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Three Essays on International Trade and Technology Spillovers

Rashid Nikzad

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Acceptance

Dedications

This thesis is dedicated to
My dear wife, Golnaz
and
My parents, Mahmoud and Parvin

Table of Contents

List of Tables and Figures

Chapter 1

Chapter 2

Chapter 3

GLOSSARY

Chapter 1

β_d	domestic spillovers
β_f	foreign spillovers
c_d	unit cost of production of the domestic firm
c_f	unit cost of production of the foreign firm
CS	domestic consumer surplus
π_d	domestic profit
π_f	foreign profit
p	price
s_d	domestic R&D subsidy
s_f	foreign R&D subsidy
t	tariff
W_d	domestic welfare
W_f	foreign welfare
x_d	domestic R&D
x_f	foreign R&D
y_d	domestic output
y_f	foreign output

Chapter 2

i	industry index, $i = 1, \ldots, 14$
t	time index, $t = 1978, \ldots, 1998$
α_i	industry effect
α_t	time effect
α_d^w	impact of the R&D of each industry in itself
α_d^t	impact of the R&D of other industries
α_f^w	impact of the foreign R&D of each industry in itself
α_f^t	impact of the foreign R&D of other industries
α_f^L	impact of the foreign R&D of Low-Tech industries
α_f^M	impact of the foreign R&D of Medium-Tech industries
α_f^H	impact of the foreign R&D of High-Tech industries
w_{ij}	input-output coefficients from industry i to industry j
M_{jkt}	country's imports from industry j in country k

X_{jkt}	country's exports of industry *j* in country *k*
FRD_{it-1}	foreign R&D stock in industry *i* at time *t-1*
RD_{it-1}	domestic R&D stock in industry *i* at time *t*-1
TFP_{it}	total factor productivity of industry *i* at time *t*

Chapter 3

i	industry index, $i = 1, \ldots, 14$
j	country index, $j = 1, \ldots, 11$
t	time index, $t = 1997, \ldots, 2003$
d_i	industry effect
λ_t	time effect
w_{ikt}	share of patents of industry *i* that are used in industry *k* at time *t*
Patent	number of patent applications of country *j* in Canada in industry *i* at time *t*
$ForPatent_{ijt}$	number of foreign patents produced by industry *i* of country *j* at time *t*
$Trade_{ijt}$	imports of Canada in industry *i* from country j at time *t*
FDI_{jt}	foreign direct investment from country j in Canada at time *t*
$Dist_j$	square of distance between Ottawa and the capital of country *j*
GDP_{it}	output of industry *i* of Canada at time *t*
RD_{it}	R&D intensity of industry *i* at time *t*
CIPO	Canadian Intellectual Property Right
EPO	European Patent Office
FDI	Foreign direct investment
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
IOM	Industry Of Manufacture
SOU	Sector Of Use

Abstract

This dissertation studies technology spillovers between countries. The dissertation consists of three chapters. The first chapter is a theoretical model that studies the impact of tariffs in the presence of R&D spillovers. The second chapter is an empirical model on the impact of spillovers through trade on productivity. The third chapter is also an empirical model on the determinants of foreign patents in a country.

In the first chapter, we study the impact of tariffs on R&D expenditures when there are R&D spillovers between firms. The firms are located in the home and foreign countries and compete in the home country's market. We consider a three-stage game, where the government determines the amount of the tariff in the first stage, firms choose their R&D expenditures in the second stage, and outputs are determined in the third stage based on Cournot competition. We show that if the foreign government gives an R&D subsidy to the foreign firm, foreign R&D will increase and the domestic firm's profit and domestic welfare will decrease. However, domestic consumer surplus will increase. The home country can recover this profit and welfare loss, partially or totally, if it uses two policy instruments simultaneously: a tariff and an R&D subsidy.

The second chapter studies the impacts of domestic and international technology spillovers on the growth rate of Canadian manufacturing industries. In this chapter, we examine whether different types of industries have different technology spillover rates. To test these hypotheses, Canadian industries are categorized into three groups based on their characteristics as low-tech, medium-tech, and high-tech. According to the empirical results, only foreign R&D has a positive and significant impact on productivity. Domestic R&D is not significant under any of the specifications; however, it helps industries absorb foreign R&D.

The third chapter estimates the diffusion rate of foreign technology into Canadian industries at the industry level by using patent data. The results of this chapter suggest that the patent activity of foreign countries is the most important factor for receiving foreign patents in Canada. Moreover, imports and foreign direct investments are important vehicles for technology transfer. The distance between countries has a negative impact on receiving foreign patents. The impacts of R&D intensity and human capital on receiving foreign patents are mixed and insignificant, but industries with a higher R&D intensity may be better recipients of foreign patents.

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INTRODUCTION

This dissertation studies technology spillovers between countries. The dissertation consists of three chapters. The first chapter is a game theorety model that studies the impact of tariffs in the presence of R&D spillovers. The second chapter is an empirical model on the impact of spillovers through trade on productivity. The third chapter is also an empirical model on the determinants of foreign patents in a country. Chapters one and two assume that most of the interactions between countries are through international trade. Chapters two and three focus on Canada for the empirical study.

In the first chapter, we study the impact of tariffs on R&D expenditures when there are R&D spillovers between firms. The firms are located in the home and foreign countries and compete in the home country's market. We consider a three-stage game, where the government determines the amount of the tariff in the first stage, firms choose their R&D expenditures in the second stage, and outputs are determined in the third stage based on Cournot competition. We show that if the foreign government gives an R&D subsidy to the foreign firm, foreign R&D will increase and the domestic firm's profit and domestic welfare will decrease. However, domestic consumer surplus will increase. The home country can recover this profit and welfare loss, partially or totally, if it uses two policy instruments simultaneously: a tariff and an R&D subsidy. For certain levels of R&D spillovers, it is optimal for the home country to encourage imports through a negative tariff.

The second chapter studies the impacts of domestic and international technology spillovers on the growth rate of Canadian manufacturing industries. In this chapter, we examine whether different types of industries have different technology spillover rates.

To test these hypotheses, Canadian industries are categorized into three groups based on their characteristics as low-tech, medium-tech, and high-tech. According to the empirical results, only foreign R&D has a positive and significant impact on productivity. Domestic R&D is not significant under any of the specifications; however, it helps industries absorb foreign R&D.

The third chapter estimates the diffusion rate of foreign technology into Canadian industries at the industry level by using patent data. The results of this chapter suggest that the patent activity of foreign countries is the most important factor for receiving foreign patents in Canada. Moreover, imports and foreign direct investments are important vehicles for technology transfer. The distance between countries has a negative impact on receiving foreign patents. The impacts of R&D intensity and human capital on receiving foreign patents are mixed and insignificant, but industries with a higher R&D intensity may be better recipients of foreign patents.

Chapter 1

Trade Policy and Innovation Policy with Asymmetric R&D Spillovers

Abstract

In this chapter, we study the effect of tariffs on R&D expenditures when there are R&D spillovers between firms. The firms are located in the home and foreign countries and compete in the home country's market. We consider a three-stage game, where the government determines the amount of the tariff in the first stage, firms choose their R&D expenditures in the second stage, and outputs are determined in the third stage based on Cournot competition. Firms can choose their optimal R&D expenditures in the second stage cooperatively or noncooperatively. In this regard, we consider three cases: (i) non-cooperation, where there is no R&D cooperation; (ii) R&D cartelization, where firms coordinate their R&D expenditures; and (iii) RJV cartelization, where firms coordinate their R&D expenditures and there is also full information sharing. The objective of the government is to maximize welfare. Also, we analyze how spillovers affect the equilibrium.

We extend the model to study the effect of a foreign R&D subsidy and a domestic R&D subsidy. We show that if the foreign government gives an R&D subsidy to the foreign firm, foreign R&D will increase and the domestic firm's profit and domestic welfare will decrease. However, domestic consumer surplus will increase. The home country can recover this profit and welfare loss, partially or totally, if it uses two policy instruments simultaneously: a tariff and an R&D subsidy. For certain levels of R&D spillovers, it is optimal for the home country to encourage imports through a negative tariff.

1- Introduction

R&D investments play an important role in increasing the productivity of firms at the micro level and the growth rate of a country. Therefore, studying the R&D behavior of firms has become an important issue in the recent industrial organization literature. R&D is particularly critical for firms' competitiveness when they compete on the international stage. Governments can leverage their firms' competitive position through various innovation and trade policy instruments. In that context, interactions between trade policy and innovation policy are important. This paper studies this interaction in the context of international R&D competition and collaboration, with asymmetric R&D spillovers between countries and the possibility of imposing a tariff to protect a domestic firm.

The present work extends the literature on trade policy and innovation policy in several ways. First, it is the first paper to allow for bidirectional spillovers, i.e. from the domestic to the foreign producer and vice-versa. Second, the paper allows for asymmetric spillovers between the two countries. This will allow us to explore the effect of each spillover (from the domestic to the foreign country, and vice-versa) separately. Third, both firms are allowed to invest in R&D. Most previous works have assumed that only the domestic producer invests in R&D, and that the foreign firm is a passive exporter.

