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Factor Intensities, Rates of Return, and International R&D Spillovers: The Case of Canadian and U.S. Industries

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ABSTRACT. – This paper estimates the effects of both intranational and international spillovers on production cost, and factor intensities (including R&D intensity) for eleven manufacturing industries in the U.S., and Canada. In addition, social rates of return to R&D capital are calculated, and decomposed into private rates of return, and the extra-returns due to intranational and international spillovers.

International spillovers are usually cost reducing, and increase R&D and physical capital intensities. International spillovers are generally labor and intermediate input intensity reducing. In Canada, international spillover effects are more elastic than domestic spillover elasticities. In the U.S. the same relationship exists, but is not as pronounced.

Social rates of return to R&D capital are substantially above the private rates in both Canada and U.S. In Canada, international spillovers generally account for a greater percentage of the social returns relative to the domestic spillovers. In the U.S. the converse occurs. Canadian social rates are from two and a half to twelve times greater than private returns, while U.S. social returns are from three and a half to ten times greater than the private rates.

Les intensités de facteurs, les taux de rendement et les externalités internationales de la « R&D » : le cas des industries du Canada et des États-Unis

RÉSUMÉ. – Ce texte évalue les effets des externalités intranationales et internationales sur les coûts de production et les intensités de facteurs pour onze industries manufacturières canadiennes et américaines. On calcule aussi les externalités internationales des taux de rendement sociaux de la R&D, qui réduisent les coûts et augmentent la « R&D » et l'intensité de capital physique, tandis que les intensités de la main-d'œuvre et d'intrants diminuent. Au Canada, les taux de rendement sociaux sont de deux et demie à douze fois plus élevés que les rendements privés. Aux États-Unis, l'écart est de trois et demi à dix fois plus élevés. Les différences de rendement sont attribuables au Canada aux externalités internationales et aux États-Unis aux externalités intranationales.

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1 Introduction

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. 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.

There is a public good aspect to R&D capital accumulation. The benefits from R&D cannot be completely appropriated by R&D performers and, inevitably, there are spillovers. There are numerous transmission channels associated with R&D spillovers. Examples relate to physical capital, and intermediate input acquisition, labor mobility, licensing agreements, and joint ventures. Spillovers (positive ones at least) imply that R&D performers have not been adequately compensated for their efforts. When R&D is performed not only investors benefit, but benefits are spilled over to other users inside and outside the performing industry. Indeed, R&D spillovers spur the diffusion of new knowledge, while simultaneously creating disincentives to undertake R&D investment. A number of recent empirical papers have shown that domestic R&D spillovers are important means of knowledge transmission (see GRILICHES [1991], and NADIRI [1993] for surveys).

In a world with international trade, foreign direct investment, and the international exchange of information, a country's stock of knowledge depends on its own R&D investment, as well as the R&D efforts of other countries. R&D spillovers extend beyond national boundaries. The purpose of this paper is to investigate the effects of both intranational and international spillovers between Canadian and U.S. industries on costs of production, and factor intensities, and to determine the relative contribution of domestic and foreign spillovers to the social rates of return to R&D capital. The focus of international spillovers between Canada and the U.S. arises because of the importance of international trade and foreign direct investment links between the two countries.

This paper is organized into five sections. Section 2 contains the estimation model. Section 3 relates to the intranational and international spillovers elasticities of production cost and factor intensities. Social rates of returns, and the contributions of domestic and foreign spillovers are discussed in section 4. The last section is the conclusion.

2 Estimation Model of Spillovers

This section develops a model of production with intranational and international spillovers for Canadian and U.S. industries. This model can be used, in part, to determine intranational and international spillover effects on production cost, and factor intensities.

We specify a variable cost function, or more precisely an average variable cost function. An average variable cost function leads to a model specification in terms of factor intensities. This feature implies that, irrespective of the degree of returns to scale, the same set of equations are estimated (apart from any parameter restrictions arising from constant returns to scale). The average variable cost function is denoted as [1],

$$
\begin{aligned}
(1)\qquad c_t^{\nu}/y_t = &\left(\sum_{i=1}^{2}\beta_i\,w_{it} + 0.5\sum_{i=1}^{2}\sum_{j=1}^{2}\beta_{ij}\,w_{it}\,w_{jt}\,W_t^{-1}\right.\\
&\left.+\sum_{i=1}^{2}\sum_{j=1}^{2}\phi_{ij}\,w_{it}\,S_{jt-1} + \sum_{i=1}^{2}\phi_i\,w_{it}\,t\right) y_t^{\eta-1}\\
&+\left[\sum_{i=1}^{2}\alpha_i\,k_{it} + 0.5\sum_{i=1}^{2}\sum_{j=1}^{2}\alpha_{ij}\,k_{it}\,k_{jt}/y_t^{\eta-1}\right.\\
&\left.+\sum_{i=1}^{2}\sum_{j=1}^{2}\psi_{ij}\,k_{it}\,S_{jt-1} + \sum_{i=1}^{2}\psi_i\,k_{it}\,t\right] W_t
\end{aligned}
$$

where the parameters to be estimated are given by $\beta_i,\ \beta_{ij},\ \phi_{ij},\ \phi_i,\ \alpha_i,\ \alpha_{ij},\ \psi_{ij},\ \psi_i,\ i,\ j = 1, 2$ and η is the inverse of the degree of returns to scale. The noncapital factor prices are denoted as w_i, $i = 1$ is the labor price, and $i = 2$ is the price of intermediate inputs. R&D spillovers are denoted by S_{1t} as the intranational (or domestic) spillover, and S_{2t} as the international (or foreign) spillover. Capital intensities are $k_i = K_i/y$, where K_i is the capital input, $i = 1$ is physical capital, $i = 2$ is R&D capital, y is output, and t is the time trend, representing non-spillover exogenous technological efficiency effects. $W = \Sigma_{i=1}^{2} a_i\,w_i$, where a_i, $i = 1, 2$ are fixed coefficients. W can be defined as a Laspeyres index of non-capital input prices. By defining W in this manner we do not have to normalize the cost function by any one noncapital input price, but rather by a weighted average of both prices [2].

