# R&D, Inter-Industry and International Spillovers of Technology and the Total Factor Productivity Growth of Manufacturing Industries in Canada, 1974-1989

**Petr Hanel**[*]

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Abstract

The paper offers new econometrics evidence on the relationship between total factor productivity and the R&D expenditures of Canadian manufacturing industries in the presence of inter-industry and international spillovers of technology. The construction of spillover proxies is based on a matrix of Canadian patent counts. The normalized distributions of inventions patented in Canada by each country of the G-7 group are weighted by their respective R&D expenditures to generate estimates of R&D expenditures in other industries in Canada and abroad, creating spillovers that can be used by each Canadian industry.

The results confirm Griliches' (1994) finding that the TFP-R&D nexus is strongly influenced by the inclusion or exclusion of the computer industry, whose TFP has been adjusted for quality improvement. They also suggest that the process-related R&D activity appears to have a statistically more significant effect on TFP than the product-related R&D. Federal grants to R&D do not appear to enhance TFP. The estimated effect of spillovers from R&D in other industies in Canada varies over time and, in contrast to former studies, is smaller than the effect of the industry's own R&D. The estimated effect of international spillovers of R&D on TFP is mostly statistically significant. Its magnitude, however, varies over time and is smaller than the effect of industry's own R&D.

Key words: Total factor productivity, R&D expenditures, spillovers, R&D grants.

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[*] Université de Sherbrooke and Centre interuniversitaire de recherche sur la science et la technologie (CIRST)

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## Abstrakt

Tato studie přináší nové ekonometrické výsledky dokumentující vztah mezi multifaktoriální produktivitou (MFP) a výdaji na průmyslový výzkum a vývoj v kanadském zpracovatelském průmyslu, včetně meziodvětvových a mezinárodních technologických externalit. Podkladem pro konstrukci proměnné resresentující technologické externality je matrice kanadských patentů. Souhrn technologických externalit, které jsou k disposici kanadskému průmyslu odpovídá normalizovanému rozdělení vynálezů patentovaných v Kanadě každou ze zemi skupiny G7 (USA, NSR, VB, Japonsko, Francie, Italie a Kanada) váženému výdaji daného odvětví na průmyslový výzkum a vývoj v každé ze sedmi zemí.

Výsledky potvrzují závěr ke kterému dospěl Griliches (1994), že vztah mezi MFP a výdaji na průmyslový výzkum a vývoj je silně ovlivněn tím, je-li do souboru zahrnut průmysl výpočetní techniky, jehož MFP bere v úvahu růst kvality. Výsledky rovněž naznačují, že výdaje na výzkum a rozvoj orientovaný na zlepšení výrobních procesů má statisticky významnější vliv na MFP než výzkum směřující k vývoji nových a vylepšených výrobků. Federální subvence na průmyslový vyzkum a rozvoj nemají vliv na MFP. Na rozdíl od výsledků předcházejících studií, technologické externality z výzkumu a vývoje v ostatních kanadských průmyslových odvětvích mají na MFP menší vliv než vlastní výzkum a vývoj v daném odvětí. Technologické externality z výzkumu a vývoje v zahraničí mají většinou rovněž statisticky významný vliv na MFP. Jeho velikost je proměnlivá a méně významná než vliv vlastního výzkumu a výdaje.



Klíčová slova: Multifaktorální produktivita, výdaje na výzkum a vývoj, technologické externality, subvence na vědu a výzkum.

## Introduction

The total factor productivity growth comes from improvements in the quality of labor and capital and from other sources of technological change, many of them in the form of externalities, spillovers, representing contributions of science and innovations in other enterprises, industries and countries. Economies of scale and scope, as well as improving x-efficiency, are among the other potential sources of total factor productivity growth.

The recent revival of interest in the growth theory focused attention on the potential contribution of investment in human capital, R&D and the accompanying externalities. However, the empirical evidence remains scattered and often inconclusive, especially for smaller economies such as Canada's.

Investment in R&D comes closest to a proxy variable for economic resources allocated by a firm, industry or nation to adoption, adaptation and creation of new technology. R&D spending by private firms and its support by various levels of government reflects the belief that new technology is contributing significantly to economic growth and competitiveness of domestic industries. While there is growing evidence, especially from the U.S., that the R&D -productivity nexus exists, it is also increasingly clear that owing to externalities and measurement problems, the issue is more complex than previously believed (Griliches, 1979, 1992 and 1994).

The goal of the present paper is to advance the debate on the contribution of R&D to productivity by presenting new evidence on several aspects of this relationship observed at the level of two- and three-digit manufacturing industries in Canada over the 1974-1989 period. Before proceeding with the survey of the rather limited literature dealing with this subject in Canada, I wish to present a series of arguments that should convince even the reader not particularly interested in Canadian productivity and R&D to carry on reading.

First, owing to its economic and geographic proximity to the US, Canada is probably a unique case for observation of international technology spillovers. The study presents an original method of constructing a proxy variable for international inter-industry technology spillovers and tests its statistical association with the TFP growth. Second, our results show that the impact of domestic and international technology spillovers does not appear to be as important as theoretically expected, and as indicated by other empirical studies. Third, as in the US (Griliches, 1994), the statistical association between TFP growth and R&D of Canadian manufacturing industries is strongly affected by the inclusion or exclusion of the

statistical outlier, the computer industry. Our results show, however, that a decomposition of R&D into its process and product components helps to arrive at a more robust relationship between R&D and TFP growth that holds even when the observations for the computer industry are not included in the regression.

This is, to my knowledge, the first study made at the industry level illustrating that Canadian industries which invested more in R&D do indeed display higher productivity growth, but only if the R&D was directed to adoption, adaptation or creation of new production processes rather than to new products. It also confirms previous findings that federal grants in support of R&D do not appear to enhance TFP growth in the recipient industries.

Technology policy in Canada has been traditionally characterized by a debate between two opposing parties. On the one side are those who believe that owing to extensive foreign ownership, Canadian firms have easy access to new technology developed abroad and that R&D performed in Canada is therefore not very relevant (Globerman, 1972, 1979). Others defend a stronger Canadian R&D involvement (Science Council, 1979; Comité spécial du Sénat sur la politique scientifique, 1971-1977). The present study estimates technology spillovers at the industry level, explicitly taking into account flows of new technology from major foreign sources into Canada, as well as the extent of foreign ownership of Canadian industries.

In the next section of the paper the reader finds a selective survey of the literature focusing on empirical findings regarding the relationship between R&D and productivity growth in Canadian manufacturing industries, followed by a theoretical model of the relationship between the productivity and the stock of productive knowledge, including spillovers. The data and the estimated models are in the fourth and fifth sections, respectively. Discussion and conclusions complete the paper.

## 2. Literature survey

The empirical research on TFP growth and R&D has been surveyed thoroughly by Mohnen (1992). Griliches' recent presidential address to the American Economic Association (Griliches, 1994) presents the current status of the debate. In order to avoid repetition I shall review here only studies that attempted to establish the productivity growth - R&D relationship in Canada, where the issue received much less attention than in the US (Robidoux, 1991; Mohnen, 1992). Only studies that used the production function approach will be surveyed here.

Details on the alternative cost function approach for estimating the rate of return to R&D and to technology spillovers by Bernstein (1988, 1989), Bernstein and Nadiri (1988) and Mohnen and Lépine (1988) can be found in Mohnen (1992).

Canadian empirical research started in the sixties with attempts to associate the productivity change in Canadian manufacturing industries with their own R&D expenditures. In the first study of this kind Lithwick (1969) found no statistically significant relationship between the TFP growth of ten two-digit level industries from 1945 to 1965 and their R&D intensity (R&D expenditures as a percentage of sales) in 1955.

Globerman (1972) regressed various measures of industrial growth and productivity on R&D intensity for fourteen two-digit industrial groups over the 1959-61 period. He did not find any statistically significant association between the R&D intensity and productivity. He persuasively argued, however, that the R&D performed outside the user firm (industry) may be of as much, or more importance as a determinant of productivity growth than the R&D performed by the firm (industry). He attempted to take indirectly into account the `unobserved' component of R&D (R&D spillovers according to today's vocabulary)[1] in his empirical analysis. In contrast to his own assumptions, the regression results show a negative rather than positive association of foreign ownership - one of the presumed sources of unmeasured R&D available to Canadian industries- with productivity growth. The empirical results derived from the small sample did not bring clear and convicing evidence that the research expenditures of an industry (R&D intensity) are associated with its productivity growth, nor did they conclusively support the contribution of technology spillovers to productivity growth.[2]

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[1] Note that the notion of technology spillovers is associated with but by no means identical to technology diffusion (Griliches 1979,1992).

[2] International productivity spillover effects of foreign direct investment in Canada, hence externalities of a more general nature than technology spillovers limited strictly to the productivity-R&D nexus, were also indirectly identified in a later article by the same author, Globerman (1979). In the most recent attempt to determine whether foreign affiliates create productivity spillovers in Canada, Globerman et al. (1994) found that foreign-owned establishments enjoy higher value added per worker than their Canadian-owned counterparts, primarly because they tend to be more capital intensive and larger. When these effects are explicitly checked for, foreign affiliates are not significantly more productive than Canadian-owned establishments. The authors' conjecture that capital intensity is a proxy variable for technological intensity is not very convincing.

