Next we test whether there are spillovers from Canada to Japan. We do this by setting the Japanese international spillover parameters ϕ_{22j} and ϕ_{12j} equal to zero. Table 1 shows that R&D spillovers exist from Canada to Japan in all industries except chemical products.[1] The estimation results based on the preferred specifications are presented in the Appendix. These results are consistent with the properties of the variable cost function.[2] In addition, as we observe from the correlation coefficient squared, the model fits the data quite well.

These results are not surprising. Even though Japan is Canada's second largest trading partner, we observe a rather weak trade link, as only 6 percent of Canadian exports and imports are accounted for by trade with Japan. These results are consistent with Bernstein (1995), where foreign spillovers in Canada are dominated by those emanating from the U.S. Moreover, the strong relationship between the U.S. and Canadian R&D capital stocks suggests that there is a North American technological link to Japan.

III. SPILLOVER ELASTICITIES

R&D spillovers affect production decisions, including R&D decisions, production cost, and hence the profitability of spillover receiving industries. In this section, we derive and discuss the elasticities of factor intensities and average variable cost with respect to intranational and international spillovers.[3]

The spillover elasticities of capital input intensities are denoted by ϵ_{kcsh}, where subscript kc $(c=1)$ indicates physical capital intensity and $(c=2)$ indicates R&D capital intensity, subscript sh $(h=1)$ is intranational spillovers and $(h=2)$ is international spillovers. Therefore, ϵ_{k1s1} is the elasticity of intranational spillovers on physical capital intensity. The spillover elasticities of capital input intensities

Table 1. Likelihood Ratio Test of No Spillovers

Industry	Japan to Canada	Canada to Japan
Chemical Products	Not Rejected* (5.912)	Not Rejected (1.064)
Electrical Products	Rejected (22.928)	Rejected (29.572)
Food & Beverage	Rejected (9.580)	Rejected (9.240)
Fabricated Metals	Not Rejected (2.166)	Rejected (127.236)
Non-electrical Machinery	Not Rejected (2.540)	Rejected (40.708)
Non-metallic Mineral Products	Not Rejected (0.136)	Rejected (20.232)
Paper & Allied Products	Not Rejected (5.954)	Rejected (139.746)
Petroleum Products	Not Rejected (3.106)	Rejected (85.572)
Primary Metals	Rejected (145.358)	Rejected (193.986)
Transportation Equipment	Not Rejected (3.550)	Rejected (96.526)

* Test statistics are in brackets.

are obtained by differentiating equation (7) with respect to spillover variables,

$$\varepsilon_{kcsh} = S_h y^{\eta-1}(\alpha_{12}\phi_{dh} - \alpha_{dd}\phi_{ch}) / \Delta k_c \qquad c, h, d = 1, 2, c \neq d. \tag{8}$$

The elasticities of non-capital input demands are given by ϵ_{vish}, where subscript vi $(i=1)$ is the labour input intensity and $(i=2)$ is the intermediate input intensity. The spillover elasticities of non-capital inputs are derived by differentiating equation (6) with respect to spillover variables,

$$\begin{aligned}\varepsilon_{vish} = [(\phi_{hh}k_h + \phi_{gh}k_g) &+ \varepsilon_{k1sh}\frac{k_1}{S_h}(\psi_1 + \sum_{j=1}^{2}\alpha_{1j}k_j y^{\eta-1} + \sum_{j=1}^{2}\phi_{1j}S_j) \\ &+ \varepsilon_{k2sh}\frac{k_2}{S_h}(\psi_2 + \sum_{j=1}^{2}\alpha_{j2}k_j y^{\eta-1} + \sum_{j=1}^{2}\phi_{2j}S_j)] a_i S_h / v_i \qquad i, h, g = 1, 2, g \neq h.\end{aligned} \tag{9}$$

There are two components to the spillover elasticities of the non-capital factor intensities; the direct effect of spillovers, which is the first term in parentheses inside the square brackets, and the indirect effect of spillovers that come from changes in the capital input intensities.