In the literature, international R&D spillovers are measured in a number of ways. COE and HELPMAN [1995] use trade flows as carriers of international R&D spillovers, EATON and KORTUM [1996], and BRANSTETTER [1996] rely on foreign patenting, whereas LICHTENBERG and VAN POTTELSBERGHE de la POTTERIE [1996] consider both trade and foreign direct investment. Trade or foreign investment linkages can bias the effects of international spillovers. KELLER [1996] shows that randomly generated trade shares lead to international spillover effects on productivity growth that are higher than those estimated using actual trade shares. Implicit in the use of patent weights is the assumption that the value of patents are assumed to be invariant across producers, within and between countries, and over time. Moreover, international transactions do not have to occur in order for spillovers to flow between nations.

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1. See DIEWERT [1982] for the properties of cost functions.
2. The attractive feature of this average variable cost function is that the curvature conditions can be imposed on the function. See DIEWERT and WALES [1987, 1988] for this discussion.

In this paper, we do not need to hypothesize any specific transmission channel. Spillovers between the U.S., and Canada arise from the stocks of R&D capital defined at an aggregate industrial level in each country. The stock of R&D capital in one country can affect production cost, and factor intensities in the other country, because spillovers occur within the context of a bilateral model of production and investment (see JORGENSON and NISHIMIZU [1978], and JORGENSON, SAKURAMOTO, YOSHIOKA, and KURODA [1990] for this class of model in the absence of R&D spillovers). The significance of this approach is that transmission channels are not specified independently of production (including R&D) decisions, and that all production decisions are modeled simultaneously.

The domestic spillover is the sum of one period lagged R&D capital stocks of all domestic industries other than the one under consideration [3]. Spillovers are estimated for industries defined at the two-digit Standard Industrial Classification (SIC) level. This means that domestic spillovers are also interindustry spillovers. The foreign spillover is the lagged R&D stock of the corresponding industry in the foreign country. International spillovers are intraindustry. Spillovers that operate across national boundaries and between industries are assumed to be indirectly captured through the domestic spillovers, which are themselves influenced by foreign R&D capital stocks.

Most existing studies of international R&D spillovers estimate simple Cobb-Douglas production functions where domestic and foreign R&D enter as separate inputs. The assumed functional form implies that factor intensities are independent of any spillovers. However, theoretically, GROSSMAN and HELPMAN [1991] have shown that spillovers affect factor intensities. In this paper a flexible functional form is specified for the cost function, which permits the estimation of factor intensity effects of international spillovers.

Using the average variable cost function, and Shephard's Lemma (see DIEWERT [1982]), noncapital input intensities, are given by,

$$(2)\quad \vartheta_{it} = \Bigg(\beta_i + \sum_{j=1}^{2} \beta_{ij}\, w_{jt}\, W_t^{-1} - 0.5 \sum_{h=1}^{2}\sum_{j=1}^{2} \beta_{hj}\, w_{ht}\, w_{jt}\, W_t^{-2}\, a_i + \sum_{j=1}^{2} \phi_{ij} S_{jt-1} + \phi_i t\Bigg) y_t^{\eta-1} + \Bigg(\sum_{j=1}^{2} \alpha_j k_{jt} + 0.5 \sum_{h=1}^{2}\sum_{j=1}^{2} \alpha_{hj} k_{ht} k_{jt} / y_t^{\eta-1} + \sum_{h=1}^{2}\sum_{j=1}^{2} \psi_{hj} k_{ht} S_{jt-1} + \sum_{h=1}^{2} \psi_h k_{ht} t\Bigg) a_i, \qquad i = 1, 2,$$

3. For any one producer, the accumulation of undepreciated R&D investment by other producers is the source of R&D spillovers. Spillovers emanate from the stocks of R&D capital. Thus it is not surprising that the use of one or two year lags on the stocks in defining spillovers does not affect the results.

where noncapital input intensities are $\vartheta_i = \nu_i / y$, $i = 1, 2$, and ν_1, is labor input, and ν_2 is intermediate input. The intensities associated with labor and intermediate inputs depend on their factor prices, output quantity, physical and R&D capital intensities, and R&D spillovers.

Based on the average variable cost function, and cost minimization, the demands for the physical and R&D capital inputs, in intensive form are [4],

$$(3) \qquad k_{it} = (\alpha_{jj} \, A_{it} - \alpha_{ij} \, A_{jt}) / \mathcal{A}, \qquad i \neq j, \quad i, j = 1, 2$$

where $A_{it} = (-\alpha_i - \Sigma_{j=1}^{2} \psi_{ij} \, S_{jt-1} - \psi_i \, t - \omega_{it} \, W_t^{-1}) \, y_t^{\eta - 1}$, $i = 1, 2$, and $\mathcal{A} = (\alpha_{11} \, \alpha_{22} - \alpha_{12}^2)$, ω_i is the factor price of the i-th capital input. The physical and R&D capital intensities depend on labor and intermediate input prices, the input prices of physical and R&D capital, output quantity, and the R&D spillovers. Equation sets (2), and (3) define the model that is to be estimated [5].

The model is estimated for each of eleven manufacturing industries. The industries are defined at the two-digit SIC level, and are; chemical products, electrical products, food and beverage, fabricated metals, nonelectrical machinery, nonmetallic mineral products, paper and allied products, petroleum products, primary metals, rubber and plastics, and transportation equipment. For each industry, Canadian and U.S. data are pooled. Thus the model is in the class of bilateral production models (see JORGENSON and KURODA [1990], JORGENSON and NISHIMIZU [1978]). The sample period is 1962-1989. The variables used in the models are defined in the Data Appendix. The estimator of equation sets (2), and (3) is nonlinear maximum likelihood. From the tables in the Estimation Results Appendix, we see that the correlation coefficients between the actual and fitted values of the endogenous variables are high. The model fits the data quite well [6].

3 Spillover Elasticities

The purpose of this section is to present and discuss the effects of domestic and foreign spillovers on average variable cost of production, and

4. The capital input demands are derived from the minimization of total cost, which is $c^{\nu} + \Sigma_k \, \omega_k \, K_k$, where c^v is given by equation (1) after multiplying both sides of (1) by y. Solving the first order conditions for the capital inputs leads to equation (3).

5. Because our interest lies in the measurement of long-run spillover elasticities, along with the determination of long-run social rates of return to R&D capital, we abstract from the dynamics arising from adjustment costs.