Postner and Wesa (1983) found that the rate of return on R&D performed by an industry and its productivity growth is not significantly different from zero. Theirs was, however, also the first evidence that, as in the US, productivity growth of Canadian industries is better explained by a proxy variable approximating effects of R&D executed in other industries than by industry's own R&D activity. Their proxy variable for indirect R&D assumes that flows of new technology are proportional to R&D incorporated in inter-industry flows of intermediate inputs and capital goods.

Hartwick and Ewen (1983) also computed the R&D embodied in intermediate goods purchases for 29 Canadian industries, broken down by the domestic and foreign control. They did not find any link between the direct (own) and indirect R&D and productivity growth.

On the other hand, Hanel (1985, 1988) found a positive and statistically significant rate of return on R&D investment in twelve manufacturing industries in Quebec over the 1971-1982 period. The rate of return to own R&D was about 50%, comparable to results reported in several US studies. Again, the indirect R&D incorporated in intermediate inputs and capital goods was a more important and statistically more significant source of productivity change.[3]

Ducharme (1991) atempted to establish a link between TFP growth, and the industry's own R&D, and compare a series of alternative R&D spillover proxies. Most of his results seem to show statistically significant associations between the variables. Although he computed and used in his regressions the whole range of R&D proxies known in the literature, he stopped short of comparing, evaluating and fully exploiting the wealth of empirical evidence contained in his dissertation.

While the above mentioned studies dealt with industry level observations, Longo (1984) tested the association of the R&D and productivity growth in a sample of 110 firms. He found that the rate of return on R&D investment was about 25%.

Allard (1987) tried to estimate the "invisible R&D import" spillover benefits enjoyed by Canadian firms under foreign control as being equal to the R&D intensity of foreign parent companies in a limited number of Canadian industries.

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[3] Hanel(1988) reports only the relationship between R&D and the growth of labor productivity from an earlier study (Hanel, Angers and Cloutier, 1986) which also included tests of the R&D-Total Factor Productivity relationship. The TFP results were similar to the labor productivity equations but statistically less robust.

He made no attempt to relate the estimated invisible R&D imports to the performance of recipient industries.

Mohnen's (1992) study is the first attempt to identify directly the effects of international spillovers of technology on Canadian industrial productivity over the 1964-1983 period.[4] He used Canadian imports of high-technology intermediate goods from the five most advanced OECD countries to construct a pool of imported spillovers. Owing to their dominant position in Canadian trade, 98% of spillovers comes from the U.S..[5] Mohnen regresses the time series of TFP of the manufacturing sector on Canadian R&D stock, the "imported" foreign R&D stock and a capacity utilization rate. The results show that the capacity utilization variable dominates all other variables. Canadian R&D is not a significant explanation of the TFP growth and the foreign spillover variable becomes significant only when capacity utilization is included in the equation. Results of Mohnen's cost function estimates indicate however, that the return on foreign R&D are significantly lower than the rate of return on domestic R&D. Coe and Helpman (1993) estimated effect of country's R&D capital stock and the R&D capital stock of its trade partners on the country's total factor productivity. Like Mohnen, they estimated the effect of R&D spillovers on the total manufacturing sector. As Griliches (1992) has demonstrated, the rates of return on aggregate knowledge capital in macro studies is higher than on micro level.

The last, and potentially most fruitful, contribution in this field comes from an ongoing study by OECD (1993). Using internationally comparable input-output tables (including the domestic fixed investment flows and the imported intermediate and capital goods flows), the authors of the study estimated for each major OECD country the input-output weighted flows of indirect R&D, including the portion that comes through imports of inputs and imports of machinery. They then used bilateral trade matrices to estimate the international spillover as the R&D embodied in purchased imported intermediate inputs and capital goods. Their study presented the direct and the indirect R&D measure for eight countries, including

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[4] Fecher (1989) constructed stock of foreign R&D performed by all OECD countries in proportion to Belgium's imports of intermediate inputs from these foreign industries. The inclusion of this proxy for foreign R&D spillovers did not result in conclusive evidence of their effects on productivity of Belgium's industrial firms.

[5] The strong, and in my opinion questionable, assumption of his approach is that the total foreign R&D stock is free and available to Canada in proportion to her import shares of the high technology products. An alternative measure of international technology spillovers available to Canada is simply the US R&D stock. Both measures result in an unrealistically high, freely available pool of foreign R&D, overshadowing the effect of Canadian R&D.

Canada; unfortunately, the international spillovers were not shown separately in their study and the R&D -productivity link was not explicitly analysed. There is little one can add to Mohnen's (1992) conclusion that "although the existence of international knowledge transmission is widely accepted in theoretical studies, the empirical evidence is sparse and not very convincing."

## 3. A model of the relationship between productivity and the stock of productive knowledge, including spillovers

Supposing a production function of the Cobb-Douglas type,[6] the output Q of an industry in period t is a combination of two separable functions, the technological progress function $A_t$ and a conventional inputs function $F_t$.

(1) $$Q_t = A_t F_t$$

The technological progress is a function of the productive knowledge specified as follows:

(2) $$A_t = \phi K_t^{\gamma}.e^{\lambda t}$$

where K is the stock of productive knowledge, $\phi$ is a constant, $\lambda$ is the trend of technological change and $\gamma$ the output elasticity of the knowledge capital.

The function of m inputs $X_m$ (capital, labour and intermediate inputs) is written as:

(3) $$F_t = \Pi X_{mt}^{\alpha m}$$

where $\alpha_m$ are elasticities of output with respect to input m. Unless stated otherwise, the returns to scale are assumed constant, $\Sigma\alpha_m = 1$. Substituting (2) and (3) into (1) determines the output

(4) $$Q_t = \phi K_t^{\gamma}.e^{\lambda t} \Pi X_{mt}^{\alpha m}$$

The stock of productive knowledge is $K_t = \Delta K_t + (1-\delta)K_{t-1}$, where $\Delta K_t$ is the investment in productive knowledge in period t, and $\delta$ is the depreciation rate

[6] According to Griliches (1979), when we are primarily interested in the effects of R&D and related spillovers on output or productivity, the Cobb Douglas production function will prove efficient.

(obsolence) of technical knowledge. Defining an index of total factor productivity $TFP_t = Q_t / F_t$ we can write:

(5) $$\ln TFP_t = \ln\phi + \gamma \ln K_t + \lambda t$$

Expressed in terms of annual growth rates:

(6) $$\Delta TFP/TFP = \lambda + \gamma \, \Delta K/K$$

Since the assumption of a common elasticity of output with respect to productive knowledge (i.e. R&D) across industries with significant differences in R&D intensity is unrealistic, it can be specified alternatively in terms of a common rate of return (marginal product) of R&D across industries (Terleckyj, 1974). The output elasticity of R&D capital $\gamma$, being replaced by its marginal product $\rho = \partial Q/\partial K$, common across industries: $\gamma \Delta K/K = \partial Q/\partial K . K/Q . \Delta K/K = \rho \, \Delta K/Q$ and the TFP growth becomes function of R&D intensity.

(7) $$\Delta TFP/TFP = \lambda + \rho \, \Delta K/Q$$

### 3.1. Knowledge and productivity spillovers

A significant portion of the new knowledge cannot be perfectly appropriated by those who created it. The stock of productive knowledge is therefore the result of the past R&D activity of the firm (industry) and of its capacity to benefit from technological externalities -spillovers- created in other firms, both domestic and foreign. Griliches (1979) identified two technological externalities: knowledge spillovers and productivity spillovers.

(i) Knowledge spillovers from other firms' R&D may enable a given firm to create or assimilate new technology at less than full cost, but the firm has to do its own complementary R&D in order to absorb the spillovers (Cohen Levinthal,1989). The degree to which the results of research effort spill over into a common pool of knowledge and become potentially available to all other firms depends on conditions of appropriability. These have been shown by Levin, Klevorick, Nelson and Winter (1987) to vary significantly from industry to industry.

(ii) Productivity spillovers are related to effects of competition in prices of new products. To the extent that imitators "compete away" a significant portion of the price of a new or improved product, buyers get a higher value than they paid for. The measured productivity effect thus spills over from the innovating firm (industry) to firms (industries) using the new technology, whence its name.

Imperfect appropriation of the results of R&D shifts the productivity effects of new technology from firms that create and manufacture innovations to those using it. Assuming that these technology shifts can be aggregated to industry level, it is possible to identify industries that are sources of technology (Hanel & Palda, 1992 and Hanel, 1994) and those using technology developed by their suppliers.

The stock of productive knowledge is a function of the industry's own R&D, and spillovers from other domestic industries, S, and from industries abroad, F:

$$(8) \qquad K_{tj} = R_{tj} + s_{tj} \Sigma_i S_{tij} + f_{tj} \Sigma_i F_{tij}$$

where j is the industry using spillovers, i industry generating them, $s_{tj}$ and $f_{tj}$ are empirically determined parameters identifying respectively the effective contribution of inter-industry and international spillovers.