The elasticities of average variable cost with respect to spillovers are denoted by ϵ_{cysh}. The elasticities of average variable cost also consists of two parts; the direct effect of spillovers and the indirect impact through altering capital intensities. The average variable cost elasticities are obtained by differentiating equation (5) with respect to spillover variables,

$$\begin{aligned}\varepsilon_{cysh} = [(\phi_{hh}k_h + \phi_{gh}k_g) &+ \varepsilon_{k1sh}\frac{k_1}{S_h}(\psi_1 + \sum_{j=1}^{2}\alpha_{1j}k_j y^{\eta-1} + \sum_{j=1}^{2}\phi_{1j}S_j) \\ &+ \varepsilon_{k2sh}\frac{k_2}{S_h}(\psi_2 + \sum_{j=1}^{2}\alpha_{j2}k_j y^{\eta-1} + \sum_{j=1}^{2}\phi_{2j}S_j)] WS_h / (c^{v} / y) \qquad g \neq h, g, h = 1, 2.\end{aligned} \tag{10}$$

The direct impact of the spillovers (the first term in parentheses inside the square brackets) reflects changes in labour and intermediate input demands. R&D spillovers can decrease non-capital intensities and hence decrease variable cost. In addition, R&D spillovers could increase product demand and hence increase the demand for non-capital inputs. This has the effect of directly increasing variable cost. In the latter case, we expect revenue to increase so that the revenue gain outweighs the cost increase.[14]

The combined direct and indirect effects from spillovers can be average variable cost-increasing. This occurs because the indirect effect includes changes in capital input intensities. For example, when a spillover directly reduces average variable cost, it can also entail decreases in capital input intensities. These decreases lead to higher variable cost. The positive indirect effect of a spillover can more than offset its negative direct effect. Hence, as a result, average variable cost increases.

Spillover elasticities are calculated for each industry in Canada and Japan and for each year in the sample period. Tables 2 and 3 show the sample mean and standard deviation of these yearly elasticities. Since there are generally no spillovers from Japan to Canada, the international flow of knowledge from Japan does not generate any effect on the cost and production structure of Canadian industries, except for electrical products, food and beverage and primary metals. All the Japanese industries except chemical products, however, are affected by spillovers from Canada. All Canadian and Japanese industries are affected by domestic spillovers. Indeed, domestic spillover effects dominate the international links between Canada and Japan.

Consider first the domestic and foreign spillover effects on average variable cost in Canada and Japan. The direct effect (shown in the last column of Tables 2 and 3) reflects the percentage change in average variable cost when capital factor intensities are fixed. This means, for example, that a 1 percent increase in the domestic spillover directly decreases average variable cost of the Japanese chemical products industry by around 0.005 percent, while the effect is about zero in the corresponding Canadian industry. The sum of the direct and indirect effects on average variable cost (shown in the second to last column of Tables 2 and 3) includes the spillover effect transmitted through capital intensity changes. We find that a 1 percent increase in the domestic R&D spillover reduces average variable cost in the Japanese chemical products industry by 0.04 percent. In Canada, the domestic spillover facing chemical products increases average variable cost by around 0.001 percent.

Table 2. Domestic Spillover Elasticities: Mean Values of Annual Elasticities (standard deviations of annual elasticities in parentheses)

CANADA

Industry	Labour Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. cost	Dir. Avg. Var. cost
Chemical products	0.001	0.001	-0.001	-0.009	0.001	0.0003
	(0.0002)	(0.0003)	(0.000)	(0.002)	(0.0003)	(0.0001)
Electrical products	-0.320	-0.622	4.220	-1.741	-0.506	-0.496
	(0.073)	(0.124)	(2.672)	(0.253)	(0.084)	(0.103)
Food & beverage	-0.233	-0.289	-0.157	0.972	-0.278	-0.282
	(0.112)	(0.077)	(0.024)	(0.088)	(0.084)	(0.083)
Fabricated metals	0.061	0.078	-0.106	2.410	0.037	0.074
	(0.020)	(0.019)	(0.021)	(0.544)	(0.011)	(0.060)
Non-electrical machinery	0.006	0.007	1.148	0.416	0.007	0.086
	(0.033)	(0.040)	(0.364)	(0.032)	(0.038)	(0.021)
Non-metallic minerals	0.077	0.100	0.177	1.723	0.092	0.168
	(0.023)	(0.018)	(0.049)	(0.175)	(0.020)	(0.028)
Paper & allied products	0.001	0.002	-0.012	0.018	0.002	0.033
	(0.0002)	(0.0002)	(0.003)	(0.004)	(0.000)	(0.008)
Petroleum products	-0.361	-0.387	-0.014	0.285	-0.386	-0.062
	(0.128)	(0.140)	(0.002)	(0.035)	(0.140)	(0.020)
Primary metals	0.335	0.465	-0.036	-1.712	0.434	0.142
	(0.093)	(0.066)	(0.007)	(1.438)	(0.063)	(0.031)
Transportation	-0.725	-0.909	-0.092	-0.111	-0.866	-0.087
	(0.351)	(0.289)	(0.018)	(0.021)	(0.301)	(0.028)