6. In the estimation we impose the restriction that the variable cost function must be concave in the noncapital input prices. Thus $\beta_{ii} = -b_{ii}^2$. In addition, with the matrix of β_{ij} parameters defined as B, the vector of β_i parameters defined as β, and the vector of coefficients a_i defined as a, we note that $(B + 2 \, a \beta^T)$ parameters are identified. Thus for identification, we introduce two restrictions, $\beta_{ii} + \beta_{ij} = 0$, $i \neq j$, i, $j, = 1, 2$. In addition, there are at least 27 observations times 4 equations minus 22 parameters or 86 degrees of freedom for each of the eleven industry models that are estimated.

factor intensities (including R&D intensity). The spillover elasticities are determined by differentiating equaitons (1), (2), and (3) with respect to S_1 and S_2. First, in terms of the capital intensities, from equation (3),

$$\text{(4)}\quad ek_c S_j = S_j y^{\eta-1}(\alpha_{12}\psi_{dj} - \alpha_{dd}\psi_{cj})/\mathcal{A}k_c \quad j{=}1,\,2,\; c\neq d,\; c,\, d{=}1,\,2$$

where, $ek_c\,S_j$ is the j-th spillover elasticity of the c-th capital intensity.

Second, turning to the noncapital input intensities,

$$\text{(5)}\quad e\vartheta_i S_h = \Bigg[[\phi_{ih}y^{\eta-1}/a_i + (\psi_{hh}k_h + \psi_{gh}k_g)] + (ek_1S_h)(k_1/S_h) \left(\alpha_1 + \sum_{j=1}^{2}\alpha_{1j}k_j y^{\eta-1} + \sum_{j=1}^{2}\psi_{1j}S_j + \psi_1 t\right) + (ek_2S_h)(k_2/S_h) \left(\alpha_2 + \sum_{j=1}^{2}\alpha_{j2}k_j y^{\eta-1} + \sum_{j=1}^{2}\psi_{2j}S_j + \psi_2 t\right)\Bigg] a_i S_h/\vartheta_i, \quad i=1,\,2\;\; g\neq h,\;\; g,\, h=1,\,2$$

where, $e\vartheta_i\,S_h$ is the h-th spillover elasticity of the i-th noncapital input intensity. There are two effects of the spillovers on the noncapital intensities. The first is the direct effect (denoted by the terms in the first set of square brackets) arising from the fact that noncapital input prices interact with the spillovers. The second effect is the indirect effect that arises because the noncapital input intensities are affected by the capital intensities. The latter intensities are directly affected by the spillovers.

The last set of elasticities shows the effects of the spillovers on average variable cost. They are,

$$\text{(6)}\quad ec_y^{\nu} S_h = \Bigg[[(\phi_{1h}w_1 + \phi_{2h}w_2)y^{\eta-1}/W + \psi_{hh}k_h + \psi_{gh}k_g] + (ek_1S_h)(k_1/S_h)\left(\alpha_1 + \sum_{j=1}^{2}\alpha_{1j}k_j y^{\eta-1} + \sum_{j=1}^{2}\psi_{1j}S_j + \psi_1 t\right) + (ek_2S_h)(k_2/S_h)\left(\alpha_2 + \sum_{j=1}^{2}\alpha_{j2}k_j y^{\eta-1} + \sum_{j=1}^{2}\psi_{2j}S_j + \psi_2 t\right)\Bigg] WS_h/(c^{\nu}/y), \quad g\neq h, \quad g,\, h = 1,2$$

where, $ec_y^{\nu}\,S_h$ is the h-th spillover elasticity of average cost. There are also two effects of the spillovers on average variable cost. The first is the direct effect, (denoted by the terms inside the first set of square brackets) and the second is the indirect effect which operates through the capital intensities.

The direct effect of spillovers on average variable cost represents changes in the non-capital input intensities; namely labor and intermediate inputs, when capital intensities do not change. R&D spillovers can decrease non-capital intensities and thereby decrease variable cost [7].

The sum of the direct and indirect spillover effects can be variable cost-increasing. Recall that the indirect effect relates to changes in capital intensities. Thus it is possible for a spillover to directly reduce variable cost, and also decrease capital intensities. Lower capital intensities imply higher variable cost. The latter effect can more than offset the direct cost-reducing effect [8].

Tables 1 and 2 show the sample mean and standard deviation of the annual spillover elasticities relating to factor intensities, and variable cost (both the direct and combined direct and indirect elasticities of variable cost).

From table 1, domestic or intranational spillovers reduce average variable cost for six U.S. industries. They are chemical products, non-electrical and allied products, primary metals, rubber and plastics. The effects are inelastic, and the elasticities range from a low of 0.002 for non-electrical machinery to a high of 0.69 for transportation equipment. In Canada, domestic spillovers reduce average variable cost in five industries. These industries are, electrical products, food and beverage, petroleum products, rubber and plastics and transportation equipment. The range of variable cost reductions is wider in Canada relative to the U.S., and except for rubber and plastics, and transportation equipment, there is little overlap in the industry groupings between the two countries. This result suggests that domestic spillover effects are different in the two countries.

TABLE 1

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

United States						
Industry	Labor Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. Cost	Dir. Avg. Var. Cost
Chemical Products	–0.0059	–0.0168	0.0015	0.0006	–0.0116	–0.0110
	(0.0011)	(0.0050)	(0.0002)	(0.0001)	(0.0022)	(0.0020)
Electrical Products	0.1107	0.2238	–0.2584	0.2221	0.1597	0.1681
	(0.0390)	(0.0152)	(0.0537)	(0.0172)	(0.0297)	(0.0348)
Food & Beverage	0.0519	0.1192	–0.0107	–0.0319	0.1004	0.0993
	(0.0053)	(0.0176)	(0.0015)	(0.0040)	(0.0117)	(0.0117)

7. Spillovers could also increase product demand, and thereby revenue. This could result in a greater demand for non-capital inputs, and higher variable cost. Although product demand is not modeled, by conditioning on output, parameter estimates capture output increases over time (including those arising from spillovers). In this situation revenue increases more than offset any rise in cost.

8. Another way spillovers can be cost increasing is if they lead to future cost reductions. Thus, in present value terms spillovers are cost-reducing, but at any point in time, they can directly lead to cost increases.