The structure of the paper is as follows. The next section reviews the literature on this topic. Section 3 presents the model. In section 4, the model is solved and the results are presented. Section 5 studies the case where the foreign government supports the foreign firm by means of an R&D subsidy. Section 6 assumes both governments give

R&D subsidies to their firms. Section 7 studies the special case where spillovers are very low or very high. Section 8 concludes.

2- Literature review

Many studies have analyzed R&D investments in the presence of international R&D spillovers. The classical paper by Spencer and Brander (1983) uses a three-stage model to study government support for R&D. In their paper, the government subsidizes R&D activities of domestic firms to increase welfare. Domestic firms are competing with foreign firms to obtain a larger share of the international market. They show that in the absence of export subsidies, national governments have an incentive to subsidize R&D. Reitzes (1991) compares the effects of tariffs and quotas in a two-stage Cournot duopoly. He shows that a quota results in higher domestic profit, less output, and less R&D expenditure than a tariff. Also, he concludes that a quota and a tariff usually have opposite effects on domestic R&D expenditures.

Hwang, Kou and Mai (1997) examine how an importing country's government sets an optimal tariff policy to maximize domestic welfare, where each foreign firm can use a low cost or a high cost technology, and the government can choose between a uniform tariff and a discriminatory tariff. Zigic (1998) analyzes the change in the optimal tariff in the case where trade between one North Country (a developed country) and one South Country (a developing country) exists. The author assumes that there exist spillovers from the North to the South; he emphasizes the interaction between tariffs and spillovers, together with its consequences for the social welfare of the North. The Northern firm is the only one assumed to conduct R&D. Qiu and Tao (1998) derive a noncooperative optimal policy towards international R&D cooperation by considering collaboration and coordination of R&D between two firms. Under collaboration, domestic and foreign firms share the benefit of their R&D investments. Under coordination, the two firms coordinate their R&D expenditures to reduce R&D overinvestment. Each firm chooses its R&D investment to maximize a weighted sum of both firms' profits.

D'Aspremont and Jacquemin (1988, 1990) study R&D cooperation in a two-stage model where there exist R&D spillovers between firms. Kamien and Zang (2000) use a three-stage game to show that both the R&D approach and the R&D budget of a firm affect the ability of the firm to absorb the R&D spillovers of other firms. Neary and Leahy (2002) consider an infinite period oligopoly model to develop an optimal trade and industrial policy. They study the implications for strategic trade and industrial policy of allowing firms to make commitments in advance. Though it is generally assumed in the literature that free trade is the best choice for domestic consumers, Kabiraj and Marjit (2003) conclude that under some circumstances a restrictive trade policy may induce the foreign firm to transfer its superior technology to the domestic firm, which could increase welfare. A similar result is found in Kabiraj and Marjit (1993). Muller and Schnitzer (2003) model an international joint venture between a multinational enterprise and a host country firm to analyze the effects of spillovers on the transfer of technology and on the host country's policy.

Mattoo, Olarreaga, and Saggi (2004) study the relationships between mode of entry, technology transfer, and market structure. For this purpose, they develop a model where a foreign firm can choose between two modes of entry: the firm may either establish a new wholly owned subsidiary or buy one of the existing domestic firms. Atallah (2005a) analyses R&D cooperation with asymmetric spillovers. He shows that whereas with symmetric spillovers cooperation is always beneficial to firms, with asymmetric spillovers only a very limited range of spillovers makes cooperation beneficial to both firms. Atallah (2005b) analyzes R&D cooperation when firms have different levels of spillovers, focusing on RJV cartelization, where firms coordinate R&D expenditures and share their research results. DeCourcy (2005) uses a three-stage game with R&D spillovers, in which each government can choose a particular R&D cooperative arrangement. There are four firms in this model, two in the home country and two in the foreign country. All four firms produce the same homogenous good. There is no tariff on goods between the two countries. Also, R&D spillovers among firms are symmetric. In his model, the government of each country chooses a type of cooperative R&D to maximize national welfare. Liao (2008) investigates the effects of R&D spillovers on the R&D choices of foreign exporters in the presence of tariffs imposed by the importing country in a four-stage, one-shot noncooperative game. By comparison free trade with the tariff regimes, he concludes that there are situations in which both the importing country and foreign exporters are better off under free trade.

It is worth mentioning the rationale behind R&D cooperation between firms and the role of technology spillover at this point. Over the last two decades, the number of inter-firm R&D cooperation agreements has increased and the share of individual R&D has decreased in most industries (Tao and Wu, 1997). Cooperative R&D may internalize externalities and help small and medium companies benefit from economies of scale.

Governments may consider cooperative R&D as a possible solution to underinvestment in R&D.

Kamien et al. (1992) cite three types of R&D cooperation. The first type is a R&D cartel where firms choose R&D to maximize their joint profit. The second type is a research joint venture where the results of R&D are fully shared; however, R&D is determined such that each firm maximizes its own profit. The third type is a research joint venture cartel where firms choose R&D to maximize joint profit, and the results of R&D are also fully shared.

Nakamura, Nelson, and Vertinsky (2003) state the following reasons for firms to get involved in cooperative R&D:

- Internalizing externalities;
- Reducing their R&D cost through collaboration, e.g. by sharing their limited resources or enjoying economies of scale;
- Obtaining expertise and information in a specific area that they lack or is very costly to acquire;
- Coordinating strategies, e.g. to gain access to markets they would otherwise be unable to enter or to improve the position of domestic firms relative to foreign competitors in international markets;
- Sharing the risk of unsuccessful R&D.

There are a number of ways firms can arrange their cooperative R&D (Nakamura, Nelson, and Vertinsky, 2003):

- *Short-term contracts*, which minimize risk and the possibility of opportunism. These contracts are difficult to write when there are great uncertainties in the future;
- *Long-term contracts*. These contracts allow modifications in the process of R&D through time. They are used when large R&D investments are made;
- *Relational-contracting*. These contracts are used when there is more uncertainty. These contracts are difficult to monitor and enforce;
- *Research joint ventures and Consortia*. Link and Bauer (1989) define a Research Joint Venture (RJV) as the formation of a new unit, which is jointly controlled by at least two firms and performs R&D. In research consortia, firms jointly fund research in which they may or may not have equal shares. RJVs have high monitoring costs and are subject to principal-agent problems.

Steensma and Corley (2000) study three types of R&D collaboration between firms: acquisition, joint development, and licensing. These three types of collaboration are decreasing in order of interdependence. They conclude that acquisition is more likely to be used when the R&D output is more unique, less imitable, and more certain. On the other hand, firms will use licensing when there is uncertainty and they want to reduce their commitment.

An important question in R&D activities is the source of R&D or the mechanisms through which R&D can be enhanced. It is generally agreed that foreign R&D is an important source of productivity growth. This is especially true for the countries that do not perform enough R&D. The growth of these countries may heavily depend on how well they can gain the R&D results produced in other countries. The characteristic of a particular R&D product and the means to appropriate its value will determine the magnitude of the spillover. For example, the spillover can be very large if the R&D product is easily copied, or it can easily be available to competitors when protection rights are weak.

Saggi (2002) summarizes the following channels for R&D spillovers through multinational firms:

- *Demonstration effect*: Local firms may adopt technologies introduced by multinational firms through imitation or reverse engineering;
- *Labor turnover*: Workers trained or previously employed by the multinational may transfer important information to local firms by switching or may contribute to technology diffusion by starting their own firms;
- *Vertical linkages*: Multinationals may transfer technology to firms that are potential suppliers of intermediate goods or buyers of their own products.

Bernstein and Mohnen (1998) classify the methods of international technology spillover transmission as follows:

- Trade in goods and services;
- Foreign direct investment;
- International alliances between firms, such as licensing agreements and joint ventures;
- International migration of scientists and engineers;
- International communication such as conferences.

A number of studies suggest that international trade is the most important source of technological transfer. For example, Breitschopf and Grupp (2004) suggest that international trade in research intensive goods is the greatest source of innovation in smaller countries because trade can help transmit knowledge internationally. This is the central insight of many open economy growth models. This means the domestic innovation system of many high technology exporting countries depends on the world market, where they receive ideas for further development. However, this assumption has recently been questioned by Keller (1998).

3- Model

This paper uses a three-stage game-theoretic framework with perfect and complete information. There are two firms, a domestic firm and a foreign firm, which compete in the domestic market. Each firm can invest in process innovation to reduce its production costs and improve its competitive position. Such innovations are subject to technological leakages through spillovers. Each unit of R&D by a firm reduces its own cost by one dollar and reduces the cost of each firm in the other industry by β dollars, where $\beta \in [0,1]$. We consider three types of interaction in R&D: no cooperation, R&D cartelization, and RJV cartelization. Under noncooperation, each firm chooses its R&D to maximize its own profits. Under R&D cartelization, firms choose their R&D investments to maximize their joint profits. Under RJV cartelization, firms coordinate their R&D expenditures in addition to sharing their research results.