JAPAN

Industry	Labour Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. cost	Dir. Avg. Var. cost
Chemical products	-0.004	-0.043	0.053	0.772	-0.042	-0.005
	(0.074)	(0.330)	(0.043)	(0.178)	(0.323)	(0.148)
Electrical products	-0.001	-0.0004	0.140	2.160	-0.001	0.090
	(0.026)	(0.048)	(0.121)	(1.740)	(0.043)	(0.056)
Food & beverage	-0.129	-0.370	0.192	0.762	-0.356	-0.135
	(0.110)	(0.392)	(0.180)	(0.284)	(0.375)	(0.156)
Fabricated metals	-0.052	-0.463	-0.121	0.737	-0.344	0.155
	(0.079)	(0.790)	(0.121)	(0.117)	(0.666)	(0.220)
Non-electrical machinery	-0.190	-0.223	-0.174	0.321	-0.214	-0.053
	(0.158)	(0.187)	(0.145)	(0.201)	(0.179)	(0.060)
Non-metallic minerals	-0.213	-0.641	-0.041	1.060	-0.583	-0.236
	(0.315)	(1.106)	(0.037)	(0.506)	(0.994)	(0.432)
Paper & allied products	-0.026	-0.054	-0.050	0.683	-0.051	0.064
	(0.019)	(0.040)	(0.043)	(0.214)	(0.039)	(0.061)
Petroleum products	2.509	1.892	0.193	0.290	1.917	0.090
	(1.738)	(1.342)	(0.190)	(0.449)	(1.357)	(0.055)
Primary metals	0.023	0.034	-0.092	0.573	0.032	0.021
	(0.034)	(0.061)	(0.081)	(0.236)	(0.055)	(0.022)
Transportation	-0.010	-0.034	0.312	0.524	-0.034	-0.018
	(0.050)	(0.139)	(0.258)	(0.168)	(0.136)	(0.123)

Table 3. International Spillover Elasticities: Mean Values of Annual Elasticities (standard deviations of annual elasticities in parentheses)

CANADA

Industry	Labour Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. cost	Dir. Avg. Var. cost
Chemical products						
Electrical products	0.046	0.089	-1.026	-0.327	0.071	0.027
	(0.040)	(0.074)	(1.692)	(0.305)	(0.057)	(0.019)
Food & beverage	0.055	0.062	-0.160	-0.074	0.061	0.054
	(0.057)	(0.053)	(0.125)	(0.053)	(0.054)	(0.049)
Fabricated metals						
Non-electrical machinery						
Non-metallic minerals						
Paper & allied products						
Petroleum products						
Primary metals	-0.072	-0.090	-0.070	2.032	-0.086	-0.025
	(0.059)	(0.060)	(0.054)	(1.892)	(0.060)	(0.017)
Transportation						

JAPAN

Industry	Labour Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. cost	Dir. Avg. Var. cost
Chemical products						
Electrical products	-0.057	-0.096	-0.255	-1.046	-0.087	-0.136
	(0.023)	(0.040)	(0.123)	(0.457)	(0.036)	(0.047)
Food & beverage	0.344	0.879	-0.439	-0.853	0.847	0.469
	(0.041)	(0.251)	(0.169)	(0.223)	(0.238)	(0.128)
Fabricated metals	0.010	0.073	-0.077	0.064	0.071	-0.047
	(0.003)	(0.031)	(0.048)	(0.019)	(0.030)	(0.022)
Non-electrical machinery	0.001	0.001	0.006	0.037	0.001	-0.002
	(0.001)	(0.001)	(0.003)	(0.012)	(0.001)	(0.001)
Non-metallic minerals	0.093	0.266	0.094	-1.308	0.242	0.119
	(0.097)	(0.344)	(0.044)	(0.692)	(0.309)	(0.153)
Paper & allied products	-0.240	-0.490	0.241	1.762	-0.464	-0.436
	(0.034)	(0.071)	(0.022)	(0.838)	(0.064)	(0.058)
Petroleum products	3.127	2.353	0.249	4.807	2.383	-0.142
	(1.496)	(1.192)	(0.090)	(3.223)	(1.201)	(0.053)
Primary metals	-0.684	-1.081	0.380	3.264	-0.987	-0.467
	(0.229)	(0.446)	(0.055)	(1.070)	(0.390)	(1.181)
Transportation	-0.010	-0.024	0.031	0.248	-0.023	-0.021
	(0.010)	(0.028)	(0.005)	(0.068)	(0.027)	(0.027)

Domestic spillovers reduce average variable cost for eight Japanese and four Canadian industries. The cost reductions from a 1 percent increase in domestic spillovers in Japan range from a low of 0.001 percent for electrical products to a high of 0.58 percent for non-metallic mineral products. In all cases the effects are inelastic. In Canada, the variable cost reductions are also inelastic, but the range is not as wide among the different industries as in Japan.