TABLE 1 (continued)

United States

Industry	Labor Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. Cost	Dir. Avg. Var. Cost
Fabricated Metals	0.0117	0.0180	–0.2631	0.3691	0.0150	–0.0102
	(0.0126)	(0.0196)	(0.0577)	(0.0379)	(0.0162)	(0.0252)
Non-electrical Machinery	–0.0016	–0.0028	0.0039	0.0009	–0.0022	–0.0016
	(0.0013)	(0.0017)	(0.0008)	(0.0002)	(0.0015)	(0.0014)
Non-metallic Minerals	0.0673	0.1086	0.1947	0.1396	0.0874	0.0232
	(0.0063)	(0.0109)	(0.0458)	(0.0859)	(0.0073)	(0.0078)
Paper & Allied Products	–0.0261	–0.0558	–0.0234	–0.3432	–0.0428	–0.0509
	(0.0046)	(0.0125)	(0.0039)	(0.0889)	(0.0075)	(0.0093)
Petroleum Products	0.0173	0.0242	0.0138	–0.2771	0.0236	0.0176
	(0.0015)	(0.0016)	(0.0035)	(0.0453)	(0.0016)	(0.0019)
Primary Metals	–0.1580	–0.3011	0.0114	–0.3976	–0.2434	–0.2467
	(0.0484)	(0.1234)	(0.0018)	(0.0934)	(0.0911)	(0.0909)
Rubber & Plastics	–0.0172	–0.0331	0.2450	0.0959	–0.0261	–0.0189
	(0.0051)	(0.0162)	(0.1401)	(0.0075)	(0.0105)	(0.0103)
Transportation Equipment	–0.4552	–0.8696	–0.5342	0.3355	–0.6925	–0.6869
	(0.1440)	(0.4225)	(0.1128)	(0.0230)	(0.2634)	(0.2721)

Canada

Industry	Labor Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. Cost	Dir. Avg. Var. Cost
Chemical Products	0.0188	0.0338	–0.0136	–0.2159	0.0303	0.0266
	(0.0088)	(0.0139)	(0.0015)	(0.0226)	(0.0126)	(0.0129)
Electrical Products	–0.0272	–0.0378	0.1220	–0.3524	–0.0336	–0.0410
	(0.0160)	(0.0110)	(0.0321)	(0.1843)	(0.0090)	(0.0104)
Food & Beverage	–0.0010	–0.0017	–0.0125	0.2426	–0.0016	–0.0014
	(0.0004)	(0.0007)	(0.0020)	(0.0199)	(0.0006)	(0.0006)
Fabricated Metals	0.0227	0.0205	–0.0579	0.4881	0.0212	0.0195
	(0.0062)	(0.0032)	(0.0094)	(0.2181)	(0.0042)	(0.0041)
Non-electrical Machinery	0.0539	0.0701	0.0694	0.7311	0.0647	0.0655
	(0.0828)	(0.1198)	(0.0170)	(0.0262)	(0.1068)	(0.1069)
Non-metallic Minerals	0.0379	0.0437	0.0556	0.1519	0.0418	0.0363
	(0.0131)	(0.0109)	(0.0060)	(0.0478)	(0.0116)	(0.0112)
Paper & Allied Products	0.0409	0.0612	–0.3214	0.1164	0.0554	0.0422
	(0.0318)	(0.0358)	(0.0400)	(0.0371)	(0.0346)	(0.0354)
Petroleum Products	–0.0093	–0.0116	–0.0137	0.3217	–0.0115	–0.0086
	(0.0015)	(0.0022)	(0.0025)	(0.0413)	(0.0022)	(0.0030)
Primary Metals	0.0266	0.0347	–0.0681	–0.0492	0.0328	0.0306
	(0.0083)	(0.0052)	(0.0072)	(0.0045)	(0.0058)	(0.0058)
Rubber & Plastics	1.1677	1.1952	–0.1557	–0.2996	–1.1743	–1.1330
	(0.9799)	(1.1588)	(0.0275)	(0.0453)	(1.1273)	(1.0963)
Transportation Equipment	–0.0600	–0.0819	–0.1825	–1.8678	–0.0769	–0.0597
	(0.0364)	(0.0337)	(0.0225)	(0.5542)	(0.0346)	(0.0339)

TABLE 2

International Spillower Elasticities: Mean Values of Annual Elasticities
(standard deviations of annual elasticities in parentheses)

United States						
Industry	Labor Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. Cost	Dir. Avg. Var. Cost
Chemical Products	0.1446	0.3994	–0.1176	0.0156	0.2790	0.2438
	(0.0272)	(0.0459)	(0.0199)	(0.0024)	(0.0078)	(0.0145)
Electrical Products	–0.0798	–0.1404	0.1365	–0.1266	–0.1072	–0.1132
	(0.0707)	(0.0830)	(0.0512)	(0.0721)	(0.0782)	(0.0842)
Food & Beverage	–0.2828	–0.6680	0.0516	0.2463	–0.5550	–0.5488
	(0.1318)	(0.3526)	(0.0157)	(0.0799)	(0.2731)	(0.2704)
Fabricated Metals	–0.0316	–0.0482	0.0539	0.0288	–0.0404	–0.0345
	(0.0181)	(0.0273)	(0.0244)	(0.0152)	(0.0228)	(0.0208)
Non-electrical Machinery	–0.1432	–0.2145	0.7234	0.2263	–0.1807	–0.0640
	(0.1859)	(0.2761)	(0.0936)	(0.0899)	(0.2299)	(0.1843)
Non-metallic Minerals	–0.0219	–0.0353	0.0407	0.2085	–0.0284	0.0198
	(0.0107)	(0.0183)	(0.0140)	(0.1310)	(0.0143)	(0.0115)
Paper & Allied Products	–0.1497	–0.3149	0.2585	0.5366	–0.2429	–0.1978
	(0.0230)	(0.0383)	(0.0276)	(0.1029)	(0.0220)	(0.0133)
Petroleum Products	–0.1528	–0.2181	0.1791	0.0067	–0.2125	–0.1885
	(0.0572)	(0.0937)	(0.0266)	(0.0025)	(0.0915)	(0.0987)
Primary Metals	0.0381	0.0692	–0.0082	0.0786	0.0568	0.0566
	(0.0070)	(0.0087)	(0.0016)	(0.0103)	(0.0073)	(0.0074)
Rubber & Plastics	–0.0469	–0.0607	–1.5544	–0.0845	–0.0560	–0.0911
	(0.0830)	(0.1218)	(1.6098)	(0.0374)	(0.1058)	(0.1232)
Transportation Equipment	0.2451	0.4346	0.0784	–0.1128	0.3556	0.3432
	(0.0498)	(0.0938)	(0.0086)	(0.0274)	(0.0362)	(0.0369)