The unit cost of production of the domestic firm is:

$$c_d = \alpha_d - x_d - \beta_f x_f , \qquad (1)$$

where c is the marginal production cost, and x_d and x_f are the R&D outputs of the domestic and foreign firms. The subscript d stands for the domestic firm's variables and the subscript *f* stands for the foreign firm's variables. The unit cost of production of the foreign firm is:

$$c_f = \alpha_f - x_f - \beta_d x_d . \qquad (2)$$

As x increases, both firms' marginal costs are reduced. Since $\beta < 1$, the reduction of a firm's marginal cost is greater than the reduction in its rival's marginal cost. However, as β increases, the difference gets smaller. Also, the possible asymmetry in spillovers between the two countries is explicitly taken into account: the technology of the domestic firm leaks at the rate β_d, while the technology of the foreign firm leaks at the rate β_f. When the marginal cost of a firm decreases, its output increases and its rival's output decreases. Therefore, when x_i increases, the output of firm *i* also increases. However, the effect of an increase in x_i on the rival's output depends on the value of β_i. For small values of β_i, an increase in x_i will decrease firm *j*'s output, but for large values of β_i, an increase in x_i will lead to a significant decrease in firm *j*'s marginal cost, which may raise its output.

Firms face an inverse demand as follows, where *y* represents output.

$$p = P(y_d, y_f) . \qquad (3)$$

For simplicity, we assume a linear relationship between price and output:

$$p = A - y_d - y_f . \qquad (4)$$

The dollar cost of x units of R&D for firm i is γx^2, and $\gamma > 0$ is a cost parameter. Firms' profits are as follows:

$$\pi_d = (p - c_d) y_d - \gamma x_d^2 , \qquad (5)$$

$$\pi_f = (p - c_f - t)y_f - \gamma x_f^2, \quad (6)$$

where t is the tariff imposed on imports. A tariff has a negative effect on the profit of the foreign firm.

Domestic social welfare, which is equal to the sum of the domestic producer's profits, consumer surplus and the tariff revenues, is given by:

$$W = CS + \pi_d + ty_f, \quad (7)$$

where CS represents consumer surplus and ty_f is the revenue from tariffs. CS is given by:

$$CS = (A - p)\frac{y_d + y_f}{2} = \frac{(y_d + y_f)^2}{2}. \quad (8)$$

Now, we consider the three-stage game. In the first stage, the government chooses the tariff rate to maximize social welfare: **Error! Bookmark not defined.Error! Bookmark not defined.Error! Bookmark not defined.Error! Bookmark not defined.**

$$\underset{t}{Max} \quad W(y_d(t), y_f(t), x_d(t), x_f(t), t). \quad (9)$$

In the second stage, firms determine their R&D expenditures simultaneously given the tariff. Two scenarios are considered for this stage. The first scenario is no cooperation, where each firm chooses its R&D expenditure to maximize its own profit. The problem of the domestic firm in this scenario is as follows:

$$\underset{x_d}{Max} \quad \pi_d(y_d(x_d, x_f, t), y_f(x_d, x_f, t), x_d, x_f, t), \quad (10)$$

and the problem of the foreign firm is:

$$\underset{x_f}{Max} \quad \pi_f(y_d(x_d, x_f, t), y_f(x_d, x_f, t), x_d, x_f, t). \quad (11)$$

The second scenario is R&D cartelization, where firms choose their R&D expenditures to maximize their joint profits. The problem in this scenario is as follows:

$$\begin{aligned}\underset{x_d, x_f}{Max} \quad & \pi_d(y_d(x_d, x_f, t), y_f(x_d, x_f, t), x_d, x_f, t) \\ & + \pi_f(y_d(x_d, x_f, t), y_f(x_d, x_f, t), x_d, x_f, t).\end{aligned} \qquad (12)$$

The rationale for R&D cooperation is to internalize the R&D external effects. This may reduce total R&D expenditures because there will be less wasteful duplication in R&D. RJV cartelization is a special case of R&D cartelization where there is full information sharing ($\beta_d = \beta_f = 1$). In the third stage, firms compete a la Cournot by setting their outputs noncooperatively:

$$\underset{y_d}{Max} \quad \pi_d(y_d, y_f, x_d, x_f, t) \quad (13)$$

$$\underset{y_f}{Max} \quad \pi_f(y_d, y_f, x_d, x_f, t). \quad (14)$$

In this stage, the tariff and the R&D outputs are given. According to this model, each firm has two incentives for R&D investment. Firstly, R&D increases each firm's profit directly by lowering the firm's marginal cost. Secondly, R&D increases the firm's profit indirectly by discouraging the other firm's production. However, when firms cooperate in R&D, each firm may reduce its R&D to mitigate its negative effect on the other firm's profit[1].

To solve this model, we use backward induction. In the third stage, the optimal outputs $y_d^*(x_d, x_f, t)$ and $y_f^*(x_d, x_f, t)$ are obtained by solving the following equations:

$$\frac{\partial \pi_d}{\partial y_d} = 0, \frac{\partial \pi_f}{\partial y_f} = 0. \quad (15)$$

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[1] Qiu and Tao, 1998.

After substituting y_d^* and y_f^* in the profit functions of domestic and foreign firms, we can find the optimal level of R&D investment in the second stage by solving the following equations[1]:

$$\frac{\partial \pi_d}{\partial x_d} = 0, \quad \frac{\partial \pi_f}{\partial x_f} = 0. \quad (16)$$

We assume in this stage that the tariff is given. By solving these equations, we obtain $x_d^*(t)$ and $x_f^*(t)$, which are the optimal level of domestic and foreign R&D investments for any given tariff. If firms are coordinating their R&D expenditures[2], the optimal R&D investments will be obtained by solving the following equations:

$$\frac{\partial(\pi_d + \pi_f)}{\partial x_d} = 0, \quad \frac{\partial(\pi_d + \pi_f)}{\partial x_f} = 0. \quad (17)$$

In the third scenario, firms share information. In this case, the optimal R&D investments are obtained by solving (16) and setting $\beta_d = \beta_f = 1$.

Finally, the government solves the following problem to determine the optimal tariff in the first stage, after substituting for x_d^* and x_f^*:

$$\frac{\partial W}{\partial t} = 0. \qquad (18)$$

4- Solving the model

In this section, we solve the model and study the sensitivity of the solution to parameters. For simplicity, we assign some values to the parameters of the model before analyzing the effect of R&D spillovers on the main variables. We compare the results of

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[1] Since the equations are too long and complicated, we do not show them in the paper.

[2] R&D cartelization.

the three scenarios: no cooperation, R&D cartelization, and RJV cartelization. Since the equations are too complicated to obtain analytical results, we use numerical simulations to compare different cases.

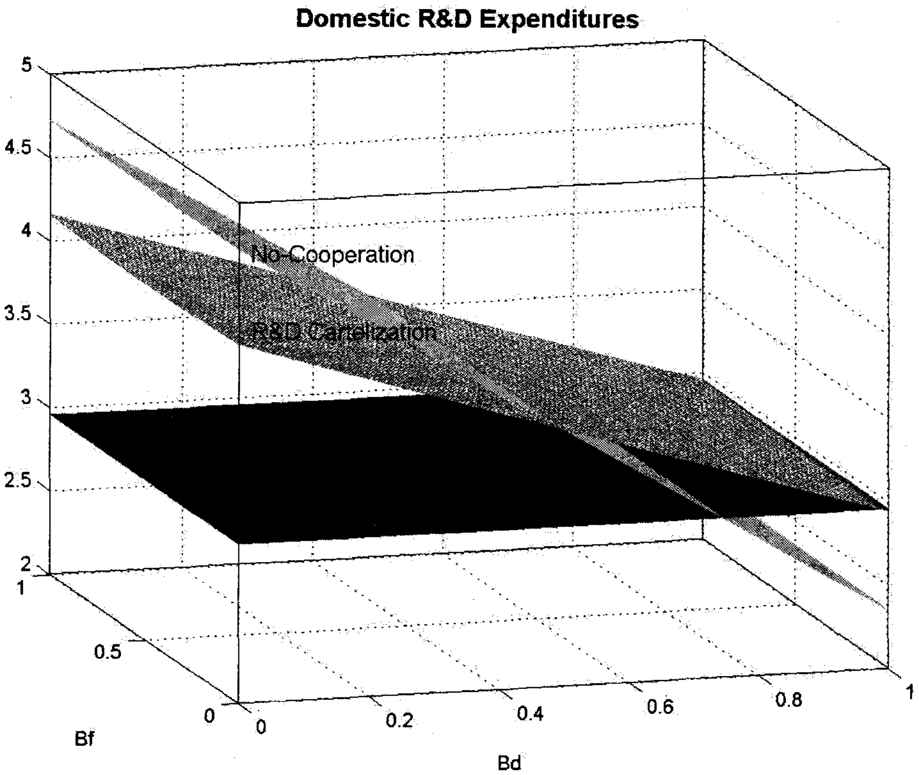
We assign some values to the parameters of the model as follows. We assume $A=1000$, $\alpha_d=\alpha_f=50$, and $\gamma=60$. By simulating the values of the variables of the model, we obtain the following results based on the values of R&D spillovers β_d and β_f. Note that none of the variables under study change with spillovers under RJV cartelization, because in this case $\beta_d=\beta_f=1$. The results of the model are as follows.

i) R&D

Figure 1 presents domestic R&D. The ranking of domestic R&D across the different scenarios depends on β_d, and is largely independent of β_f. For low β_d, domestic R&D is higher under no cooperation. This is due to the well known reduction in duplication that results from R&D cooperation with low spillovers. For high β_d, R&D cartelization yields the highest level of domestic R&D. Curiously, RJV cartelization, which typically yields more R&D, never maximizes domestic R&D. It does yield more R&D than no cooperation for very high values of β_d, but in this range it is dominated by R&D cartelization. Domestic R&D under R&D cartelization is always higher than under RJV cartelization, except when the domestic spillover is very close to 1. These results are independent of β_f.