### 3.2. Empirical measurement of spillovers

Apart from case studies, there are three sources of information on inter-industry flows of new technology that have been used to construct proxies for inter-industry spillovers of new technology: 1/input-output tables of inter-industry flows of intermediary goods, services and capital equipment; 2/patent matrices cross-classifying patents according to industry of manufacture and industry of use of the newly patented invention; 3/ innovation matrices cross-classifying in the same way innovations from economy-wide innovation surveys, Mohnen (1990), Hanel and Palda (1992) and DeBresson (1990).

### 3.3. Inter-industry spillovers of technology

In the present study the information on spillovers comes from the Canadian patent statistics.[7] Only a fraction of patented inventions are manufactured and used by the same industry that created them.[8] The majority are used by other industries e.g. a new chemical substance may be invented in and manufactured by the chemical industry but used in agriculture, the paper industry or the pharmaceutical industry, to name only a few obvious examples.

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[7] The R&D statistics contain current intramural R&D expenditures by the industry that incurred them. The information on which industry is using the improved or new products resulting from the R&D is currrently not available. Since patented inventions are one of the few systematically measured results of R&D activity, the inter-industry distribution of patents is used as a proxy for the inter-industry flows of new technology.

[8] Their number depends on the industrial classification used. According to our calculations, at the 2 and 3 digit level SIC, only 32% of all inventions patented in Canada over the 1982-85 period were expected to be used by the same industry that manufactured them.

To capture these inter-industry flows of technology, each patented invention in our data base is classified according to the industry most likely to manufacture it, and the industry most likely to use it. This double classification of patented inventions creates a matrix representing inter-industry flows of new technology. In order to avoid the bias created by the well-known inter-industry differences in propensity to patent, the normalised distribution of patents is weighted by the R&D expenses of the most likely industry of manufacture (Scherer, 1982) and Englander, Evenson, and Hanzaki (1989). Thus the flow of new technology between industries is expressed in R&D dollars. The inter-industry flows of patent-weighted R&D were calculated for Canada for three periods, 1978-81, 1982-85 and 1986-1989, Hanel (1994).[9]

### 3.4. International productivity spillovers of technology

Foreign inventors and firms intending to work their inventions in Canada or export patented products into Canada may protect them by applying for a Canadian patent. In the subset of patents issued in Canada to business corporations, approximately 95% are granted to foreign patentees.[10] The large proportion of Canadian patents granted to foreign residents suggests that:

(i) foreign inventors tend to seek patent protection in Canada because of its very open economy and access to the important US market;
(ii) Canadian industry has easy access to foreign technology;
(iii) the pattern of Canadian patents granted to foreign residents is likely to be closely associated with inflows of foreign technology into Canada.

In contrast to studies that viewed the inflow of foreign technology to Canada as being embodied in imported intermediate inputs (Mohnen, 1992; OECD,1993), I construct a proxy that is a function of patenting and production by foreign- owned firms in Canada. In reality, both mechnisms are used.[11]

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[9] There are slight differences in the industrial breakdown between the matrices used in Hanel(1994) and in the present article. However, the methodology, the main results and their interpretation are very similar.

[10] Of the total 56 007 Canadian patents granted to business corporations in the 1986-89 period, only 3 159 had at least one Canadian inventor and/or patentee, i.e. only 5.6%. A comparison with earlier studies (Firestone, 1971) shows that this percentage has not changed significantly over the last 25 years.

[11] Modelling the inflow of foreign technology as proportional to imported inputs has the advantage of better representing technology embodied in imported inputs, irrespective of foreign control. On the other hand, one can argue that the transfer of technology through intra-firm channels of a multinational enterprise is more efficient than mere import of foreign high

Owing to the very high level of foreign control and ownership, foreign subsidiaries are likely to be the main outside sources of new technology, progressive management and entrepreneurship. I further suppose that foreign firms patent in Canada inventions that they intend to work or export there. Last but not least, I assume that subsidiaries owned in Canada by country k have access to a technology pool that can be represented by the R&D expenditures used by industry j in the country of origin k. The R&D used by industry j in country k is computed from national patent matrices. Patent matrices have been constructed for each of the principal industrialised countries belonging to the G-7 group (Canada, United States, Japan, United Kingdom, Germany, France and Italy).[12] The elements of each national patent matrix $[P_{ijk}]$ indicate the number of Canadian patents issued to business corporations from country k. The subscript i indicates the industry that is, according to the judgement of Canadian Patent Office experts, the most likely to manufacture the patented invention. The subscript j indicates the most likely industry to use it, and the subscript k indicates the country of origin of the firm holding the patent. There are therefore k such matrices. The information provided by the patent matrix is used to assign the R&D expenditures of each manufacturing industry i in country k to each user industry j, in proportion to the number of Canadian patents for inventions expected to be manufactured by industry i in country k. The patent output coefficient $p_{ijk}$ for country k is used for the distribution of the industrial R&D expenditures of that country across user industries j.

$$p_{ijk} = \frac{P_{ijk}}{\sum_i P_{ijk}}$$

where $P_{ijk}$ are the patent counts from the national patent matrix.

Formally, $R_{ijk} = [R_{ik} . p_{ijk}]$ , where $R_{ik}$ is the product-related R&D expenditure by industry i in country k. A matrix $[R_{ijk}]$ represents the matrix of technology flows from industries i, to industries j, for a country k. The breakdown of R&D expenditures into process vs. product components of research and development is

technology inputs and, therefore, a proxy relying on foreign control is more plausible. The technology transferred through foreign subsidiaries also includes a large portion of new technology embodied in intra-firm imports. Thus, an important fraction of foreign technology transferred into Canada is common to both measures.

[12] The seven countries own together more than 95% of all Canadian manufacturing industries.

estimated from the Patdat data for each country[13] except for Canada, where this information is available from Statistics Canada.

Since only a fraction of technology available in country k is likely to be spilled over to (and used by) Canada, I assume that the actual inflow of foreign technology is proportional to the share of industry's i sales accounted for by subsidiaries owned by country k in Canada. The total R&D used by industry i in Canada, taking into account the contribution of foreign subsidiaries, is computed as follows:

(i) R&D flows from manufacturing industries i, to user industries j, per dollar of sales of the user industry j, $Q_{jk,}$ are calculated for each source country k, $r_{jk} = \Sigma_i R_{ijk}/Q_{jk}$.

(ii) The contribution of each country's R&D intensity $r_{jk}$ to Canadian industry j is proportional to the share of ownership of Canadian manufacturing industry j by firms with headquarters in country k, $c_{jk} = Q_{jkc}/Q_j$ where $Q_{jkc}$ are the sales of subsidiaries owned by country k in Canada's industry j (k=Canada, US, UK, Japan, Germany, France, Italy), and $Q_j$ are the total sales of industry j in Canada.

(iii) The total intensity of j'th industry use of "imported" R&D is the weighted sum of R&D intensities of all of the seven countries. The shares of ownership $c_{jk}$ are the weights.

$$FURI_j = \Sigma_k \Sigma_i (R_{ijk}/Q_{jk}).c_{jk}$$

As a result, the portion of R&D deemed to be spilled over and/or transfered[14] to a given Canadian industry from country k is proportional to the share of Canadian sales by k's subsidiaries. [15] [16]

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[13] The patent matrices for the six most important sources of foreign technology for Canada are available on request from the author.

[14] The foreign spillover variable includes not only spillovers but also regular transfers of technology. The amounts paid by Canadian subsidiaries to their parent firms for regular transfers of technology are, however, not broken down by industry. It is therefore impossible to isolate foreign spillovers from technology transfers to Canadian industries. The present proxy for spillovers overestimates the true amount.

[15] Take for example the Canadian motor vehicle industry (MVI). All figures are in millions of US $ (converted at constant PPP (1980). The US-owned subsidiaries in Canada were responsible for 84.3% of this industry's sales in Canada, i.e. $20,000. Total sales in Canada were $23,726 in 1985. The total R&D expenditure executed by the MVI in the US was $5,307, the total R&D used by the same industry in the US was $5,646. The sales of the MVI in the US were $149,355 hence the direct R&D intensity (R&D/sales) in the US was 3.55%. Including the

Although the present proxy for the international technology spillovers has some advantages over the alternative measures, it shares many problems related to patent statistics (Archibugi,1992; Griliches, 1990). Since the available data make it impossible to separate knowledge and productivity spillovers, FURI represents a combination of the two externalities.

## 4. Data sources

### 4.1. Total factor productivity data

The source of the TPF data is the experimental series of TPF published by and/or available from Statistics Canada, covering 1961-1989 period, at a 2 digit PM and 3 digit PL classification, based on Canadian Input-Output classification. Statistics Canada constructed several measures of TFP, Durand (1993). Since our objective is to analyze productivity determinants at the industry level, we selected the TFP of gross sales (total industry sales corrected for changes in inventories) which contains data on intermediate inputs and primary factors of production, i.e. capital and labor (measured by the number of hours worked rather than the number of employed persons). To achieve compatibility with the industry definition for which

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R&D borrowed from other US industries, the used R&D intensity was 3.78%.

We assume that the US-controlled portion of the industry in Canada had the same R&D intensity as in the US. Since 84.3% of the automobile industry's sales in Canada were accounted for by the US-owned affiliates, it is assumed that 84.3% Canadian MVI had the same R&D intensity as its US counterpart. The ratio of this "imported R&D" to sales in Canada is therefore 3.18% (.843x3.78).