International spillovers generally decrease average variable cost, as seven Japanese industries attain cost reductions directly from R&D expansion in Canada. Direct average variable cost reductions in Japan associated with a 1 percent increase in Canadian R&D capital range from a low of 0.001 percent for non-electrical machinery to a high of 0.46 percent for primary metals. These elasticity estimates are new to the literature. Moreover, the magnitudes are generally smaller than those obtained by Bernstein (1995) for Canadian industries affected by spillovers from the U.S. The elasticities are also smaller than the average obtained by Mohnen (1990) for Canadian manufacturing as an aggregate with spillovers from five industries of five OECD countries.

Intranational and international spillovers generally affect R&D capital intensity relatively more than other factors. We observe that domestic spillovers and R&D capital demand are strong complements in Japan; domestic spillovers increase R&D capital intensity in all Japanese industries. The increases in R&D capital intensity are in the range of 0.29 percent to 2.16 percent. In Canada, domestic spillovers are complementary to R&D capital in six industries. A 1 percent increase in spillovers from within the country increases Canadian R&D capital intensity between 0.02 percent and 2.41 percent. Domestic spillovers decrease R&D capital intensity in four Canadian industries; namely, chemical products, electrical products, primary metals and transportation equipment. The range of decrease is between 0.01 percent and 1.74 percent. The decrease in R&D capital intensity for these industries is also found in Bernstein (1988).

Spillovers from Canada are generally complements to Japanese R&D capital. R&D capital intensity rises in six industries; namely, fabricated metals, non-electrical machinery, paper and allied products, petroleum products, primary metals and transportation equipment. R&D capital intensity increases from 0.03 percent to 4.81 percent with a 1 percent increase in Canadian R&D expansion. The three industries where R&D capital intensity falls are; electrical products, food and beverage and non-metallic mineral products. The decreases are between 0.85 percent and 1.31 percent. Although these are the first estimates of spillovers linking Canadian to Japanese industries, the results are consistent with Mohnen (1990) where Canadian R&D capital is complementary to international R&D spillovers.

With respect to non-R&D input intensities, the spillover effects are mixed. In Japan, domestic spillovers increase physical capital intensity in five of the ten industries. In Canada, physical capital is substitutable for domestic spillovers in seven industries. We find that the three remaining industries are relatively more R & D capital intensive. Indeed, in both countries domestic spillovers reduce physical capital intensity in industries that are relatively less R&D capital intensive. Moreover, international spillovers from Canada to Japan result in higher physical capital intensity in six Japanese industries. Complementarity is also found in Mohnen (1990) between Canadian physical capital intensity and international spillovers.

Labour and intermediate input intensities always respond in the same direction to either domestic or foreign spillovers. In Japan, non-capital factor inputs are substitutes for domestic spillovers. International spillovers from Canada to Japan cause non-capital input intensities to decrease in about half of the industries. These industries are characterized by relatively lower labour input intensities. In Canada domestic spillovers reduce non-capital factor intensities in four industries. As in Japan, these four industries are relatively less labour intensive. We find that these results are consistent with Bernstein (1988) for Canada and Suzuki (1993) for Japan.

IV. RATES OF RETURN

Due to spillovers, the returns to R&D are not completely appropriated by the R&D investor. Therefore, a wedge is created between the private and social rates of return. The private return is the return from R&D performance. The social return is the return from the use of R&D; hence it is inclusive of R&D spillovers.

The social rate of return to R&D capital is measured as the sum of the private rate of return and the rate of return associated with intranational and international spillovers. Consider first the private rate of return to R&D capital for each industry in each country. The private rate of return is the marginal cost reduction per dollar of R&D capital expansion. It is equal to the rental rate divided by the acquisition price of R&D capital, and obtained from the first order condition given by equation (7). The private rate is the before-tax gross of depreciation rate of return. The private rate of return in period t for industry f in country j is defined as follows,

(11) $$\rho_{rt}^{fj} = -(\partial c_t^{vfj} / \partial K_{rt}^{fj}) / q_{rt}^{fj} ,$$

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

The spillover contribution to the rate of return to R&D can be calculated by considering jointly the Canadian and Japanese cost of production. Joint cost is defined as,

(12) $$\Omega_t = \sum_{j=1}^{2} \sum_{i=1}^{10} (C^{vij} (w_t^{ij}, y_t^{ij}, K_t^{ij}, S_t^{ij}) + \sum_{k=1}^{2} \omega_{kt}^{ij} K_t^{ij}),$$

where the superscript i denotes the industry and j denotes the country.