Canada						
Industry	Labor Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. Cost	Dir. Avg. Var. Cost
Chemical Products	–0.0434	–0.0778	0.0266	0.5385	–0.0696	–0.0611
	(0.0252)	(0.0415)	(0.0047)	(0.0525)	(0.0375)	(0.0376)
Electrical Products	–0.6640	–0.7987	0.3576	0.6264	–0.7351	–0.6874
	(0.5593)	(0.2050)	(0.0568)	(0.0242)	(0.2741)	(0.2623)
Food & Beverage	–0.7540	–1.2567	0.9681	0.3153	–1.1489	–1.1321
	(0.4035)	(0.7425)	(0.0078)	(0.0296)	(0.6529)	(0.6486)
Fabricated Metals	–0.4810	–0.4275	1.2628	2.8523	–0.4455	–0.3929
	(0.1879)	(0.1273)	(0.0651)	(0.9532)	(0.1469)	(0.1443)
Non-electrical Machinery	–0.1426	–0.2123	0.1320	0.1399	–0.1879	–0.1774
	(0.0756)	(0.0904)	(0.0428)	(0.0169)	(0.0857)	(0.0837)
Non-metallic Minerals	–0.4673	–0.5334	0.5831	0.2105	–0.5111	–0.4371
	(0.2035)	(0.1864)	(0.0505)	(0.0468)	(0.1916)	(0.1799)
Paper & Allied Products	–0.0420	–0.0524	0.2228	0.8684	–0.0495	–0.0448
	(0.0677)	(0.0879)	(0.0605)	(0.4925)	(0.0818)	(0.0806)
Petroleum Products	–0.3220	–0.4077	1.0786	–0.4325	–0.4038	–0.3588
	(0.1098)	(0.1578)	(0.0744)	(0.0542)	(0.1562)	(0.1662)
Primary Metals	–0.1980	–0.2556	0.2757	0.2940	–0.2422	–0.2326
	(0.0760)	(0.0590)	(0.0266)	(0.0319)	(0.0621)	(0.0615)

TABLE 2 (continued)

Canada						
Industry	Labor Intensity	Interm. Input Intensity	Phy. Cap. Intensity	R&D Cap. Intensity	Avg. Var. Cost	Dir. Avg. Var. Cost
Rubber & Plastics	1.0078	1.7086	–0.3075	–0.5507	1.2793	1.1992
	(0.8769)	(1.5140)	(0.1028)	(0.1797)	(0.4928)	(0.4546)
Transportation Equipment	–0.3435	–0.4947	2.4249	1.7695	0.4281	0.3887
	(0.1262)	(0.0847)	(0.2127)	(0.6727)	(0.1009)	(0.0947)

The elasticities of international spillovers on average variable cost point out that foreign spillovers also operates differently in the two countries. U.S. R&D capital generates relatively more elastic effects in the corresponding Canadian industry, compared to the effects of international spillovers from Canada. In addition, in Canada, international spillover elasticities of average variable cost tend to be more elastic relative to intranational spillovers. The same result is observed for the U.S., but it is not as robust. However, the relative magnitude of international spillover elasticities in Canada could reflect differences in the size of the R&D capital stocks in the two countries, and the fact that international spillovers are also intraindustry. In the U.S. situation, the result shows that intraindustry/international spillovers dominate interindustry/intranational spillovers, even though Canadian R&D capital stocks (the source of international spillovers) are much smaller than the interindustry sum of U.S. R&D capital stocks (the source of domestic spillovers).

International spillovers generally reduce average variable cost. In Canada, spillovers from U.S. R&D capital reduce average variable cost in nine of elevent industries. Cost increases occur in only rubber and plastics and transportation equipment. In the U.S., foreign spillovers from Canada reduce average variable cost in eight industries. Cost increases arise in chemical products, primary metals, and transportation equipment. Thus transportation equipment is the only industry common to both countries that exhibits increasing cost. This result could arise from the special bilateral relationship between the two countries, known as the North American Auto Pact.

The spillover elasticities on R&D intensity generally show that there is a complementary relationship between R&D intensity and the international spillover in each country. Increases in the foreign spillover increase R&D intensity in eight U.S. industries, and nine Canadian industries. The increases in R&D intensity are in the range from 0.01 percent for petroleum products to 0.54 percent for paper and allied products in the U.S., and from 0.14 percent for nonelectrical machinery to 2.85 percent for fabricated metal products in Canada.

With respect to domestic spillovers, the number of industries that exhibit a complementary relationship between R&D intensity and the spillover are seven in the U.S. and six in Canada. The Canadian range is from 0.24 percent for food and beverage to 0.73 percent for nonelectrical machinery.

The U.S. range is from 0.001 percent for chemical products to 0.37 percent for fabricated metal products. In Canada, foreign spillover effects on R&D intensity are relatively more elastic than domestic spillover effects. In addition, in the U.S., about half the industries display a similar type of behavior. This result is, perhaps, not so surprising given the fact that international spillovers are intraindustry, while intranational spillovers are interindustry.

The last set of spillover elasticities relates to the non-R&D capital intensities. International spillovers increase physical capital intensity in eight U.S. industries, and ten Canadian industries. However, Canadian domestic spillovers are generally substitutable for physical capital, or, in other words, physical capital reducing. This result occurs in eight industries. In the U.S., domestic spillovers increase physical capital intensity in six of the eleven industries. Labor and intermediate input elasticities always respond in the same direction to either intranational or international spillovers. International spillovers are usually noncapital input intensity reducing in both countries (eight industries in the U.S., and ten in Canada). The effects of domestic spillovers in the U.S. on labor and intermediate input intensities is mixed. However, in Canada, unlike international spillovers, domestic spillovers generally reduce noncapital intensities.

The results relating to domestic spillovers, which are interindustry, are consistent with BERNSTEIN [1988] for Canada, and BERNSTEIN and NADIRI [1988] for the U.S. The international spillover results are the first estimates of spillover elasticities linking Canadian and U.S. industries. The Canadian findings are consistent with MOHNEN [1990], where Canadian manufacturing R&D, and physical capital are complementary to the aggregate international spillover from five OECD countries. There are few studies that investigate the effects of international spillovers on factor intensities, or factor demands of U.S. industries. Most studies just consider the productivity effects of international spillovers (see the survey by NADIRI [1993]). It is interesting to note that O'SULLIVAN and ROGER [1991] find no evidence of aggregate international spillovers from developed nations to the U.S. BERNSTEIN and MOHNEN [1997] find no evidence of Japanese spillovers to the U.S. Clearly, the significant spillovers from Canadian to U.S. industries found in this paper, highlight the importance of distinguishing among nations, and industries as sources of R&D spillovers to the U.S.