Hence the intensity of R&D used by the MVI in Canada is 3.2% of sales instead of the 0.2% of sales, which would be suggested by the ratio of the Canadian MVI own R&D expenditures to sales in 1985 or 0.24% of sales including the R&D borrowed from other Candian industries.

Another way of interpreting the FURI variable is to say that Canadian industry j "imports" a share of R&D used by industry j in country k, which is proportional to that industry's sales in Canada relative to its domestic sales in country k. For example, since the sales of US automobile manufacturers in Canada represented 13.4% of domestic sales of US auto manufacturers in 1985, the Canadian automobile industry is assumed to have used 13.4% of R&D used by the US automobile industry (sales in Canada by US affiliates/total sales in the US= 20,000/149,355=13.4%), i.e. \$755.3 (13.4%x \$5640=\$755). This represented 3.18% of automobile industry's total sales in Canada (23,726).

The alternative interpretation of the FURI variable is evident from the following substitution:

$$FURI_j = \Sigma_k \Sigma_i (R_{ijk}/Q_{jk}).c_{jk} = \Sigma_k \Sigma_i (R_{ijk}/Q_{jk}) \bullet Q_{jkc}/Q_j = \Sigma_k \Sigma_i R_{ijk} \bullet (Q_{jkc}/Q_{jk}) \bullet /Q_j$$

[16] An analogous distribution of (direct) R&D expenses in proportion to sales by US foreign affiliates is used by the US tax authorities in apportioning, for tax purposes, the R&D expenditures of US multinationals among their foreign affiliates.

ANBERD R&D data were available for all countries included in the analysis, it was necessary to aggregate several productivity series from the 3 digit PL series. Details and the TFP series are available on request from the author.

### 4.2. Patent and R&D data

The patent counts are from the PATDAT data bank, kindly made available to us by Consumer and Corporate Affairs, Canada. PATDAT contains all Canadian patents granted from 1978 to 1989. In order to reduce annual fluctuations, the subset of patents granted to firms (domestic and foreign) was grouped into three four-year periods (1978-81, 1982-85 and 1986-89) and patent matrices $[P_{ij}]$ were created for each period and country k.

The R&D series lead the patent matrices by three years. They identify the total intramural R&D expenditures, and come from the OECD ANBERD data bank.[17] The R&D flows and intensities were calculated for three four-year periods 1975-1978, 1979-1982 and 1983-1986. The R&D matrixes are calculated for two sets of R&D variables. The first is a four-year flow of R&D expenditures in constant US$. The second set is the capital stock of R&D expenditures $SR^{ijk}$, calculated according to the perpetual inventory method $SR_t = SR_{t-1}(1-d) + R_{t-1}$, with the depreciation rate $d = .15$. The R&D series starts with the 1963 observation and the initial R&D capital is given by the quintuple of the 1963 R&D expenditure in constant 1980 US dollars; this corresponds to an annual growth rate of 5% and a depreciation rate of 15%. The R&D data from 1963 to 1973 are from various issues of the International Statistical Year, OECD and for 1973-89 from OECD ANBERD statistics. Canadian R&D data were adjusted according to a special tabulation provided by Statistics Canada. The stocks were calculated for 1973, 1979, 1981 and 1989 and converted to annual growth rates from one period to another. To compute the R&D intensities, i.e. the ratio of R&D expenditures to sales, the R&D flows were divided by industry sales for the corresponding periods. The industry sales data are from OECD STAN data bank.

Since the OECD Directorate for Science and Technology (OECD,1993) calculated the total used R&D intensity for 1986 according to an alternative methodology (including inter-industry and international spillovers based on input-output tables), their series of direct DIROECD, and total used R&D intensity TOTOECD for Canada will also be used for comparisons with our data.

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[17] Except for Canadian R&D which was kindly provided by Statistics Canada. We understand that this listing was the "official" input of Statistics Canada into the ANBERD data bank. It was submitted in reaction to some discrepancies that appeared in Canadian R&D figures cited in the first published version of ANBERD.

### 4.3. Other data

The foreign control measures for each Canadian manufacturing industry $c_{jk}$, for 1975,1980, 1985 were kindly provided by Statistics Canada. A measure of scale elasticities of Canadian manufacturing industries are from Robidoux and Lester (1992).

## 5. Estimated models

The TPF index fluctuates substantially from year to year because of changes in the capacity utilization and other short-term temporary influences. As Griliches and Lichtenberg (1984) have shown, the high short-term volatility of the TPF index makes it difficult to successfully regress the growth rate of TFP on the R&D stock. The main determinant of the TFP is in the short run the capacity utilization rate. In order to minimize the influence on the TFP index of annual variations in the capacity utilization over the economic cycle, the TFP growth rate was computed for a series of peak-to-peak periods. The periods were as follows: 1974-79, 1979-81, 1974-81, 1981-85, 1985-89 and 1981-89.[18] The annual rates of TFP growth are presented in the appendix, where the corresponding figures for the sixties are also shown for comparison. This comparison is important because it shows that while all industries had a positive TFP growth from 1961 to 1966, more than half of them experienced a decline in TFP growth rate between 1985 and 1989! In contrast, the growth rate of own R&D stocks was more stable and mostly positive. On the other hand, changes in the size and structure of inter-industry flows of R&D abroad, especially in the first half of the eighties, resulted in a decline of R&D imported into Canada in many industries.

The first estimated model corresponds to equation (6) expressing the annual rate of growth of total factor productivity as a function of the annual rate of growth of the own R&D stock, GCTS, the stock of used R&D from other industries in Canada, GCU, and the stock of R&D "imported" from abroad, GUFS. This model assumes that all industries share a common elasticity of output with respect to R&D stock. Other variables not directly related the R&D may influence the productivity growth. Owing to the small size of the Canadian market, economies of scale may be a significant determinant of productivity growth. Industries with high degree of foreign ownership may experience a higher growth of TFP owing to better management and other proprietary advantages of transnational

[18] 1985 was not really a peak of the whole business cycle, but the capacity utilization rate in that year was higher than in the years preceding and following it.

corporations. Both scale elasticity and foreign ownership are included in the vector X. The specification of the model is as follows:

$$(\Delta TFP/TFP)_j = \lambda + \eta_1(\Delta GCTS/GCTS)_j + \eta_2(\Delta GCU/GCU)_j + \eta_3 \Delta GUFS/GUFS)_j + \kappa X_j + \mu_j$$

Estimates of this version by OLSQ with the White correction for heteroscedascity are presented in Table 1. The results lead to two important findings. First, the estimated coefficients depend entirely on the inclusion or exclusion of the observation for the computer industry. The computer industry is an outlier in the statistical sense but, at the same time, its real importance in the technological change militates against its exclusion.[19] Second, they suggest that there is an important lag between the changes in the "direct" and "indirect" R&D stock and associated changes in TFP.

**Table 1:** *Total factor productivity growth as a function of R&D stock variations*

| Eq. | Periods TFP RD | Const. | GCTS | GCU | GUFS | $R^2$adj | n |
|---|---|---|---|---|---|---|---|
| 1 | 81-89; 81-89 | -.008 (-1.01) | .184 (2.23)b | .007 (0.12) | -.003 (-.06) | .113 (1.85) | 21 |
| 2 | 81-89; 81-89 | -.024 (-.50) | -.024 (-.41) | .009 (.28) | -.002 (-.06) | -.160 (.08) | 20 |
| 3 | 81-89; 73-81 | -.001 (-.34) | .069 (1.56) | -.065 (-3.38)a | .068 (2.14)b | .436 (5.89)a | 20 |
| 4 | 81-89; 73-81 | -.001 (-.50) | 0.071 (1.66) | -.071 (-2.70)b | .070 (2.56)b | .232 (2.81)c | 19 |
| 5 | 81-89; 73-79 | -.0004 (-.20) | .092 (1.83)c | -.046 (-3.29)a | .057 (2.03)c | .415 (5.49)a | 20 |
| 6 | 81-89; 73-79 | -.0004 (-.21) | .094 (1.78)c | -.005 (-1.83)c | .059 (1.91)c | .203 (2.53)c | 19 |

Note: The computer industry is not included in equations (2) to (6) and the aerospace industry is excluded from equations (4) and (6). The confidence levels of t statistics are: a=.01, b=.05, c=.1.

[19] The peculiar behaviour of the computer industry in all models of the TFP -R&D relationship was idendified and presented by the author at a public seminar at CERGE-Economic Institute in Prague on 17 May 1994, before he had the chance to read Griliches' (1994) presidential address dealing at length with this issue. The author is indebted to Kristian Palda of Queen's University, who after attending the seminar in Prague, called his attention to Griliches' article.