Consider equation (12) when it is evaluated at the equilibrium input-output ratios for each industry and country. Joint cost is not minimized at the equilibrium due to the existence of intranational and international spillovers. The reason is R&D capital stock is jointly used by industries both domestically and internationally, so that additional profit is generated as R&D spillovers are internalized. The additional profit is the reduction in joint cost resulting from two sources; domestic and international spillovers.

Using equation (5), differentiate equation (12) with respect to R&D capital, The joint domestic cost effect per dollar of R&D capital at equilibrium in period t from an increase in the fth industry's R&D capital in the jth country is,

$$(13) \qquad d_{rt}^{fj} = \sum_{i=1, i \neq f}^{10} \sum_{h=1}^{2} k_{ht}^{ij} \phi_{h1}^{ij} W_t^{ij} y_t^{ij} / q_{rt}^{fj} \qquad f = 1, \ldots, 10, \; j \; 1, 2.$$

Next the joint foreign cost effect that results from a dollar increase in the R&D capital of the fth industry in the jth country is,

$$(14) \qquad i_{rt}^{fj} = \sum_{h=1}^{2} k_{ht}^{fk} \phi_{h2}^{fk} W_t^{fk} y_t^{fk} / q_{rt}^{fj} \qquad f = 1, \ldots, 10, \quad j \neq k, \; j, k = 1, 2.$$

Equations (13) and (14) define the domestic and foreign wedges between the social and private rates of return per dollar of R&D capital evaluated at equilibrium that arises from the R&D capital of the fth industry in the jth country.

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

$$(15) \qquad \gamma_{rt}^{fj} = \rho_{rt}^{fj} + d_{rt}^{fj} + i_{rt}^{fj} \qquad f = 1, \ldots, 10, \quad j = 1, 2,$$

which consists of three components: the private rate of return, the return from domestic spillovers and the return from international spillovers.[15]

The rates of return to R&D capital in the Canadian and Japanese industries are presented in Tables 4 and 5 respectively. Note that the rates of return reported in these tables are comparable since they are purchasing power parity returns. The first column in both tables represents the private rate of return.

Table 4. Social Rates of Return to R & D in Canadian Industries (mean percent)

Industry	Private Rate of Return	Spillover Return Domestic	Spillover Return International	Social Rate of Return
Chemical Products	17.200	134.503		151.703
Electrical Products	17.200	71.531	23.134	111.865
Food & Beverage	17.200	65.739	-4.355	78.583
Fabricated Metals	17.200	118.168	-2.548	132.820
Non-electrical Machinery	17.200	125.377	1.497	144.075
Non-metallic Mineral Products	17.200	123.169	-23.994	116.375
Paper & Allied Products	17.200	128.061	57.932	203.193
Petroleum Products	17.200	166.976	22.703	206.878
Primary Metals	17.200	164.001	1.595	182.797
Transportation Equipment	17.200	117.424	19.495	154.119

Table 5. Social Rates of Return to R & D in Japanese Industries (mean percent)

Industry	Private Rate of Return	Spillover Return Domestic	Spillover Return International	Social Rate of Return
Chemical Products	17.360	48.938		66.297
Electrical Products	17.360	40.150	-0.972	56.538
Food & Beverage	17.360	15.989	-7.031	26.318
Fabricated Metals	17.360	46.248		63.608
Non-electrical Machinery	17.360	53.804		71.164
Non-metallic Mineral Products	17.360	30.466		47.826
Paper & Allied Products	17.360	55.607		72.968
Petroleum Products	17.360	35.448		52.808
Primary Metals	17.360	40.150	0.778	58.289
Transportation Equipment	17.360	42.042		59.402

Since the private rate is defined as the rental rate deflated by the R&D capital purchase price and, since the same inflation rate is assumed across industries but different for each country, the private rates of return are the same across industries in Canada or Japan. The before-tax gross of depreciation private return in Canada is very similar to the one in Japan. The rates are respectively 17.2 percent and 17.4 percent.

The returns from domestic and international spillovers are shown in the second and the third columns of Tables 4 and 5. In Canada, the domestic spillover related returns are quite high in every industry, compared to the returns accruing from international spillovers to Japan.[16] In industries where there are positive international returns, domestic spillovers account for an average of 77 percent of the social rate of return, while international spillovers account for 13 percent on average. We see that there are also negative returns from international spillovers. Negative returns are possible when spillovers give rise to direct cost increases in production. However, any negative international externality is small so that the combined spillover returns for these industries are positive.