A notable feature is that domestic R&D declines with β_d under R&D cartelization. This is surprising, given that in this type of model, in the absence of a tariff, domestic R&D would increase with β_d under R&D cartelization, given that firms are cooperating, hence the externality is internalized. This result is due to the presence of the tariff. As it will be shown below, the optimal tariff first increases then decreases with β_d. The increase in the tariff raises the total unit cost of the foreign firm, reduces the value of R&D to the venture, and induces the domestic firm to reduce its R&D. As the tariff declines for higher values of β_d, this improves the competitive position of the foreign firm, increasing its market share, and reducing the R&D of the domestic firm.

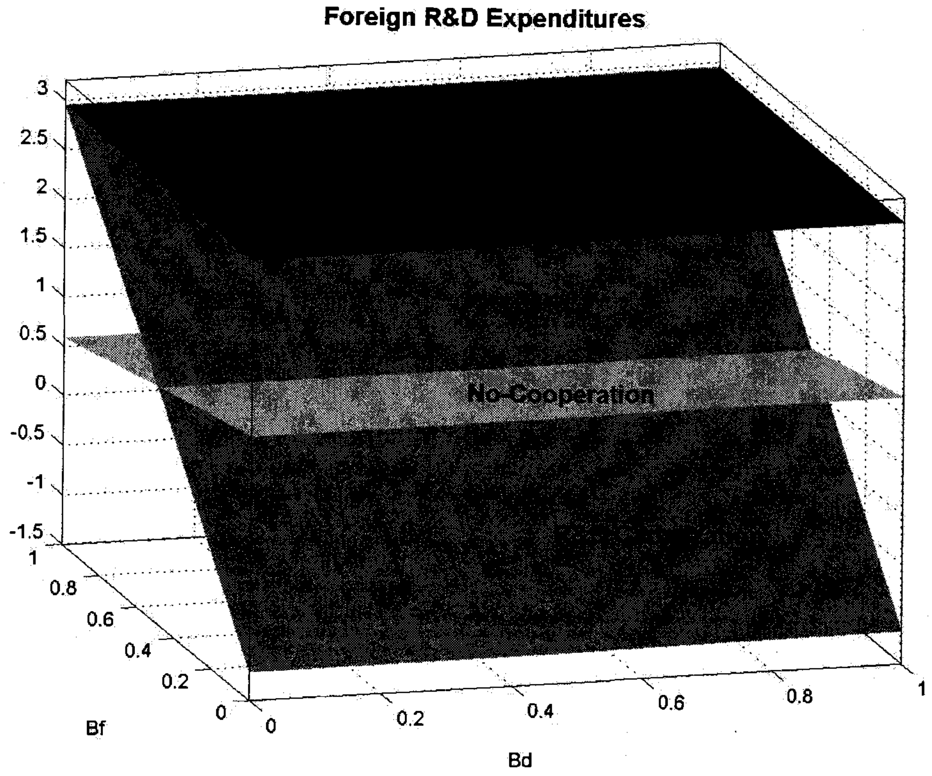
Figure 1- Domestic R&D



Foreign R&D is presented in figure 2. It is highest under RJV cartelization. For high (low) values of β_f, foreign R&D is higher (lower) under R&D cartelization than under no cooperation. These results are independent of the value of domestic spillovers.

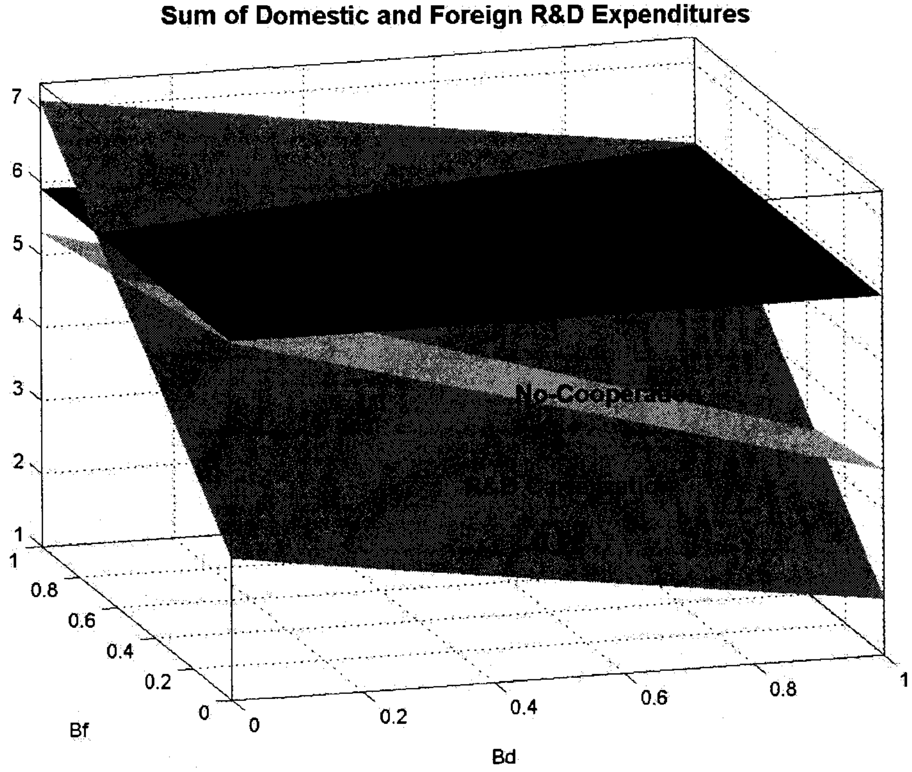
The independence of the rankings of no cooperation and R&D cartelization of the spillover rate of the other firm confirm the results of Atallah (2005b), who shows that in a domestic duopoly, the effect of R&D cartelization on R&D investment by a firm depends only on its own spillover rate.

Figure 2- Foreign R&D



It is interesting to see how total R&D changes under different scenarios. Figure 3 presents the sum of domestic and foreign R&D. As we can see, total R&D is always higher under RJV cartelization than non-cooperation.

Figure 3- Total R&D



ii) Production costs

Figure 4 illustrates the domestic unit cost as a function of spillovers. In general, RJV cartelization yields the lowest domestic cost, except for high β_f where R&D cartelization yields a lower domestic cost because β_f is already high. As we can see, if both domestic and foreign spillovers are low, non-cooperation results in lower domestic unit cost than R&D cartelization. Otherwise, R&D cartelization gives lower domestic unit cost than non-cooperation. The reason is that when spillovers are low and firms do not cooperate, each firm invests in R&D both to reduce its marginal cost and to affect adversely its rival's output and profit. However, when firms cooperate, they may reduce their own R&D in order to reduce its negative effect on the other firm. This means the marginal cost of the firm will be higher. On the other hand, when spillovers are high, a firm not only benefits from its own R&D, but also from the R&D of the other firm, and this may mitigate the negative effect of the other firm's R&D when there is cooperation. Also, RJV cartelization always gives lower domestic unit cost than non-cooperation. RJV cartelization always gives lower domestic unit cost than R&D cartelization unless the foreign spillover is high and the domestic spillover is low.