The impact of the computer industry is evident from equation (1), where the annual TFP growth rate over 1981-1989 is regressed on the growth rates of R&D stocks, of both the industry itself and the inter-industry and international spillovers over the same period. Only the variation of the own R&D stock appears with a positive, statistically significant regression coefficient; the other two variables are not statistically different from zero, and neither is the whole equation. The "good" fit of the GCTS variable is, however, entirely owed to one observation- the computer industry. When this observation is excluded from the sample (equation (2), n=20 observations), the relationship collapses! Except for the computer industry, the result suggests that there is no relationship between the contemporaneous change in the R&D stocks and TFP. This is of course not surprising. It takes time to translate R&D results into cost reductions and/or new products, and in view of this fact even the computer industry's result appears spurious. Ravenscraft and Scherer (1982) found that there is a mean lag of from four to six years between the industrial R&D and its effect on profitability and the lag structure is bell-shaped. The indirect efffects of inter-industry and international flows of new technology are likely to take even more time. The choice of a proper lag structure was however constrained by the available data.

Regressing the rate of productivity change on the R&D performed ealier confirms the existence of an important lag, both for the direct R&D and for the"imported" indirect R&D via inter-industry and international spillovers. As the comparison of equations (3) and (4) with equations (5) and (6) shows, the introduction of a lag structure reveals a TFP-R&D relationship, not only for the growth of the stock of direct "own" R&D expenditures but also for the TFP- indirect R&D. However, the outlying computer industry strikes again.

When the computer industry is included in the equation, (not shown in the table) for R&D stock variation from 1973 to 1981, it destroys the relationship. Coefficients of both spillover variables become not signifiantly different from zero and only the direct, own industry's R&D remains very weakly significant (at the non-conventional 12% level) but its output elasticity more than doubles from 7% to over 18%.[20] The annual rate of TFP growth of the computer industry over the 1981-89 period was 7.3%, more than four times as high as in the next most productive industry. Its R&D stocks, though also increasing impressively, did not outpace other industries by the same order of magnitude. When the relationship is reestimated without the computer industry in equation (3) the TFP growth

[20] Regression on R&D stock variations for 1973-79 period results in a similar but even less significant pattern (not presented).

appears, as expected, positively associated with direct R&D and international spillovers of R&D but, contrary to the theoretical expectations and former studies, the domestic R&D spillovers appear with a negative sign. A closer srutiny of the underlying data shows that the size of the negative regression coefficient of the GCU variable is, to an important degree, due to another outlier, the aircraft industry. This industry is a great user of inter-industry spillovers while its productivity growth is relatively slow. Excluding it from the sample reduces the spuriously high fit of the GCU variable and the proportion of explained variance but it does not significantly change other regression coefficients. Excluding other observations does not affect significantly the estimated relationship that appears as equation (4) or (6) respectively with a shorter and longer lag. Comparison of both results suggest that longer lags marginally increase the value of estimated coefficients of the own R&D and decrease the coefficients of spillover variables. This appears to go against the intuition that the effect of spillovers will take longer to make itself felt than the effect of own R&D. None of the two other variables, the scale elasticity and the foreign ownership share is associated with the TFP growth and they were not included in the estimations reported in Table 1.

Given the significant inter-industry differences in technological opportunity (Cohen and Levinthal, 1990), the assumption of an identical output elasticity with respect to R&D accross all manufacturing industries with widely different R&D intensities is not very realistic. The limited number of observations precluded the possibility of estimating the output elasticity specifically for each industry or for a limited number of closely related industries. Owing to the low number of observations, the variability of spillover proxies from one period to another[21] and the rather low explanatory power of all results, they have to be considered only very tentative. The next step is to relax the assumption of the common output elasticity of R&D.

The second model corresponding to equation (8) relates productivity growth to various measures of R&D intensity:

$$\Delta(TFP/TFP)_j = \lambda + \rho_1 (\Delta R/Q)_j + \rho_2 (\Delta RU/Q)_j + \rho_3 (\Delta FURI/Q)_j + \eta X_j + \mu_j$$

[21] Especially the foreign spillovers appear surprisingly volatile. The imported R&D from abroad decreased notably in the eighties due to a combination of several factors, such as the decrease in the foreign ownership of many Canadian manufacturing industries, a reduction of R&D expenditures in real terms and changes in the estimated inter-industry flows of R&D resulting from changes in the inter-industry pattern of patenting in Canada. Since an overwhelming proportion of new technology is imported to Canada from the US, the observed decline means that the contribution of US technology declined in several industries.

where
$(\Delta TFP/TFP)_j$ is the average annual rate of growth of total factor productivity of 21 Canadian manufacturing industries (peak-to-peak) period 1985-1989,
$(\Delta R/Q)_j$ is the R&D intensity proxy for direct R&D expenses of j-th Canadian industry,
$(\Delta RU/Q)_j$ is a proxy for intensity of R&D spillovers from other Canadian industries, used by j,
$(\Delta FURI/Q)_j$ is a proxy for intensity of foreign R&D spillovers "imported" by j-th industry,
$X_{1j}$ are the other variables potentially affecting TPF,
X1= Scale elasticity, X2= degree of foreign ownership.

The model was estimated by OLSQ with White correction for heteroscedascity for the following four peak to peak periods: 1974-1979; 1979-1981; 1981-1985 and 1985-1989. In order to reduce the volatility of the TFP growth rate, the GCTS variable was replaced by AG which is the growth rate of TFP over the period calculated from the average TFP index for the beginning and the end of the sub-period.[22]

The first three sub-periods are identified by dummy variables D1, D2 and D3. Since the Chow test indicated that the regression coefficients for the own R&D intensity variables (RDINT and RCINT) are not significantly different from one period to another, the observations for the four periods were pooled. However, the intercept, which is the estimate of the trend of autonomous productivity change, varies from one period to another as indicated by the regression coefficients of dummy variables.[23] The trend of productivity change in the first an third period was faster by approximately one half a percentage point than in the fourth reference period. The trend in the second period was not significantly different from the one in the fourth period.

In a simple regression of AG on R&DINT for the whole sample the regression coefficient appears positive and statistically significant. However, a look at the residuals shows that the large productivity increase of the computer industry is

[22] The average TFP index AG is the mean of TFP indexes for two (one) years before and two (one) year(s) after the beginning and the end of the considered period. For the period ending in 1989 the mean was calculated using +- one year only (1988-89-90).

[23] Since the dummy variables indicate that the trend of technological change was significantly different from the reference period (4th) only in the first and third periods, the dummy D2 is excluded from further estimations.

associated with high R&D intensity, leading to heteroscedascity of the estimated simple regression. When the estimated equation is corrected for heteroscedascity (White correction) the regression coefficient of the RDINT variable loses statistical significance, as shown in Equations (1) and (2) in Table 2.

As in the previous R&D stock model, and consistent with U.S. findings (Griliches, 1994), the computer industry dominates the regression results. When it is excluded from the sample, the regression coefficient of the RDINT variable becomes statistically insignificant. In contrast to Griliches (1994) whose analysis was limited to the association of the TFP growth rate and total intramural R&D intensity, our data enabled us to look into the productivity-R&D nexus in more depth by disaggregating R&D into its two chief components. One is the R&D activity aiming at the process innovation, the other is related to the product innovation. Expressing both R&D components in relation to industry sales, the variable measuring the intensity of the process R&D is labeled RCINT and the intensity of the product-related R&D is RCTNT. As the following results will demonstrate, this distinction is crucial for the productivity-R&D nexus.

**Table 2**: *Total factor productivity as a function of industry's own R&D*

| Eq. | Intercept | D1 | D3 | RDINT | RCINT | NRRC | $R^2_{adj.}$ | n |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0045<br>(2.)b | | | 0.001<br>(1.23) | | | .039<br>(4.44)b | 84 |
| 2 | .001<br>(.44) | .007<br>(2.30)b | .006<br>(2.07)b | -.0001<br>(-.19) | | | .087<br>(2.88) | 80 |
| 3 | -.0034<br>(-1.79)c | .0086<br>(3.16)a | .007<br>(2.60)a | | .0225<br>(2.75)a | | .194<br>(7.32)a | 80 |
| 4 | -.0028<br>(-.86) | .008<br>(1.71)c | .008<br>(1.72)c | | .0392<br>(2.77)a | | .112<br>(4.49)a | 84 |
| 5 | .0005<br>(.16) | .007<br>(1.90)c | .008<br>(1.53) | | .033<br>(2.37)b | -.075<br>(-2.15)b | .128<br>(4.05)a | 84 |
| 6 | -0.002<br>(-.90) | .008<br>(3.12)a | .007<br>(2.56)b | | .020<br>(2.32)b | -.032<br>(-1.16) | .197<br>(5.86)a | 80 |

Note: The computer industry not included in the equations (2),(3) and (6). Equation (2) also included a dummy D2 (reg. coefficient= -.002 (t=-.059). The confidence levels of t statistics are: a=.01, b=.05, c=.1.