4 Private and Social Rates of Return

An analysis of R&D spillovers from the vantage point of spillover sources relates to the private and social rates of return. The social rate of return to R&D capital consists of the private return plus the extra-private return due to the spillover. These latter returns are calculated by considering a situation where the spillovers are internalized. In this regard, define joint costs to be,

$$(7) \qquad \Omega_\tau = \sum_{j=1}^{2} \sum_{i=1}^{11} (C^{\nu ij}(w_\tau^{ij}, y_\tau^{ij}, K_\tau^{ij}, S_{\tau-1}^{ij}, t^{ij}) + \omega_\tau^{ijT} K_\tau^{ij})$$

The superscript j refers to the country, and superscript i refers to the industry.

Consider the right side of equation (7), evaluated at the equilibrium factor intensities for each country. In equilibrium, the cost for each producer is at a minimum. However, joint cost is not minimized relative to the case where the spillovers are internalized. With the internalization of the R&D spillovers, there is additional cost variability from each of the R&D capital stocks. Using the average variable cost function, equation (1), differentiate equation (7) with respect to R&D capital. The joint domestic cost effect per dollar of R&D investment, from an increase in the R&D capital from the f-th industry in the j-th country is,

$$(8) \quad d_{2t}^{fj} = \sum_{\substack{i=1 \\ i \neq f}}^{11} \left[\sum_{g=1}^{2} \phi_{g1}^{ij} w_{gt}^{ij} (y_t^{ij})^{\eta^{ij}-1} + \sum_{h=1}^{2} k_{ht}^{ij} \psi_{h1}^{ij} W_t^{ij} \right] y_t^{ij} / q_{2t}^{fj}, \quad f = 1, ..., 11, \; j = 1, 2$$

where q_2 is the price of R&D investment.

Next the joint foreign cost effect per dollar of R&D investment is

$$(9) \quad i_{2t}^{fj} = \left[\sum_{g=1}^{2} \phi_{g1}^{fk} w_{gt}^{fk} (y_t^{fk})^{\eta^{fk-1}} + \sum_{h=1}^{2} k_{ht}^{fk} \psi_{h1}^{fk} W_t^{fk} \right] y_t^{fk} / q_{2t}^{fj}, \quad f = 1, ..., 11, \; j \neq k, \; j, k = 1, 2.$$

Equations (8), and (9) define the domestic and foreign wedges between the social and private rates of return to R&D capital that arise from the R&D capital of the f-th industry in the j-th country.

The private rate of return to R&D capital in long-run equilibrium is the marginal cost reduction per dollar of R&D investment. This return is defined gross of depreciation and before tax. The private return is the before tax rental rate deflated by the price of R&D investment. Defining ρ_{2t}^{fj} to be the private rate of return to R&D capital for industry f in country j, then the social rate of return to R&D capital is [9],

$$(10) \qquad \gamma_{2t}^{fj} = \rho_{2t}^{fj} + d_{2t}^{fj} + i_{2t}^{fj}.$$

The social rates of return to R&D capital for the U.S., and Canada are presented in tables 3, and 4, respectively. The private rate of return averages

9. The private rate of return can be derived from equation (1). Indeed, $\rho_{2t}^{fj} = (\partial c_t^{\nu fj} / \partial k_{2t}^{fj}) / q_{2t}^{fj}$.

among the U.S. industries to be 16.4 percent, and for the Canadian industries the rate averages 12.8 percent. These are before tax gross of depreciation, purchasing power adjusted (Canada to U.S.), nominal rates of return. The returns from the intranational and international spillovers are presented in the first and second columns of tables 3, and 4. These columns define the domestic and foreign spillover wedges between the private and social rates of return to R&D capital.

From table 3, in the U.S. the extra-private returns that arise from the domestic spillovers are generally more important than the returns obtained from the externalities sent to Canada. We find in two U.S. industries that the foreign-based spillover returns substantially exceed the domestic-based returns. These are primary metals and transportation equipment. In three industries the returns from domestic and foreign spillovers are about the same. These industries are food and beverage, fabricated metals, and non-metallic minerals. In the remaining six industries the domestic spillover returns are vastly greater than the international returns, and in one industry (rubber and plastics) the return from the international spillover is negative. This result occurs when the direct cost effect of the spillover is cost increasing. However, even in the rubber and plastics industry, the sum of the intranational and international spillover returns is positive.

From table 4, the spillover returns for Canadian industries show that for eight of the eleven industries, the returns from international spillovers

TABLE 3

Rates of Return

United States (mean percent)			
Industry	Spillover Return		Social Rate of Return
	Domestic	Foreign	
Chemical Products	80.550	1.635	98.244
Electrical Products	75.723	6.535	95.555
Food & Beverage	80.625	84.663	183.134
Fabricated Metals	63.047	77.854	157.266
Non-electrical Machinery	63.759	2.504	85.334
Non-metallic Minerals	63.981	50.841	132.144
Paper & Allied Products	66.470	14.236	99.223
Petroleum Products	103.837	52.703	174.518
Primary Metals	39.495	54.738	111.212
Rubber & Plastics	34.495	–2.661	43.876
Transportation Equipment	15.784	58.002	88.459

TABLE 4

Rates of Return

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

dominate the returns from the domestic externalities. In fact, in the three industries where domestic returns are more important, the returns from international spillovers are negative. These three industries are chemical products, primary metals, and transportation equipment. Nevertheless, these negative returns are more than offset by the positive domestic-based returns.

The social rates of return to R&D capital in the U.S. and Canada are found in the last column of tables 3 and 4 respectively. It is important to note that these returns are purchasing power parity-based. Canadian data is purchasing power parity adjusted to the U.S. data. Hence these returns are comparable across countries. In each country, the social returns greatly exceed the private rates of return. In Canada, the social returns two and a half to twelve and a half times the private rates of return. In the U.S. the social returns are from three and a half to ten times the private rates of return.

With respect to the ranking of social returns in the two countries, the ordering of the industries differ. There is no uniform ranking across countries because the magnitude of international spillover returns of the U.S. relative to the international spillover returns to Canada, differ across industries. Although international spillovers are intraindustry, a high international spillover return in a U.S. industry (relative to other U.S. industries), does not imply a high international spillover return in the same Canadian industry (relative to other Canadian industries). Five of the eleven industries are roughly in (or close to) the same position in Canada and the U.S.