Figure 4- Domestic unit costs

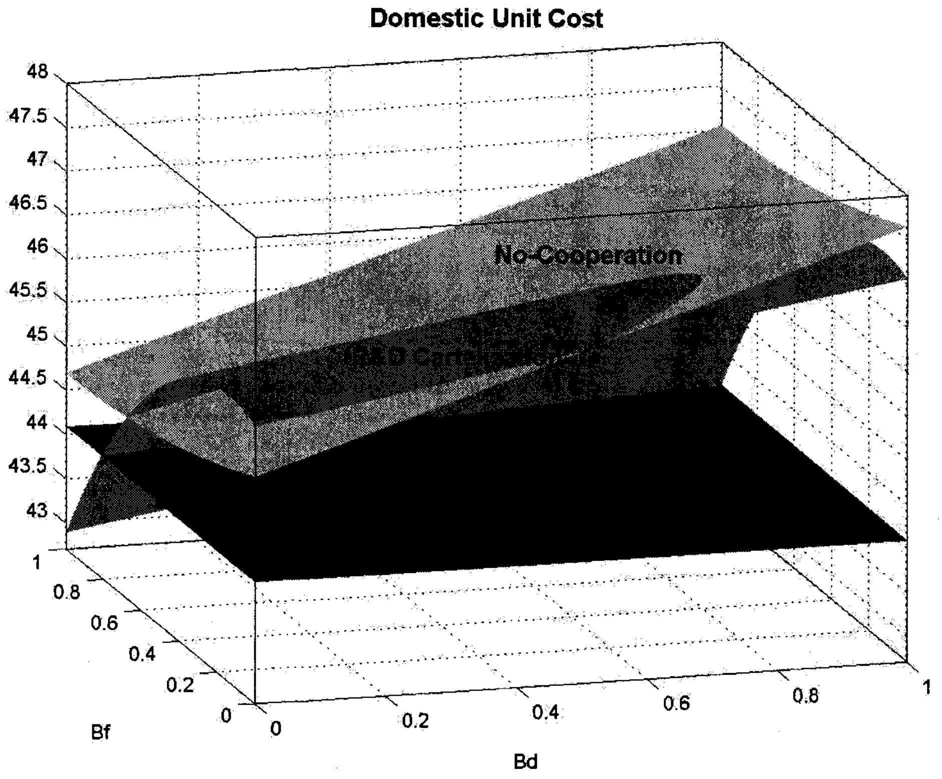
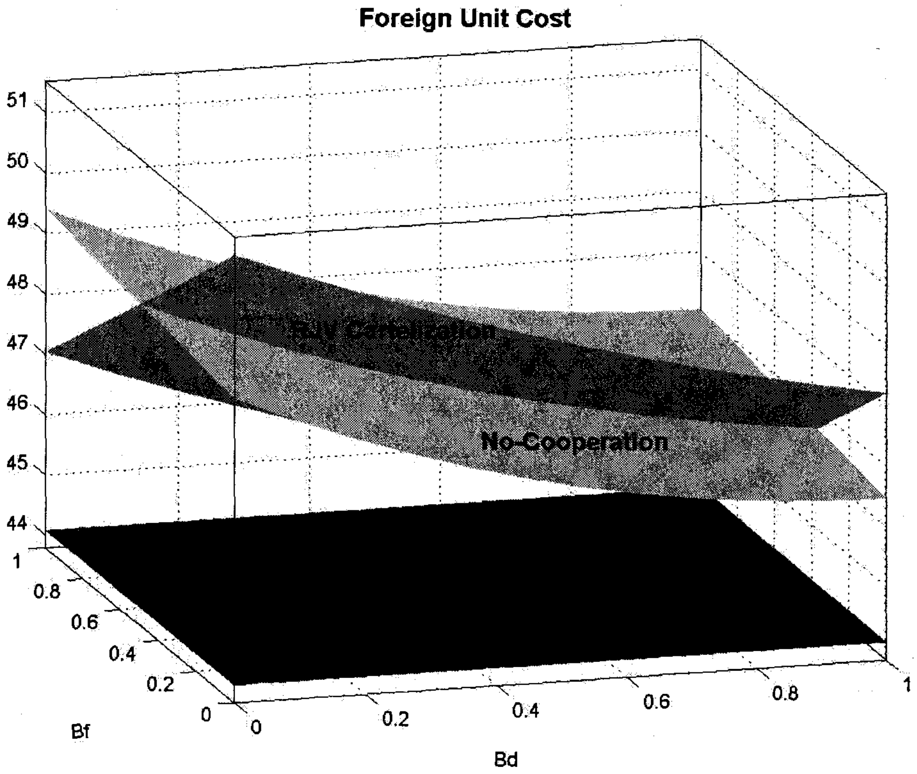


Figure 5 presents changes in the foreign unit cost based on foreign and domestic spillovers. The foreign unit cost is lower under R&D cartelization than non-cooperation when the foreign spillover is high, regardless of the value of the domestic spillover. The foreign unit cost is higher under R&D cartelization than non cooperation when the foreign spillover is low, regardless of the value of the domestic spillover. The foreign unit cost always decreases with the domestic spillover because a higher β_d means that the foreign firm benefits more from the technology of the domestic firm. The different behavior of the domestic and foreign unit costs with respect to spillovers is due to the tariff imposed by the government. The foreign unit cost is always lower under RJV cartelization than under R&D cartelization and non-cooperation.

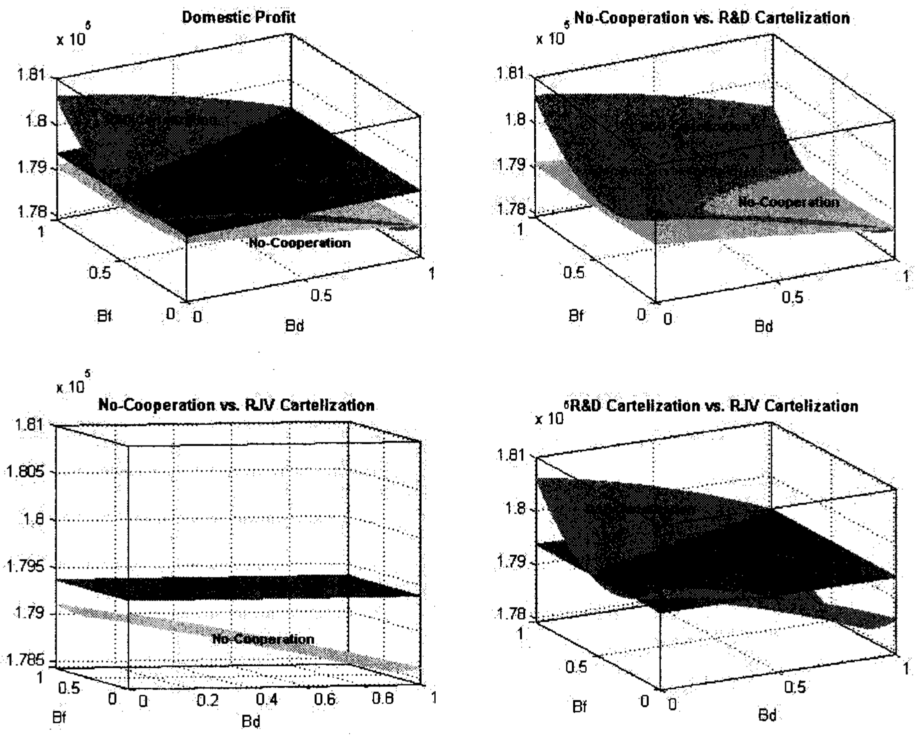
Figure 5- Foreign unit costs



iii) Profits

Figure 6 presents the domestic firm's profit. The domestic firm always earns a higher profit under RJV cartelization than under non-cooperation. Also, its profits are higher under RJV cartelization compared to R&D cartelization unless either the foreign spillover is very high, or both domestic and foreign spillovers are low. The domestic firm's profit is higher under R&D cartelization than under non-cooperation unless the domestic spillover is high and the foreign spillover is not very high.

Figure 6- Domestic firm's profits



iv) Consumer surplus

Figure 7 shows domestic consumer surplus[1]. Consumer surplus is always higher under RJV cartelization than R&D cartelization and non-cooperation. The reason is that the sum of the outputs of the firms yields a higher amount under RJV cartelization.

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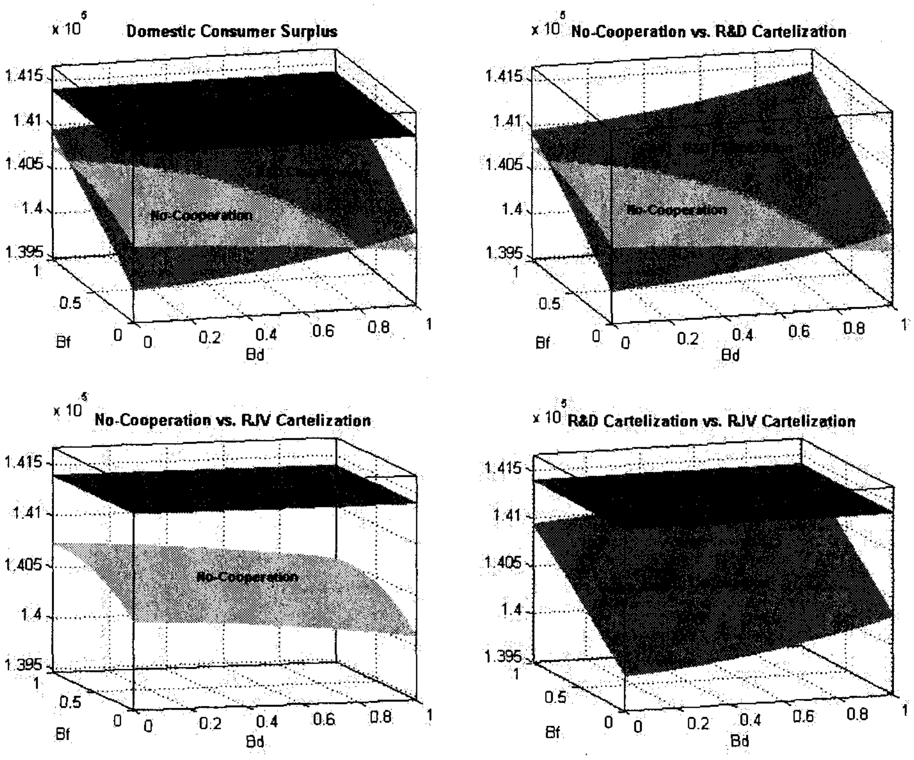
[1] In this and some of the following figures, the first quadrant compares all three scenarios simultaneously, while the three other quadrants compare the scenarios pairwise for more clarity.