The regression estimates of AG on RCINT and dummy variables are presented in equations (3) and (4).[24] When the computer industry is excluded from the sample in equation (3), the estimated regression coefficient of RCINT drops sharply, but the association between the TFP growth rate and the intensity of the process-related R&D remains statistically significant. For the US manufacturing industries defined at the 3 digit level Griliches found no statistically significant relationship between the unadjusted TFP growth[25] and the R&D intensity. In contrast, our results show that process-directed R&D intensity remains a statistically significant explanation of the TFP growth in the sample of Canadian two-and-three digit manufacturing industries. The difference between the total R&D intensity and the process-related R&D intensity and TFP growth is shown graphically in scatter diagrams for the two regressions excluding the computer industry, Figure 1 and Figure 2, respectively.[26]

The model tested so far assumes that the rate of return to R&D is the same for all industries. As Englander et al. (1988) have shown, this is not necessarily the case. To determine whether the rate of return varies between technologically backward and advanced industries a dummy variable[27] was used to identify industries with R&D/sales ratio inferior to the median R&D/sales for all industries in the given

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[24] Experimentation with dummy variables D1, D2 and D3 shifting the intercept for the respective sub-periods relative to the reference period 1986-89 has demonstrated that only D1 and D3 significantly improve the estimated equation. The sum of intercept and the regression coefficient of the dummy variable is equal to the trend of autonomous technological change for the respective periods. The trend in the second period 1979-1981 (D2) is not significantly different from the trend in the reference period 1986-1989 and the dummy variable D2 was therefore not included in further regressions. However, the Chow test for the equality of regression coefficients of the RCINT for the sub-periods shows that the hypothesis of the equality of the regression coefficient cannot be rejected [$F=0.21$), $F_{2,76}$critical$= 7.00$] and slope dummy variables were not called for.

[25] Finding that the computer industry behaves as an outlier in the productivity growth -R&D intensity equation, Griliches (1994) found no statistically significant association between the two variables once the outlying computer industry observation was excluded from the sample. Since only the computer industry's productivity index was adjusted in the US to take into account the quality improvements achieved by the products of this industry, Griliches argues and demonstrates that if similar adjustments were performed for other high-technology industries, the productivity-R&D intensity relationship would remain valid.

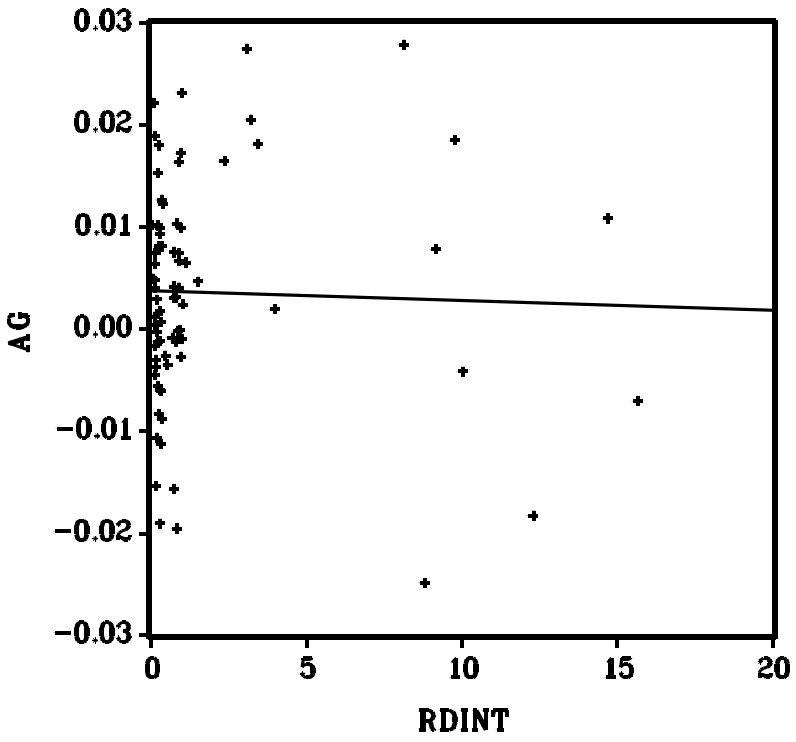
[26] Since the total R&D is closely correlated with the product related R&D, the relationship between the TFP change and the product related R&D is not significantly different from zero according to the conventional 95% probability test (not shown in Table 2).

[27] I owe the idea of splitting the sample according to R&D intensity to P. Mohnen.

period. Experimenting with the dummy variable revealed that the intercept, i.e. the autonomous rate of TFP growth is not significantly different for industries with low R&D intensity. The rate of return to process- related R&D in these industries is, however, negative, as indicated by the sum of the regression coefficients of RCINT and NRRC estimated in equation (5) and (6).[28] Thus the process R&D is associated positively with TFP growth only industries with higher than median R&D intensity.

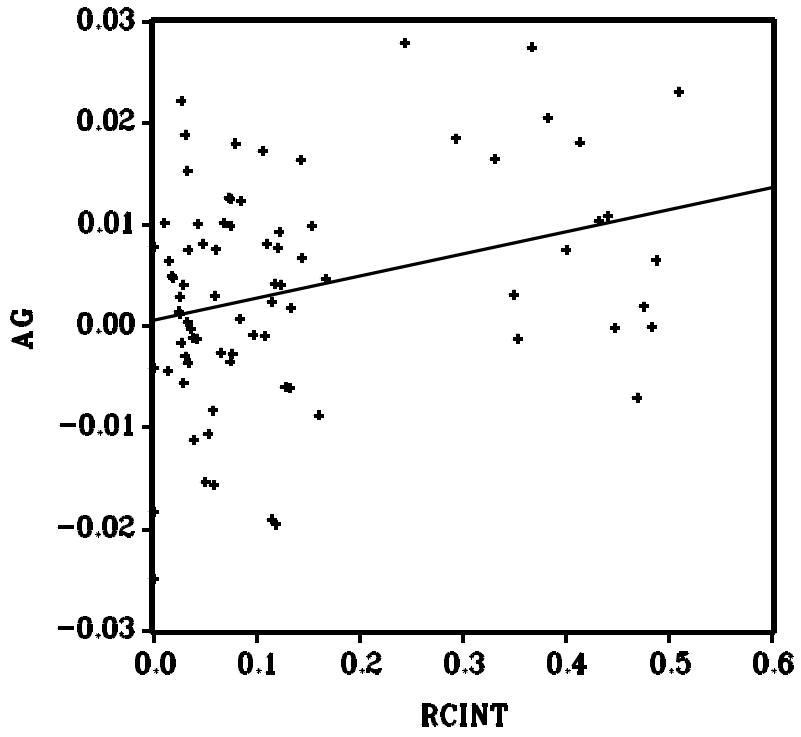
*Figure 1*

TPF% as a function of RDINT, (computer ind. excluded)




[28] NRRC is a dummy variable that is equal to 1 x RCINT if the R&D intensity of the industry is inferior to the median R&D intensity for the given period, and zero otherwise.

*Figure 2*
TPF% as a function of RCINT, (computer ind. excluded)




## 6. The effect of spillover variables on productivity growth

An attempt to estimate the complete model, equation (7) including all three sources of productive knowledge, and equation (8), i.e own process R&D, RCINT, domestic and foreign R&D spillovers CAUI and FURI respectively, ran into multicollinearity problems when all three variables were included at the same time.[29] Indeed, industries with high RCINT also use important amount of R&D

[29] The correlation matrix for the independent variables for all 84 observations is:

| | RCINT | CAUI | FURI | UUSRI |
|---|---|---|---|---|
| CAUI | .48 | 1.00 | | |
| FURI | -.04 | .26 | 1.00 | |
| UUSRI | -.08 | .23 | .98 | 1.00 |

I have also tried to identify with dummy variables industries using intensively inter-industry and international spillovers but it did not solve the multicollinearity problem.

executed in other Canadian industries, CAUI, and the latter is correlated with imported R&D from abroad FURI. Simple regressions of productivity growth on each individual source of R&D are biased due to a specification error but they have the merit of showing that the TFP growth is associated not only with industry's own research intensity but also with the intensity of Canadian inter-industry spillovers, CAUI. However, no significant relationship was found between the productivity growth and the R&D "imported" from abroad, FURI, (and its alternative variants). An examination of residuals suggests, however, that the computer and aerospace industries are again statistical outliers. Both are the largest consumers of "imported" R&D and since the computer industry had the fastest growth of TFP and the aerospace industry one of the slower ones, their joint presence destroys the statistical association. When only one of them is included, it results either in a positive or a negative bias, so both were excluded and the equations reestimated (Eq.4 to Eq.9) in Table 3.

Regression results show that the productivity is affected not only by R&D executed in other Canadian industries, CAUI, but this time the R&D imported from abroad, FURI, is also a significant source of productivity change. The joint presence of own process R&D intensity and each spillover source (Eq.5 and Eq.7) reduces the size of the regression coefficients and their statistical significance, but the results present statistically significant evidence that all three sources of spillovers are positively associated with the rate of productivity change. When all three independent variables are included in the equation (Eq.8), the statistical significance falls owing to multicollinearity but the size of the regression coefficients remains comparable with estimates in the previous simple regressions. They suggest that the marginal product (with respect to sales rather than to value added) of industry's own expenditures for process R&D is more than twice as large as the marginal product of inter-industry spillovers. The latter is again twice as large as the effect of spillovers imported from abroad. The size of all three estimated coefficients is much lower than former estimates for the US and for Canada.[30] Surprisingly, in contrast to results of other researchers, including those of the present author, the influence of inter-industry spillovers is lower than the effect of industry's own R&D. International spillovers have an even lower impact on the TFP growth. Even regressing AG directly on the R&D intensity of the U.S. industries, UUSRI (Eq.9), results in a regression coefficient similar to the one of the FURI variable, but statistically less significant.