In Japan, spillover returns are essentially domestic-based. In seven industries, internationally-based returns are zero. Among the three industries who are senders of spillovers to Canada, we observe very small rates of return related to international spillovers.

The last column shows the social rates of return for each industry in each country. These results suggest that the social rate of return can exceed the private rate quite substantially. In Canada, the social returns can be as high as 12 times the private rate. The social rates of return in the Canadian industries are in the range of 78 percent to 206 percent. In Japan, the social rate of return is 1.5 to over 4 times greater than the private rate. The social rates of return in the Japanese industries range from 26 percent to 73 percent.

The large differential between the private and social rates of return is found in many studies dealing with U.S. and Canadian industries. Social rates of return can exceed private rates of return anywhere between 9 percent to 160 percent (see Griliches (1991) and Nadiri (1993)). In this paper we also find large differentials for Japanese industries. In addition, social rates of return are higher in Canada than in Japan. High rates of social return imply that R&D capital is substantially underinvested. This underinvestment, however, is surely not attributable to any spillovers between Canada and Japan.

V. SUMMARY AND CONCLUSION

In this paper we find that international R&D spillovers from Japan do not generally exist in Canada. However, international spillovers from Canada affect Japanese industries, although the elasticities are small. These spillovers generally decrease average variable cost. The direct average variable cost reductions in Japan associated with a 1 percent increase in Canadian R&D capital range from 0.001 percent to 0.46 percent.

Domestic and foreign spillovers generally exert a greater influence on R&D capital intensity compared to other factor intensities. International spillovers from Canada are complementary to Japanese R&D capital. Domestic spillovers are complements to R&D capital in Japan, and in Canada they mostly increase R&D capital intensity as well. In both countries, we find that domestic spillovers decrease physical capital intensity in industries that are relatively less R&D capital intensive. International spillovers from Canada to Japan tend to increase physical capital intensity. Non-capital factor intensities generally decrease as a result of domestic and international spillovers.

Social rates of return to R&D exceed private returns quite substantially in both countries. The private rates of return are very similar for Canada and Japan. The before-tax, gross of depreciation private rates are around 17 percent. The social returns in Canada are much higher than those in Japan for every industry. In Canada the social returns are in the range of 78 percent to 206 percent. In Japan social rates of return are between 26 percent to 73 percent. In both countries, the wedge between social and private returns do not arise from spillovers between the two countries.

The results from this paper show that there important asymmetries in the senders and receivers of international R&D spillovers. Industries that are significant sources of international spillovers are not necessarily recipients. We find that domestic R&D spillover linkages are quite different from international spillover networks. In addition, in the case of Canada and Japan, domestic spillovers dominate international ones in generating social rates of return. Lastly, we find that it is necessary to distinguish individual countries as potential senders and receivers of international R&D spillovers. Distinct bilateral R&D spillover relationships exist among nations and determining their existence and effects are important avenues for future research.

ENDNOTES

1. Domestic intraindustry spillovers are assumed to be internalized because the analysis is conducted at the two-digit standard industrial classification level. Interindustry R&D spillovers between nations are captured indirectly from the intranational spillover through the domestic industry and then to the corresponding industry in the foreign country.
2. See Diewert (1982) for the properties of production functions.
3. We are concerned with the determination of long-run social rates of return to R&D capital, so we abstract from the dynamics arising from adjustment costs.
4. Using an average variable cost function implies that the equilibrium conditions are specified in terms of factor intensities. This allows for the same set of equations to be estimated, irrespective of the degree of returns to scale (except for parameter restrictions resulting from constant returns to scale).
5. To see this, note that the degree of returns to scale is given by $\eta^{-1} = (1 - \Sigma_k \partial lnc_t^v / \partial lnK_{kt}) / (\partial lnc_t^v / \partial lny_t)$. In this model, we do not restrict the degree of returns to scale. The parameter η is called the variable cost flexibility.
6. The rental rate formulas for physical and R&D capital are available from the authors upon request.
7. Nadiri and Prucha (1993) estimated that R&D depreciates at a rate of 10 percent.
8. See Griliches (1991) and Nadiri (1993) for a discussion on the measurement issues associated with R&D spillovers.
9. The purchasing power parity prices are available from the authors upon request (see Jorgenson and Kuroda (1990), Jorgenson and Nishimizu (1981), and Kravis, Heston and Summers (1978).
10. Tests were conducted on the degree of returns to scale. We estimate that returns to scale are the same in five of the ten Canadian and Japanese industries. They are: chemical products, electrical products, non-electrical machinery, paper and allied products and petroleum products industries. The other five industries where returns to scale differ are: food and beverage, fabricated metals,