Consumer surplus is higher under R&D cartelization if either foreign or domestic spillovers are high, and it is higher under non-cooperation if both foreign and domestic spillovers are low.

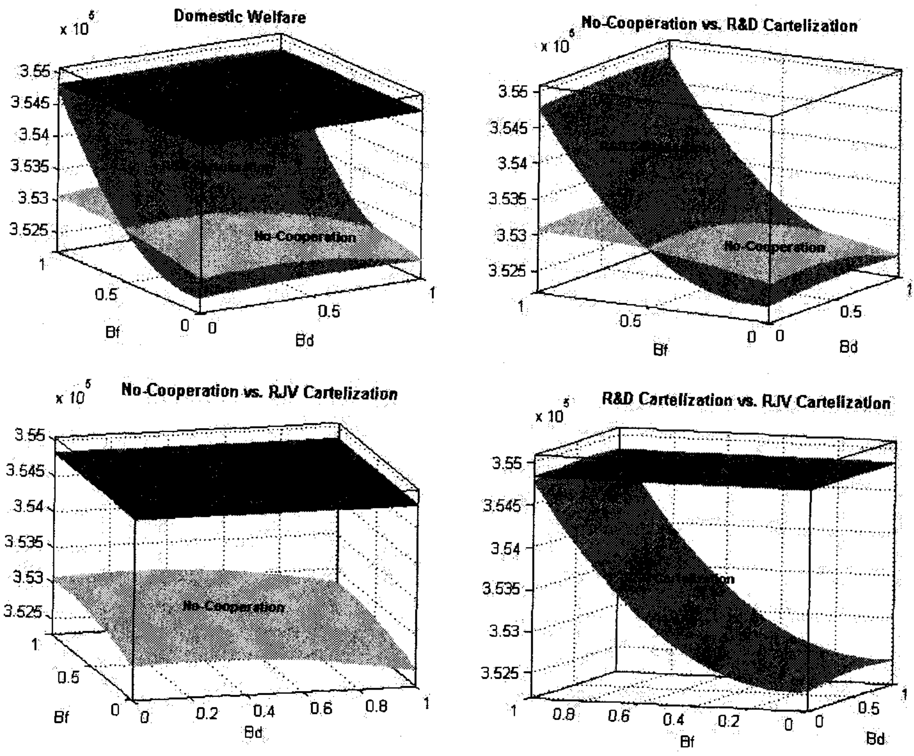
Figure 7- Domestic consumer surplus



v) Welfare

Figure 8 presents changes in welfare based on the changes in domestic and foreign spillovers. Welfare is always higher under RJV cartelization than non-cooperation. Welfare is always higher under RJV cartelization than R&D cartelization, except when the domestic spillover is intermediate and the foreign spillover is close to 1. The reason welfare is higher under RJV cartelization is that there is less waste of resources, and both firms can fully benefit from each other's R&D expenditures. When the foreign spillover is high, welfare is higher under R&D cartelization than under non-cooperation. When the foreign spillover is low, welfare is higher under non-cooperation than under R&D cartelization. These results are independent of β_d. Note that under R&D cartelization welfare is essentially flat with respect to domestic spillovers, but increases steeply with β_f. The reason is that the benefits of the domestic firm increase with β_f.

Figure 8- Domestic welfare



vi) Optimal tariff

The government aims at maximizing total welfare, which is equal to the sum of domestic profits, consumer surplus and tariff revenues. Tariff revenues are negligible relative to the two other components[1]; hence we focus on the tradeoff between consumer surplus and domestic profits. Consumers are better served when most output is produced at the lowest possible cost, which results in a lower price. Domestic profits, however, increase with the market share of the domestic firm, even when it has higher costs than the foreign firm. Hence, when domestic production costs are low, there is complementarity between benefiting consumers and favoring the domestic firm. When the foreign firm becomes relatively efficient, however, there is a conflict between the interests of domestic producers and consumers, and the government may decide to favor one or the other, depending on who gains more from a given policy. This tradeoff explains why the optimal tariff is neither zero nor infinite.

As figure 9 shows, under non-cooperation, the optimal tariff increases with β_d. An increase in β_d induces the domestic firm to reduce its R&D under non-cooperation, which hurts both domestic profits and consumers. To mitigate this effect, the tariff is increasing in β_d, so as to improve the competitive position of the domestic firm, reduce the decline in R&D by the domestic firm, benefiting both the domestic producer and consumers.

At the same time, under non-cooperation, the optimal tariff declines with β_f. As β_f increases, the foreign firm reduces its R&D, which benefits the domestic producer, but hurts consumers. To mitigate the loss to consumers, and mitigate the reduction in R&D by the foreign producer, the government reduces the tariff as β_f increases.

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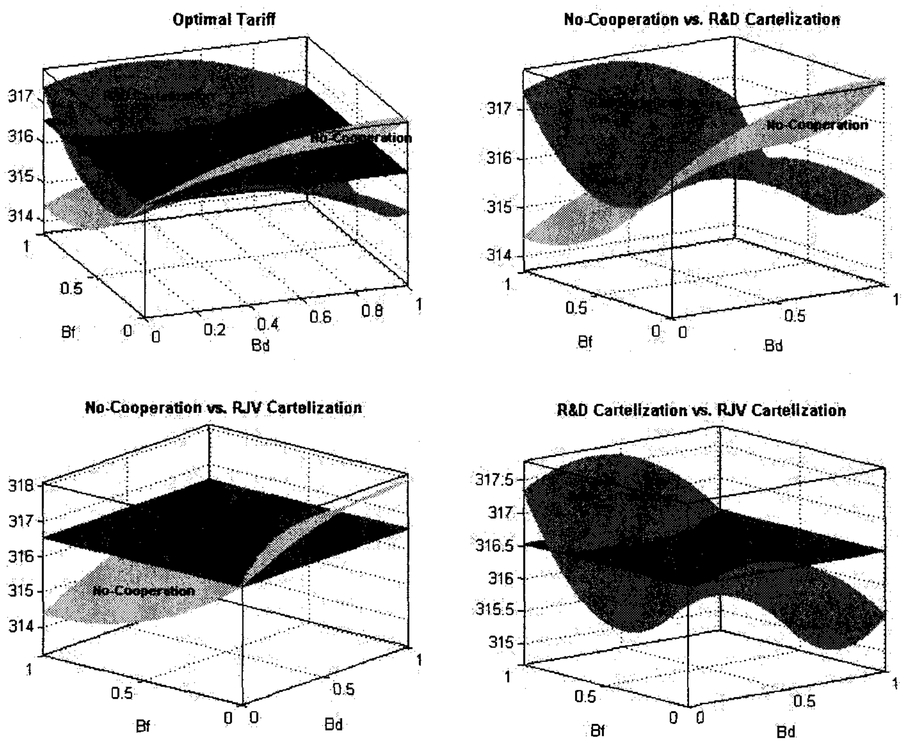
[1] In the numerical simulations used here, tariff revenues represent less than 10% of total welfare.

Figure 9- Optimal tariffs



Under R&D cartelization, the tariff first increases then decreases with β_d. It first increases with β_d to protect the domestic firm: as β_d increases, the domestic firm reduces its R&D investment (see figure 1), the competitive position of the foreign firm improves, and the government responds by helping the domestic firm through an increase in the tariff. As β_d increases further, however, the competitive position of the foreign firm improves significantly, and the gain for consumers from its low cost outweighs the loss to the domestic firm, hence the government reduces the tariff. In contrast, the optimal tariff (under R&D cartelization) first decreases and then increases with β_f. It first decreases with β_f because as β_f increases, the foreign firm increases its R&D,

improving its competitive position; to allow consumers to benefit from this change, the government reduces the tariff. However, as β_f increases further, the competitive position of the domestic firm improves, triggering the government to want to increase its market share, which helps both the domestic firm and consumers; hence the government increases the tariff.