[30] Since the R&D intensity is expressed in the present paper with respect to sales rather than with respect to industry's value added, an exact comparison with results based on R&D/VA is not possible.

**Table 3**: *Total factor productivity as a function of industry's direct and indirect R&D, 1974-89*

| Eq. | Const. | D1 | D3 | RCINT | CAUI | FURI | UUSRI | $R^2$adj | n |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -.003<br>(-1.41) | .008<br>(2.54)b | .007<br>(1.56) | | .026<br>(2.97)a | | | .350<br>(16.2)a | 84 |
| 2 | .001<br>(.55) | .006<br>(1.64) | .008<br>(1.48) | | | .001<br>(.94) | | .041<br>(2.2) | 84 |
| 3 | -.005<br>(-1.63) | .008<br>(1.98)b | .008<br>(1.49) | .040<br>(2.79)a | | .001<br>(1.11) | | .138<br>(4.33)a | 84 |
| 4 | -.001<br>(-.70) | .007<br>(2.92)a | .007<br>(2.90)a | | .008<br>(2.89)a | | | .192<br>(6.94)a | 76 |
| 5 | -.002<br>(-1.35) | .008<br>(2.95)a | .007<br>(2.93)a | .012<br>(1.49) | .006<br>(1.96)c | | | .210<br>(5.90)a | 76 |
| 6 | -.002<br>(-.90) | .007<br>(2.92)a | .007<br>(2.89)a | | | .003<br>(2.32)b | | .189<br>(6.82)a | 76 |
| 7 | -.003<br>(1.56) | .008<br>(3.0)a | .007<br>(2.93)a | .014<br>(1.87)c | | .002<br>(1.90)c | | .215<br>(6.14)a | 76 |
| 8 | -.003<br>(-1.50) | .008<br>(3.05)a | .007<br>(2.83)a | .011<br>(1.31) | .004<br>(1.02) | .002<br>(1.19) | | .217<br>(5.17)a | 76 |
| 9 | -.002<br>(-.85) | .007<br>(2.96)a | .007<br>(2.84)a | | | | .002<br>(1.93)c | .175<br>(6.30)a | 76 |

Note: Equations (4) to (9) do not include the computer and aerospace industries.
The confidence levels of t statistics are: a=.01, b=.05, c=.1.

Including other explanatory variables in regression such as the scale elasticity, X1, or the share of foreign ownership X2 (instead of FURI and in addition to it) did not give good results and the coefficients are not presented in Table 2. Using various combinations of spillover variables did not lead to results worth reporting either. The same is true for an alternative proxy of foreign spillovers represented by the foreign control weighted US R&D intensity (not presented in the Table).

The distinctive feature of the present approach is the use of patent-weighted R&D flows to construct proxy variables for both domestic and foreign R&D spillovers. How would the present results compare with those using the input-output flows of goods and services for construction of inter-industry and inter-country technology flows? The available data from the OECD enabled us to perform only a partial test.[31] The TFP growth rate for 1986-89 period was regressed on the total "used

[31] The OECD article shows only the intensity of total R&D used by each industry. It is the sum of industry's own direct R&D expenditures plus the "imported" R&D flows proportional

R&D" intensity in 1986 computed by the OECD, TOECD86 and alternatively on TUSED computed according to our definition. Both results are comparable when the two outliers -the computer and aerospace industries- are included in the sample. When they are excluded, the regressions become statistically insignificant, the regression coefficient of TUSED being significant only at the 15%, and the statistical significance of the coefficient of the TOECD86 falling to 48%. Since the OECD did not present separately the international component of imported R&D intensity, further comparison was not possible.

### 6.1. Are federal subsidies to R&D improving productivity?

The Federal Government disbursed 465 million dollars in various subsidies to R&D activities of private industrial enterprises in 1989.[32] Previous studies suggest that neither in Canada (Hanel, 1988; Poole and Bernard, 1992 ) nor in the United States (Lichtenberg, 1984) was it possible to establish a positive association of direct R&D subsidies and productivity growth. To test the hypothesis of no association between the federal R&D subsidies and TFP growth in manufacturing industries on the present data, the total intramural R&D expenditures were split into two parts. The privately financed R&D and the R&D financed by federal grants were both expressed relative to the industry's sales as PRIV and FED respectively. Since the federal grants to R&D do not identify whether they were used for process or product innovation, it was not possible to test this dimension on the present data.[33]

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to interindustry purchases of goods and services from Canada and from abroad, the latter weighted by imports of the high-technology inputs and capital goods.

[32] The fiscal cost of tax exemptions related to R&D is not included in the analysis.

[33] The Statistics Canada data on federal R&D grants were, for some years, not available at all or were aggregated to preserve the confidentiality of reporting companies. On the other hand, the data for several high-tech industries were not collected before 1980, hence the data set is not complete for this period and in a few cases the grants to industries were estimated from a more aggregated figure; the description of data adjustments is available on request.

**Table 4**: *Total factor productivity growth as a function of federal R&D grants*

| Eq. | Period | Const. | D1 | D3 | PRIV | FED | RCINT | $R^2_{adj}$ | n |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1974-89 | -.006<br>(-.18) | .010<br>(2.12)b | .008<br>(1.49) | .004<br>(1.75)c | -.014<br>(-2.04)b | | .165<br>(4.41)b | 70 |
| 2 | 1974-89 | -.001<br>(-.70) | .007<br>(2.42)b | .008<br>(3.10)a | .003<br>(1.86)c | -.038<br>(-1.79)c | | .114<br>(3.43)b | 62 |
| 3 | 1982-89 | -.0005<br>(.14) | | .009<br>(1.78)c | .004<br>(1.79)c | -.021<br>(-2.52)b | | .304<br>(7.12)b | 43 |
| 4 | 1982-89 | -.003<br>(-.74) | | .009<br>(1.67)c | | -.007<br>(-.60) | .047<br>(2.25)b | .113<br>(2.65)c | 40 |
| 5 | 1982-89 | .005<br>(.20) | | .007<br>(2.59)b | .002<br>(.78) | -.018<br>(-.84) | | .100<br>(2.36)c | 38 |
| 6 | 1982-89 | -.002<br>(-.73) | | .007<br>(2.75)b | | -.007<br>(-1.34) | .021<br>(2.10)b | .189<br>(3.87)b | 38 |

Note: The aerospace and computer industries excluded from the sample for equation (2), (5) and (6). The aerospace industry is excluded from the sample for equation (4).

The regressions generally confirm the conclusions of the previous studies. It is not possible to reject the hypothesis that the inter-industry distribution of federal R&D grants is not associated with improvements in total factor productivity. In fact, when all industries are included in the sample, (see Equation (1) for the whole period 1974-1989 and Equation (3) for the 1982-1989 period in Table 4), the conclusion is even more discouraging for taxpayers; federal R&D grants apppear be correlated negatively with productivity improvements when the largest recipient of federal R&D subsidies- the aerospace industry- is included in the sample. It results in a statistically significant negative regression coefficient for the FED variable, while the regression coefficient of private R&D expenditures remains positive and significant (one tail tests). Since the sample does not cover all industries in the 1974-1981 period and the federal grant policies of such a distant past are today of academic interest only, the rest of the regressions were run on the second, more complete half of the sample covering the two recent periods 1982-1985 and 1986-1989. If anything, the results reject even more persuasively the hypothesis of a positive association between the distribution of federal grants and TFP growth.

However, as before, the results are heavily influenced by the two statistical outliers, the computer industry on the positive side and the aircraft industry on the negative side. Another problem is the high multicollinearity between the FED and

PRIV variables and also between FED and spillover proxy variables FURI, RUSED and TUSED, which, for this reason, were excluded from the tests. When the two outliers are excluded from the sample, the regression coefficients of both PRIV and FED variables become statistically insignificant and the correlation disappears. Since the aerospace industry received the major share of federal grants and the computer industry much less, one is tempted to conclude that the evidence should be based on results for the total sample and in this case it is not possible to claim that the distribution of federal subsidies is associated with positive productivity growth. In a purely statistical view of things, the results suggest that when observations of both outlying industries are excluded, neither the private nor the federally-funded R&D expenditures were correlated with TFP growth. However, when the privately financed R&D PRIV is replaced in the equation (4) by the process-related R&D RCINT, the latter variable remains positive and statistically significant and FED remains negative and weakly significant even for the sample excluding the outliers.[34] Thus the present data do not provide evidence that industries that benefited from federal grants were more productive than those that did not. If anything, the results suggest that the less productive industries benefited more from federal R&D support.

## 7. Discussion and conclusion

The theoretical model assumes implicitly that productivity has been growing over time and its increase is mainly a function of advancing productive knowledge. As we have seen, however, the measured total factor productivity of many Canadian manufacturing industries decreased.[35] The trend of productivity growth (the intercept in the estimated equation) was mostly negative in the 1979-81 and 1986-

[34] I am aware that by replacing variable PRIV by RCINT (r=.34) I commit a specification error since RCINT contains an unknown federally subsidized component which leads to double counting. However, this specification error is likely to be smaller than the effects of a strong multicollinearity between PRIV and FED variables (r=.90) for the sample 1974-89 and (r=.72) for the latter half of the period 1982-89. However, the federal grants are not distributed to industries with strong process-related R&D. The correlation between FED and RCINT in 1982-89 was nil (r=-.0009). Since only process-related R&D intensity, RCINT, is correlated with productivity growth, the federal subsidies do not appear to be associated with TFP improvement. A closer look at the data would very likely reveal that the defense-related R&D grants (to aerospace, avionics and electronics etc.) are the culprits, (Pool and Bernard, 1992).