non-metallic mineral products, primary metals and transportation equipment industries. There are constant returns to scale in the Canadian and Japanese electrical products and paper and allied products, the Canadian food and beverage and the Japanese transportation equipment industries. The Canadian and Japanese chemical products, fabricated metals, non-metallic mineral products, primary metals and the Japanese food and beverage industries are found to exhibit increasing returns to scale, while decreasing returns to scale are observed for the Canadian and Japanese non-electrical machinery, petroleum products and the Canadian transportation equipment industries.

11. We conducted the same test where we set the Japanese spillover parameters equal to zero first. The test gives us identical results as in Table 1. Therefore, it is independent of the order in which we test the existence of spillovers.

12. The properties of the function are outlined after equation (2) and see Diewert (1982).

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

14. We do not model the product demand side, but we are conditioning on output, so our estimates capture output increases over time from the spillovers. Spillovers can also be cost increasing in the present if they lead to future cost reductions. In present value terms spillovers are cost-reducing, although at a point in time cost can rise.

15. Our formula for the social rate of return does not explicitly include the revenue gain from output changes that come from product demand increases, and thus may actually be biased in a downward direction. However, the social rate of return reflects cost changes due to spillovers, and since these changes depend on output, then implicitly our measure of the return is inclusive

of the revenue gain.

16. The domestic returns in this paper differ from Bernstein (1995), which deals with international spillovers between Canada and the U.S.. Bernstein finds that spillovers from the U.S. generally increase Canadian R&D intensity. This increase causes the domestic spillover pool to rise and leads to high social returns. Our findings are consistent with these results, which in this paper manifest themselves as high domestically-based social returns.

APPENDIX: Estimation Results

Parameter	Chemical Products		Electrical Products		Food & Beverage		Fabricated Metals	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β_{1C}	1.522	.644	0.638	0.030	0.199	0.020	1.596	0.611
β_{1J}	-0.252	.205	0.373	0.067	0.059	0.063	-0.679	0.254
b_{11}	0.965	.222	0.256	0.046	0.459	0.043	-1.025	0.157
η_C							0.848	0.033
η_J	0.832	.040			0.924	0.039	0.939	0.034
ψ_{1C}	-2.613	1.215					2.252	2.093
ψ_{1J}	-3.150	1.503	-2.469	1.819	-5.725	3.032		
ψ_{2C}	0.653	.453	0.043	0.354	-1.069	1.181	1.730	0.256
ψ_{2J}	1.362	.740	0.649	0.906	-8.161	8.153	-2.157	1.243
α_{11}	1.380	.862	15.132	7.288	13.986	9.237	3.585	2.755
α_{22}	0.978	.661	5.489	2.156	181.822	172.031	62.836	10.190
λ*	-0.531	.268	-0.100	0.040	0.005	0.007	0.014	0.026
ϕ_{11C}					-0.0001	0.0001	-0.000004	0.0001
ϕ_{11J}	0.00009	.00003	0.0004	0.0001	-0.0001	0.0001	0.00001	0.00004
ϕ_{22C}			0.00001	0.0001	0.003	0.005		
ϕ_{22J}			0.0004	0.0002	0.009	0.008	-0.0004	0.001
ϕ_{12C}			0.0001	0.0001	0.002	0.002		
ϕ_{12J}			-0.001	0.0002	0.004	0.003	0.0008	0.002
ϕ_{21C}	0.000002	.00001	-0.0002	0.0001	-0.0003	0.0003	-0.0005	0.001
ϕ_{21J}	-0.0002	.00005	-0.0001	0.0001	-0.001	0.001		
β_{2C}	5.551	2.467	0.789	0.051	0.883	0.115	3.116	1.211
β_{2J}	7.977	3.065	1.572	0.198	1.831	0.736	2.222	0.675

	Chemical Products	Electrical Products	Food & Beverage	Fabricated Metals
Log of likelihood function	408.908	344.520	683.869	521.516
Correlation Coefficient Squared				
Labour Demand	0.96	0.86	0.99	0.99
Interm. Demand	0.98	0.99	0.99	0.99
Phy. Cap. Demand	0.95	0.97	0.95	0.76
R&D Cap. Demand	0.89	0.97	0.99	0.97
Variable Cost	0.99	0.99	0.99	0.99