In other words, under R&D cartelization, the optimal tariff increases with β_d when it is low and with β_f when it is high; and it decreases with β_d when it is high and with β_f when it is low. A low β_d or a high β_f imply a favorable position for the domestic firm; the government reinforces this favorable position by increasing the tariff with spillovers in this case. At the same time, a high β_d or a low β_f imply a favorable position for the foreign firm; the government tries to counter this position by increasing the tariff.

Comparing the optimal tariffs under the three scenarios, we see that the tariff is higher under non-cooperation when β_f is sufficiently low and β_d is sufficiently high; in this case the domestic firm is in a strong position, and the high tariff under non-cooperation benefits both the domestic firm and consumers. When β_f is sufficiently high, the tariff is highest under R&D cartelization. In this range $\beta_f > \beta_d$, and the R&D of the foreign firm is high; to limit its market penetration, the tariff is set at a high level. When β_f is intermediate (or β_f is low and β_d is very low), the tariff is highest under RJV cartelization. In this range, the tariff declines sharply with β_f under non-cooperation, and is still going up under R&D cartelization.

5- The effect of a foreign R&D subsidy

In this section, we assume that the foreign government gives an R&D subsidy to support the foreign firm. This can be seen as a protection mechanism aimed at reducing the effect of the tariff imposed by the domestic government. We modify the model of section 3 slightly to include this change. We assume that the government subsidizes the firm based on its R&D outcome. The profit of the foreign firm will change as follows:

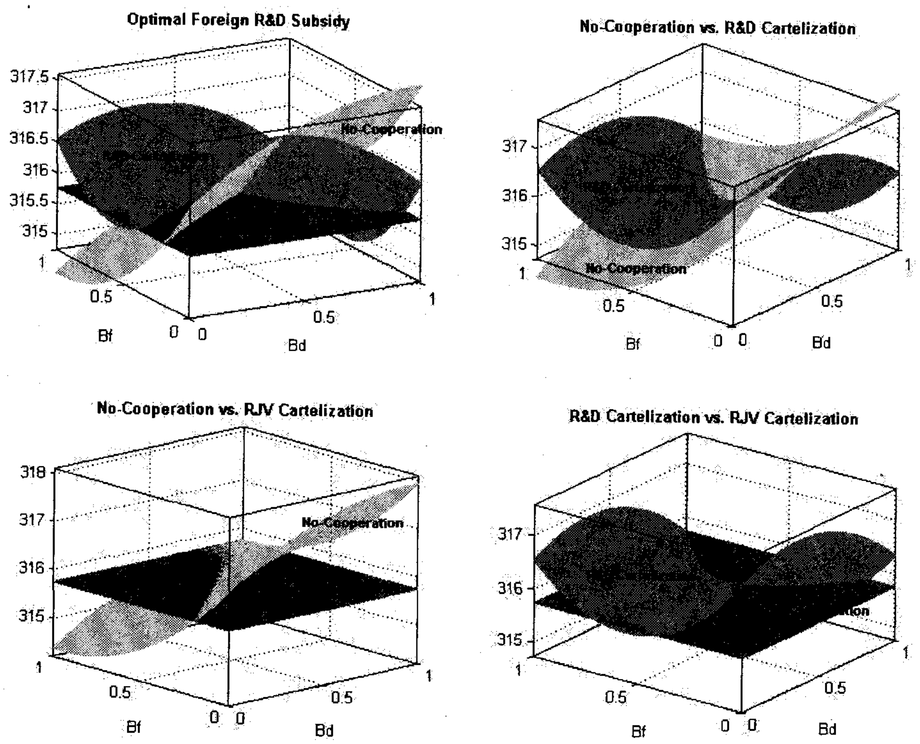
$$\pi_f = (p - c_f - t)y_f - \gamma x_f^2 + s_f x_f,$$

where s_f is the subsidy (or tax if negative) of the foreign country to the R&D of the foreign firm. Also, the welfare of the foreign country will be as follows:

$$W_f = \pi_f - s_f x_f.$$

The rest of the model is as in section 3. The government of the foreign country will set the level of s_f on the foreign firm in the first stage, simultaneously as the domestic government sets the level of the tariff. Given the levels of foreign R&D subsidy and the tariff, the domestic and foreign firms will decide on the level of their R&D, $x_i(s_f, t),\ i = d, f$, in the second stage. R&D can be performed cooperatively or noncooperatively as before. Given the domestic tariff, foreign subsidy, and the levels of foreign and domestic R&D, the firms will compete a la Cournot in the third stage to set their outputs, $y_i(x_d, x_f, s_f, t),\ i = d, f$. We assume the same values for the parameters of A, α_d, α_f, and γ as before. Figure 10 presents the optimal R&D subsidy to the foreign firm.

Figure 10- Optimal foreign R&D subsidy

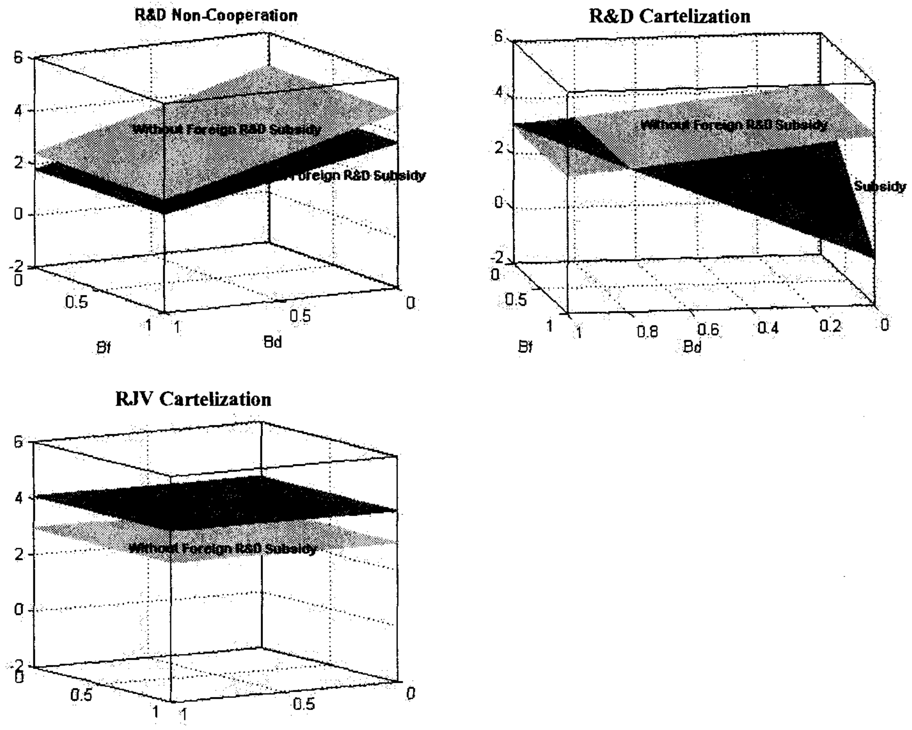


We compare the solutions of this modified model where there exists a foreign R&D subsidy with the previous model where there was no such subsidy. The results are as follows:

i) R&D

Figure 11 compares domestic R&D with and without the foreign subsidy. Domestic R&D under non-cooperation is higher when there is no foreign R&D subsidy, and it is lower under RJV cartelization.

Figure 11- Domestic R&D; foreign R&D subsidy vs. no foreign R&D subsidy

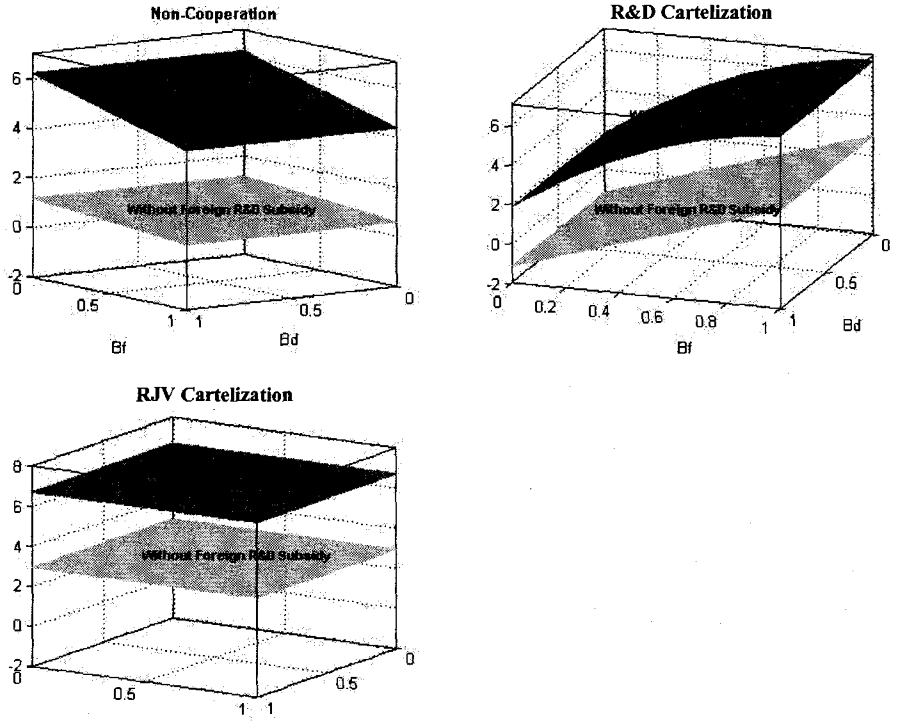

R&D Non-Cooperation

R&D Cartelization

RJV Cartelization

Figure 12 compares foreign R&D between the two models. Foreign R&D is higher in all cases when the foreign government gives an R&D subsidy to the foreign firm.