These industries are food and beverage, fabricated metals, paper and allied products, and chemical products. Three industries that are near the top of the Canadian ranking are close to the bottom of the U.S. ranking. These industries are non-electrical machinery, electrical products, and rubber and plastics. In addition, three industries ranked near the bottom in Canada are close to the top in the U.S. The three are; petroleum products, non-metallic minerals, and primary metals. We see that the rates of return to R&D capital in Canada vary from around 32 percent to 162 percent and in the U.S. the returns range from 44 percent to 183 percent.

Clearly, there are large social returns to investing in R&D capital, and a major portion of these returns are international in nature. Large differentials between private and social returns are found in many studies (see GRILICHES [1991], and NADIRI [1993]). Social rates of return can exceed private rates from 9 percent to 160 percent. The vast majority of these studies relate to domestic spillovers. However, the large productivity gains associated with international spillovers (see COE and HELPMAN [1995]) imply that international spillovers cause social returns to be far in excess of private returns. The large social returns, estimated in this paper, imply that at existing levels of R&D capital, there is substantial underinvestment in R&D. Moreover, this underinvestment arises from both intranational and international spillovers.

5 Conclusion

International (but intraindustry) spillovers between Canadian and U.S. industries generally exert greater influence on production cost, and factor intensities relative to domestic (but interindustry) spillovers. This effect is not as pronounced in the U.S., as it is in Canada. In addition, spillovers emanating from the U.S. generate greater effects than spillovers from Canada to the U.S.

International spillovers tend to reduce cost and increase both R&D and physical capital intensities. This conclusion is found for both countries. In addition, in the U.S., and Canada, international spillovers reduce labor and intermediate input intensities.

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 U.S. In Canada, international spillovers generally account for a greater percentage of the social returns relative to the domestic spillovers. In the U.S. 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 non-electrical machinery. Social rates are from two and a half to twelve times greater than private returns. In the U.S. social returns are from three and a half to ten times greater than private rates. The social rates 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 social returns mean that at current R&D levels, there is substantial underinvestment in R&D. This underinvestment arises from both intranational and international spillovers. Indeed, we can interpret these returns such 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. Our findings point to an important set of relationships between the two economies that are not reflected in international trade, and foreign investment, but in international knowledge diffusion.

APPENDIX 1

Data

The non-R&D data is described in detail in DENNY et al. [1992]. The quantity of output is measured in millions of 1986 dollars. The price of output is a price index which is obtained by dividing current dollar gross output by 1986 dollar gross output. The price is indexed to 1.00 in 1986. The quantity of labor is labor compensation in millions of 1986 dollars. The price of labor is current dollar labor compensation divided by 1986 dollar labor compensation and is indexed to 1.00 in 1986. The quantity of intermediate inputs is obtained by netting value added from gross output, and its price is obtained in the same manner as the price of output.

Both physical and R&D capital stocks are measured in 1986 millions of dollars. In constructing R&D capital we assumed a 10 percent depreciation rate. Recent work by NADIRI and PRUCHA [1993], has estimated rates of depreciation that are close to 10 percent. In addition, to deflate Canadian R&D expenditures, we used the price indexes from BERNSTEIN [1992] for the period 1964-1987, and extrapolated back to 1962 and forward to 1989 using the percentage change in the gross domestic product deflator. To deflate U.S. R&D expenditures, the R&D price index was obtained from JANKOWSKI [1993], for the period from 1969 to 1988, and we extrapolated back to 1962 and forward to 1989 using the percentage change in the U.S. gross domestic product deflator.

The rental rates (that is the factor prices) of physical and R&D capital are obtained as follows. The rental rate of physical capital is before-tax and is defined as,

$$\omega_k = q_k\,(r + \delta_K)\,(1 - itc_k - u_c\,z)/(1 - u_c)$$

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

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

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

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

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

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

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

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

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

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

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

$$\omega_r = q_r\,(r + \delta_r)\,((1 - u_c)\,(1 - itc_r) - u_c\,d)/(1 - u_c)$$

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

The present value of incremental investment allowances at time t is:

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

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

APPENDIX 2

Estimation Results

The estimation results are presented in the following tables. We performed likelihood ratio tests to see if the set of spillover parameters should be included in the industry models. In each case we could reject the hypothesis of no spillovers. In addition, we set $\alpha_{12} = \lambda(\alpha_{11}\,\alpha_{22})^{.5}$, so that for convexity of the variable cost function in the capital inputs, $\lambda^2 < 1$; and $\alpha_{ii} > 0$. These conditions are satisfied for each industry. In the tables when no estimate is presented for the inverse of the degree of returns to scale, η, it means that $\eta = 1$. For each industry, intranational and international spillover parameters, first order parameters, and the degree of returns to scale can differ between the two countries.

Estimation Results

Parameters	Chemical Products		Electrical Products		Food & Beverage		Fabricated Metals	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β1U	0.8736	0.3367	1.0090	0.4980	0.5737	0.1358	0.4562	0.2064
β1C	0.4112	0.0801	0.6934	0.2427	0.3462	0.0504	1.4656	0.4471
b11	0.5088	0.1228	0.6758	0.1428	0.2336	0.1355	0.5310	0.1579
α1U	– 2.4615	0.9350	– 3.1741	0.7118	– 10.9893	2.6222	2.2709	0.8048
α1C	– 2.8447	0.5856	– 4.4627	0.7524			1.4702	0.4291
α2U	– 8.6792	3.2739	– 1.5072	0.6059	– 6.6427	3.4459	– 1.5023	0.5840
α2C	1.0830	0.8833	– 0.6714	1.0417	– 0.8258	0.3115	2.8132	0.9571
α11	2.3466	0.8739	13.8208	6.1451	27.8762	6.7870	3.7694	1.2285
α22	0.8754	0.5129	3.0489	1.3092			42.7053	13.1159
λ	– 0.0333	0.0175	0.2151	0.1991	0.0055	0.0030	– 0.0416	0.0305
ψ11U	– 0.0780	0.0248	0.0002	0.0001	– 0.0002	0.0001	– 0.0001	0.0001
ψ11C	– 0.9867	0.2841	0.0002	0.0001			0.0004	0.0002
ψ22U	– 0.0011	0.0011	0.00001	0.00001	– 0.0003	0.0001	– 0.0006	0.0004
ψ22C	– 0.0001	0.0001	0.00004	0.00002	– 0.0005	0.0002	– 0.0004	0.0003
ψ12U	0.0006	0.0001	– 0.00006	0.00007	0.0080	0.0033	0.0003	0.0001
ψ12C	0.00001	0.00002	– 0.00001	0.000007	0.0079	0.0024	– 0.0001	0.0001
ψ21U			– 0.15515	0.43834	– 0.0007	0.0006	– 0.0003	0.0004
ψ21C	0.0001	0.0001	0.91369	0.93690	– 0.0010	0.0008	– 0.0002	0.0002