* $\alpha_{12} = \alpha_{21} = (\lambda\alpha_{11}\alpha_{22})^{0.5}$

Parameter	Machinery		Mineral Products		Paper & Products		Petroleum Products	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β_{1C}	0.210	0.068	2.674	1.420	0.665	0.230	0.014	0.010
β_{1J}	0.232	0.075	2.145	1.574	0.158	0.055	0.002	0.003
b_{11}	0.089	0.201	-1.217	0.201	0.061	0.302	0.010	0.032
η_C				0.792	0.056			
η_J	1.066	0.034	0.697	0.071			1.153	0.070
ψ_{1C}	-1.100	0.911	-2.299	1.048	-4.528	2.749	-6.962	2.734
ψ_{1J}	-1.554	1.719					-2.297	2.245
ψ_{2C}	0.075	1.204	0.121	0.944	-1.163	4.258	-0.873	0.831
ψ_{2J}	1.062	0.527	-3.063	1.766	-2.496	2.038	0.891	1.279
α_{11}	6.222	0.862	0.721	0.535	7.449	4.837	177.795	165.269
α_{22}	41.492	18.188	3.054	1.971	28.988	4.693	69.759	109.228
λ*	-0.033	0.028	0.134	0.150	-0.027	0.044	-0.001	0.002
ϕ_{11C}	0.0001	0.0001	0.00003	0.00002	-0.001	0.00001	-0.00001	0.00004
ϕ_{11J}			0.00002	0.00004	-0.00002	0.00001	0.0001	0.0002
ϕ_{22C}								
ϕ_{22J}	-0.0001	0.0001	0.004	0.002	0.00007	0.0001	-0.001	0.001
ϕ_{12C}								
ϕ_{12J}	0.000003	0.00003	-0.0001	0.001	-0.001	0.0004	-0.0002	0.002
ϕ_{21C}	-0.0001	0.0002	-0.0002	0.0001			-0.00003	0.00003
ϕ_{21J}			-0.0004	0.0002			-0.00001	0.0001
β_{2C}	0.357	0.123	5.313	2.991	1.557	0.612	0.355	0.245
β_{2J}	0.632	0.217	15.166	9.070	1.538	0 .451	0.052	0.039

	Machinery	Mineral Products	Paper & Products	Petroleum Products
Log of likelihood function	439.091	460.252	481.817	616.619

Correlation Coefficient Squared

Labour Demand	0.96	0.99	0.97	0.96
Interm Demand	0.99	0.90	0.99	0.99
Phy. Cap. Demand	0.96	0.87	0.98	0.97
R&D Cap Demand	0.95	0.96	0.90	0.94
Variable Cost	0.99	0.99	0.99	0.99

* $\alpha_{12} = \alpha_{21} = (\lambda\alpha_{11}\alpha_{22})^{0.5}$

Parameter	Primary Metals Estimate	Primary Metals Standard Error	Transportation Equipment Estimate	Transportation Equipment Standard Error
β_{1C}	2.277	1.316	0.127	0.086
β_{1J}	9.735	8.985	0.069	0.043
b_{11}	1.992	0.406	-0.253	0.094
η_C	0.768	0.054	1.112	0.078
η_J	0.699	0.081		
ψ_{1C}			-2.263	1.669
ψ_{1J}	-2.631	4.708	-5.737	6.451
ψ_{2C}	-1.124	0.674	0.628	1.736
ψ_{2J}	0.713	1.882	7.766	8.906
α_{11}	0.562	0.570	19.585	23.274
α_{22}	0.119	0.074	159.856	164.423
λ*	0.222	1.808	-0.010	0.010
ϕ_{11C}			-0.00001	0.00001
ϕ_{11J}	0.0001	0.00004	0.0002	0.0001
ϕ_{22C}	-0.0002	0.0001		
ϕ_{22J}	-0.0004	0.001	-0.001	0.001
ϕ_{12C}	0.00001	0.00001		
ϕ_{12J}	-0.001	0.0004	0.0001	0.001
ϕ_{21C}	0.0001	0.0001		
ϕ_{21J}	-0.0001	0.0001		
β_{2C}	9.039	5.623	0.393	0.266
β_{2J}	35.223	36.084	1.898	0.923

	Primary Metals	Transportation Equipment
Log of likelihood function	480.742	520.803

Correlation Coefficient Squared

	Primary Metals	Transportation Equipment
Labour Demand	0.99	0.99
Interm. Demand	0.98	0.99
Phy. Cap. Demand	0.86	0.96
R&D Cap Demand	0.87	0.97
Variable Cost	0.99	0.99

* $\alpha_{12} = \alpha_{21} = (\lambda\alpha_{11}\alpha_{22})^{0.5}$

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