[35] TFP decreased in eight out of 21 industries from 1986 to 1989, in five industries from 1982 to 1985, in eleven industries from 1979 to 1981 and in four industries in the initial 1974-1977 period.

1989 periods. Fluctuations and the short-term evolution of conventionally measured total factor productivity may have little to do with innovation shifting the production possibility frontier assumed in the model. From the theoretical point of view, several hypotheses underlying our approach may be inaccurate: The gross output production function is in reality not separable as assumed in the model; complementarity between primary inputs and R&D exists and the commercial success or failure of an innovation often depend on the availability of complementary assets. Factors may not be paid their marginal product, and factor adjustment is unlikely to be instantaneous and perfect (Bernstein and Mohnen, 1991).

There is also the total factor productivity measurement problem discussed in detail by Griliches (1994) and some specifically Canadian aspects by Sharpe (1990). Price indices, with the exception of the computer industry price index, are not adjusted for quality changes, hence the TFP index is necessarily biased. As Griliches (1994) has shown, if the price indices of other high industries were adjusted for the quality improvements, the TFP -R&D relationship would probably be stronger, both as regards its importance and its statistical significance.

Industrial classification has also an important impact on the statistical tests.[36] As indicated by the generally poorer results of the R&D stock specification than the R&D intensity specification, the hypothesis of a common output elasticity of R&D for all industries is less realistic than that of a common rate of return on R&D. When the sample of industries is split into high and low R&D intensity, the rates of return to process R&D are positive for the former group only. As exceptional behaviour of the computer industry indicates, it is likely that at a less aggregated level, one could also find significant inter-industry differences in the rate of return to R&D, accompanied by differences in the gestation lags both for the direct and indirect R&D.

The declining productivity observed in many industries from 1986 to 1989 is difficult to reconcile with increasing R&D effort. Obviously other forces are involved. The growing competitive pressure makes appropriation of R&D results increasingly difficult, especially in the case of new and improved products; their prices do not reflect quality improvements. Innovation rents are `competed away' by imitators and by an ever increasing arrival of new products. This is probably

[36] Consider, for example, the impact of decomposing the computer industry into several sub-branches. Instead of observing a statistical outlier, there would be a group of industries displaying a stronger and more significant R&D-productivity relationship.

the main reason why the product-related R&D is less correlated with TFP than the process R&D, a finding also reported by Scherer (1982) and Griliches & Lichtenberg (1984). R&D aimed at satisfying ecological and other government regulations is unlikely to show up in increased conventionally measured TFP. The complex issue of social acceptance of new technology and industrial restructuring may reduce or even inhibit the positive impact of innovation on productivity. The list of simplifications intrinsic in the model is long but necessarily incomplete. It points out that one should not expect very significant and robust statistical support for the TFP-R&D link in the short and medium term.

The present study is among the first to document the existence of a statistically significant link between the stock of R&D and TFP in Canadian manufacturing industries. The statistical association improves with longer gestation lag. The elasticity of output with respect to R&D expenditures is about ten percentage points when the computer industry is not included, and about twice as much when it is. Indirect R&D spilled over from other Canadian industries shows up consistenly with an unexpected negative sign.[37] On the other hand, as expected, the R&D `imported' from abroad is correlated positively with TFP growth in the later period. The impact of R&D spillovers from abroad is at best of equal magnitude as that of the direct R&D. It tends to decline to about one half of that size when spillovers are computed using the R&D flow matrix of a more remote period. Present results suggest that even though Canadian manufacturing industries benefit from R&D spillovers from abroad, their magnitude is far less important than that of industry's own R&D. This finding is in contrast to Mohnen's (1992) TFP estimates but consistent with his cost function results.

When the rate of growth of TFP is regressed on R&D intensities in the larger sample of pooled cross-section observations for four periods, results become more robust and interesting. But, as in the first model, they suggest the presence of a measurement problem in TFP variable which does not take into account the price-quality variations in the calculation of TFP. Two outlying observations - the computer and the aerospace industries - influence strongly the size and the statistical significance of the regression coefficient of both R&D spillover stocks. In this regard, the present results point in the same direction as Griliches' conclusions for the US relationship between TFP and R&D intensity. The important impact on regression results of the presence or absence of the computer

[37] The negative sign of the GCU% variable is in part due to multicollinearity between the GCTS% and GCU% variables ()r=.36). A simple regression of the TFP% on GCU% results in a statistically insignificant negative correlation.

industry in the sample suggests that, as in the US (Griliches, 1994), the results of previous studies (both those estimating the TFP and those working with cost functions of Canadian manufacturing industries), might have been influenced strongly by problems of measuring prices. However, the present study shows that the effect of the computer industry is mainly felt with regard to the product-related R&D. The process-related R&D remains a statistically significant determinant of the TFP growth even when the computer industry is excluded. However, its impact on industries with low R&D intensity is uncertain.

Attempts to estimate the total model including with the direct R&D also the two spillover variables suffered from multicollinearity. Estimations of several partial models show, admittedly with some specification error, that both the R&D executed in other Canadian industries and the R&D imported from abroad through intra-firm transfers and spillovers of technology from foreign-owned canadian subsidiaries affect the TFP growth. The distinguishing feature of the present results is however the smaller magnitude of estimated rates of return on both direct and borrowed and imported R&D than those of earlier studies (Ducharme, 1991; Hanel, 1985).[38] Second, in contrast to all former studies which estimated that the R&D borrowed from other industries (Scherer, 1982, Hanel, 1985; Ducharme, 1991) and other countries (Mohnen, 1992) and Coe and Helpman (1993) had a larger impact on TFP than the direct R&D, the coefficients associated with both spillover variables in this study are significantly smaller than the coefficient associated with the direct R&D.

The comparison of our results with those using OECD input-output based proxy for spillovers suggests that the small magnitude of estimated rates of return on spillovers is not related to our choice of patent-based proxies for technology spillovers. Further research may also confirm that the patent matrix is the superior approximation of technology flows for this purpose.

Last but not least, the present study brings additional new evidence that the federal R&D grants have not improved TFP. In fact when the largest beneficiary of federal R&D grants -the aerospace industry- is included in the sample, the portion of R&D financed by federal grants appears with a statistically significant negative regression coefficient.

[38] Both authors used the total R&D intensity and not the process R&D intensity as in the present study.

Future research with company level observations should determine the relationship between the domestic and imported R&D, as well as the impact of R&D grants and tax advantages on R&D and productivity. The present results suggest that the advantage drawn from the access to foreign technology should not be interpreted as an argument to discourage indigenous R&D activity.

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## Appendix 1

| Industries | | | |
|---|---|---|---|
| #1 | Food, beverage, tobacco | 12 | Shipbuilding |
| 2 | Rubber & plastics | 13 | Other transport |
| 3 | Textiles & clothing | 14 | Electronics, communication eqpt. |
| 4 | Wood & furniture | 15 | Computers & office eqpt. |
| 5 | Paper & printing | 16 | El. machinery |
| 6 | Ferrous metals | 17 | Stone, clay, glass |
| 7 | Non-ferrous metals | 18 | Petroleum refining |
| 8 | Fabricated metal prod. | 19 | Pharmaceuticals |
| 9 | Non el. machinery | 20 | Chemicals |
| 10 | Aerospace | 21 | Instruments* |
| 11 | Motor vehicles | 22 | Other manufacturing |

Note: TFP is not available for Instruments, hence this observation is included in spillover calculations but not in the TFP regressions.

## Summary statistics

| Variable | Period | Mean | St. deviation |
|---|---|---|---|
| AG | 1974-79 | .0098 | .013 |
| annual | 1979-81 | .0026 | .021 |
| | 1981-85 | .0114 | .023 |
| | 1985-89 | .0034 | .015 |
| R&D intensities | | | |
| RCINT | 1974-77 | .1196 | .132 |
| (%) | 1978-81 | .1304 | .147 |
| | 1982-85 | .1599 | .161 |
| | 1986-89 | .1667 | .159 |
| RDINT | 1974-77 | 1.437 | 2.53 |
| (%) | 1978-81 | 1.611 | 2.81 |
| | 1982-85 | 2.328 | 4.32 |
| | 1986-89 | 2.288 | 4.01 |
| Spillover intensity | | | |
| CAUI | 1973-76 | .191 | .366 |
| (%) | 1977-81 | .185 | .317 |
| | 1982-85 | .287 | .469 |
| | 1986-89 | .287 | .469 |
| FURI | 1973-76 | 1.98 | 3.89 |
| (%) | 1977-81 | 1.58 | 2.91 |
| | 1982-85 | 1.62 | 2.81 |
| | 1986-89 | 1.62 | 2.81 |