Estimation Results

β2U	2.3395	0.9454	1.30880	0.70022	0.7738	0.3765	3.2386	1.3326
β2C	1.5168	0.3706	1.47590	0.56923	1.19124	0.2917	2.7701	0.6649
ηU	0.8660	0.0441					0.9186	0.0043
ηC							0.8515	0.0035
Log of the Likelihood Function	362.584		312.771		598.044		493.312	
Correlation Coefficient of Actual and Fitted Values								
Labor Intensity	0.96		0.99		0.99		0.99	
Inter. Input Intensity	0.91		0.96		0.69		0.90	
Phy. Capital Intensity	0.99		0.99		0.99		0.99	
R&D Capital Intensity	0.99		0.99		0.99		0.99	
Variable Cost	0.99		0.99		0.93		0.99	

Estimation Results

Para-meters	Non-electrical Machinery		Non-metallic Minerals		Paper & Allied Products		Petroleum Products	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β1U	0.2601	0.5696	0.4248	0.0588	0.5513	0.0871	0.0687	0.0110
β1C	0.6692	0.1155	0.5269	0.0674	0.2533	0.0552	0.0040	0.0016
b11	0.0814	0.0261	0.5012	0.1067	0.0652	0.0693	0.0071	0.0032
α1U	– 2.1437	0.8233			– 1.9984	0.8735		
α1C	– 1.0311	0.7092	– 1.4751	0.2332	– 0.7864	0.4281	– 5.2793	2.6110
α2U	5.0248	0.2010	0.5345	0.1820	– 1.7339	0.4611	– 0.3812	0.1400
α2C	0.0717	0.0539	0.2971	0.1591	– 1.9544	0.6282	– 0.8440	0.3271
α11	6.3299	0.7410	0.6615	0.3639	1.7158	0.0554	53.5902	41.2804
α22	40.4963	17.1125	3.1060	1.8736	8.7641	3.6680	27.4732	20.3332

Estimation Results

λ	– 0.0231	0.0251	0.1095	0.1027	– 0.0739	0.0419	0.0820	0.0499
ψ11U					0.0002	0.0001		
ψ11C	0.0001	0.0001	0.00003	0.00002	0.0004	0.0002	– 0.0005	0.0003
ψ22U	0.0003	0.0002	0.00004	0.00001	0.0001	0.0001	–0.0001	0.0002
ψ22C	0.0001	0.0001	0.00003	0.00001	0.0008	0.0013	– 0.00001	0.00004
ψ12U			– 0.00005	0.00008	– 0.0003	0.0002	– 0.0003	0.0003
ψ12C	0.000005	0.000004	– 0.00010	0.00006	– 0.0001	0.0001	– 0.0001	0.0001
ψ21U			– 0.00005	0.00003	0.0005	0.0004	– 0.0002	0.0003
ψ21C	– 0.0001	0.0002	– 0.00003	0.00002	0.0010	0.0006	– 0.0003	0.0002
β2U	0.8477	0.3945	2.8504	0.9938	1.2621	0.5334	0.3931	0.1451
β2C	0.5731	0.1962	1.1533	0.2366	0.8791	0.1181	0.0684	0.0421
ηU			0.7604	0.0399				
ηC	1.0580	0.03916	0.8225	0.0561				
Log of the Likelihood Function	336.759		278.195		466.837		490.220	
Correlation Coefficient of Actual and Fitted Values								
Labor Intensity	0.99		0.99		0.97		0.99	
Inter. Input Intensity	0.97		0.85		0.91		0.87	
Phy. Capital Intensity	0.93		0.99		0.99		0.99	
R&D Capital Intensity	0.99		0.85		0.99		0.98	
Variable Cost	0.99		0.99		0.99		0.95	

Estimation Results

Parameters	Primary Metals		Rubber & Plastics		Transportation Equipment	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β1U	1.8890	0.5663	2.5331	0.1624	0.1469	0.0873
β1C	2.4714	0.8031	0.8218	0.4371	0.2142	0.0331

Estimation Results

b11	1.7766	0.4147	0.6113	0.3552	– 0.6477	0.2611
α1U					– 4.4481	1.9007
α1C	– 0.9501	0.4998	– 4.6145	2.6622	– 2.1744	1.6539
α2U	– 0.7763	0.4312	– 1.7203	0.7238	2.4533	1.0441
α2C	– 1.1361	0.7233	– 1.0008	0.7507	0.7815	0.3255
α11	0.5983	0.3269	18.1376	6.4237	13.8021	12.0915
α22	0.1130	0.0920	23.3702	9.3721	39.3561	29.9807
λ	0.2257	0.8318	– 0.0252	0.0186	– 0.0660	0.0417
ψ11U	0.0006	0.0002	– 0.0003	0.0002	– 0.0003	0.0001
ψ11C	0.0006	0.0003	– 0.0001	0.0001	0.0002	0.0002
ψ22U	– 0.0002	0.0001	0.0005	0.0002	– 0.0002	0.0002
ψ22C	– 0.0004	0.0002	– 0.0004	0.0003	– 0.00001	0.00001
ψ12U	0.0002	0.0003	0.0002	0.0001	– 0.00003	0.00001
ψ12C	0.0001	0.0002	0.0002	0.0001	– 0.000008	0.000004
ψ21U	0.0004	0.0002			– 0.0001	0.0001
ψ21C	0.0006	0.0004	– 0.0002	0.0001	– 0.00004	0.00003
β2U	9.3310	3.2077	0.6721	0.4732	1.1121	0.4388
β2C	13.8166	10.2944	0.4316	0.2155	0.3962	0.1343
ηU	0.8144	0.0529				
ηC	0.7710	0.0540			1.0998	0.0771
Log of the Likelihood Function	422.552		184.225		316.660	
Correlation Coefficient of Actual and Fitted Values						
Labor Intensity	0.99		0.96		0.98	
Inter. Input Intensity	0.86		0.97		0.97	
Phy. Capital Intensity	0.96		0.76		0.98	
R&D Capital Intensity	0.93		0.99		0.98	
Variable Cost	0.97		0.99		0.99	

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