Figure 12- Foreign R&D; foreign R&D subsidy vs. no foreign R&D subsidy


Non-Cooperation

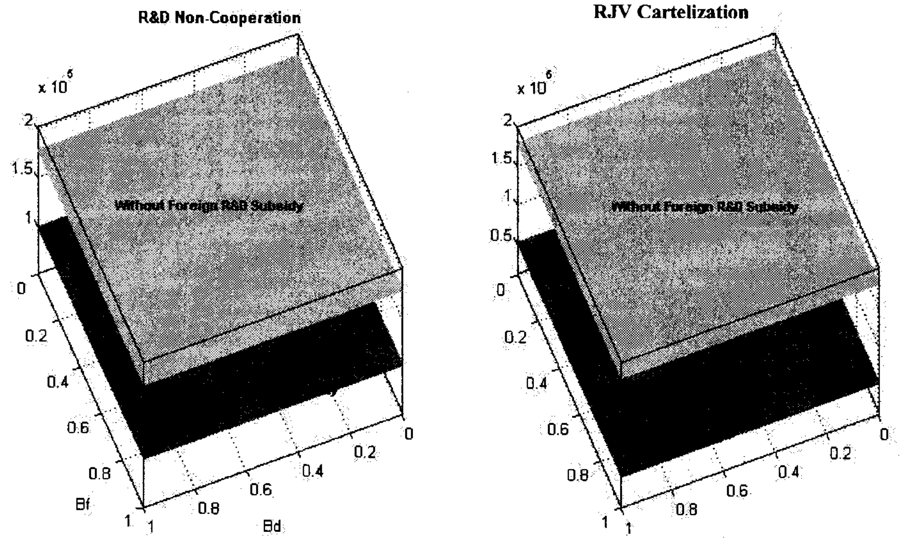
R&D Cartelization

RJV Cartelization

ii) Profits

Figure 13 shows that domestic profit is always lower when the foreign government gives an R&D subsidy to the foreign firm. This is because the foreign firm now has more market power. Under R&D non-cooperation, even though the domestic firm benefits from the R&D of the foreign firm, it reduces its own R&D (see Figure 11), which increases its production costs and reduces its market share. Under RJV cartelization, the domestic firm increases its R&D with the subsidy to the foreign firm. While this increase benefits the foreign firm fully, because of information sharing, the full cost of this increase is borne by the domestic firm, which means its profit decreases.

Figure 13- Domestic profit; foreign R&D subsidy vs. no foreign R&D subsidy

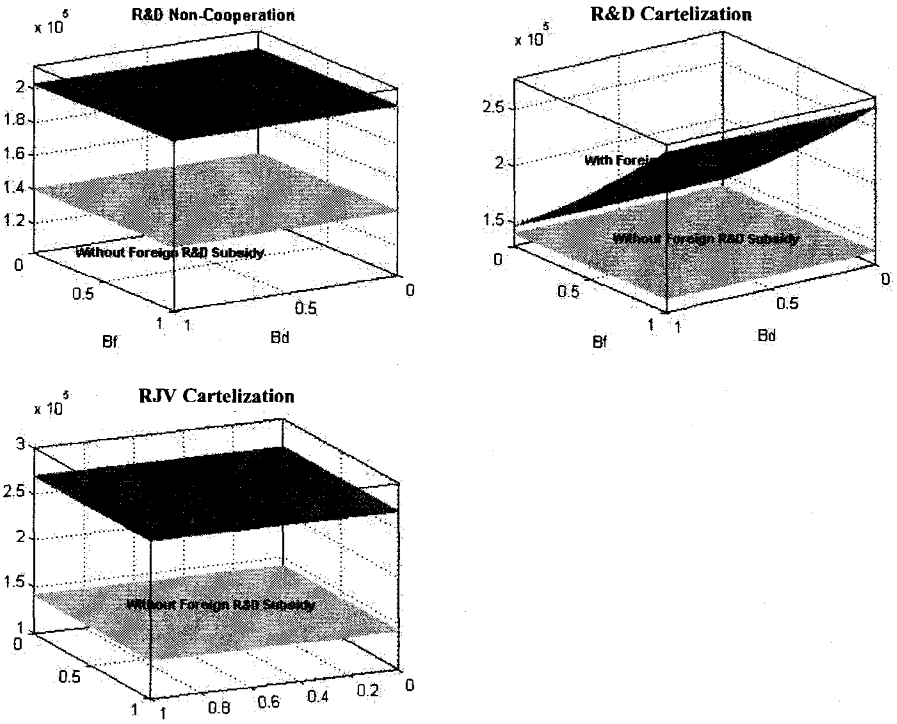

R&D Non-Cooperation

RJV Cartelization

iii) Consumer surplus

Figure 14 shows that domestic consumer surplus is always higher when there is a foreign R&D subsidy. The reason is that the production of the foreign firm increases due to the foreign R&D subsidy and more output is available in the market, and part of this output is produced at a lower cost, which reduces the market price. The foreign R&D subsidy benefits the domestic economy in providing cheaper products, without the domestic economy having to bear the direct cost of this foreign subsidy (only through the reduction of the profits of the domestic firm).

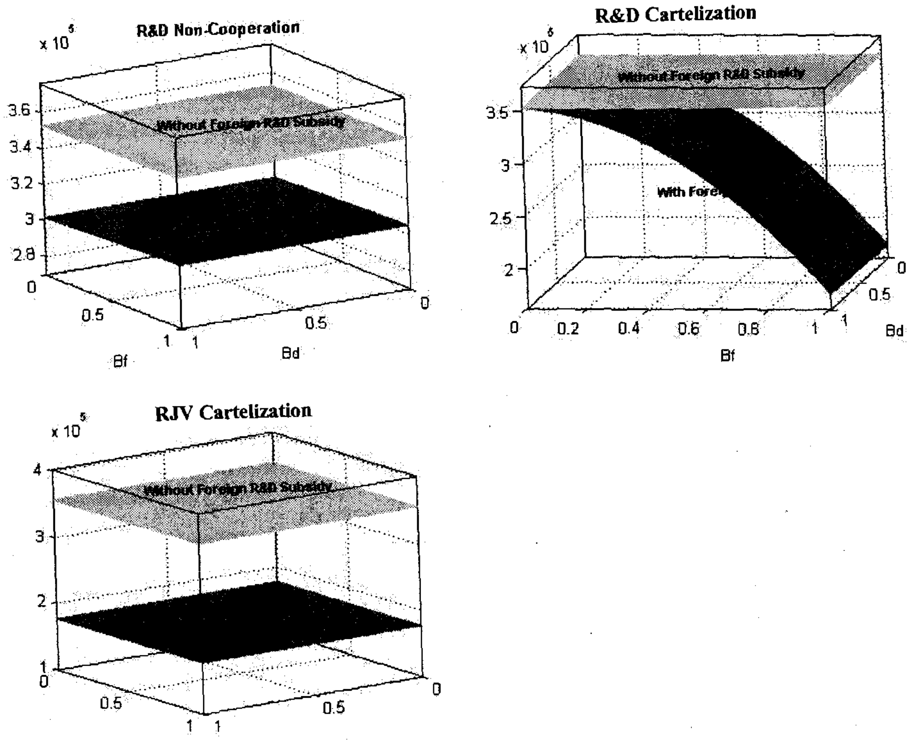
Figure 14- Domestic consumer surplus; foreign R&D subsidy vs. no foreign R&D subsidy



iv) Welfare

Figure 15 suggests that domestic welfare is always higher when the foreign government does not support the foreign firm through an R&D subsidy. The difference is negligible when the foreign spillover is very low. We have two opposite effects when the foreign R&D subsidy is introduced. On one hand, consumer surplus will be higher because consumers enjoy a higher level of production by the foreign firm. On the other hand, there is a reduction in the profit of the domestic firm. These two effects have been shown in figures 13 and 14. Figure 16 suggests that the profit loss outweighs the consumer surplus gain in this case.

Figure 15- Domestic welfare; foreign R&D subsidy vs. no foreign R&D subsidy



R&D Non-Cooperation

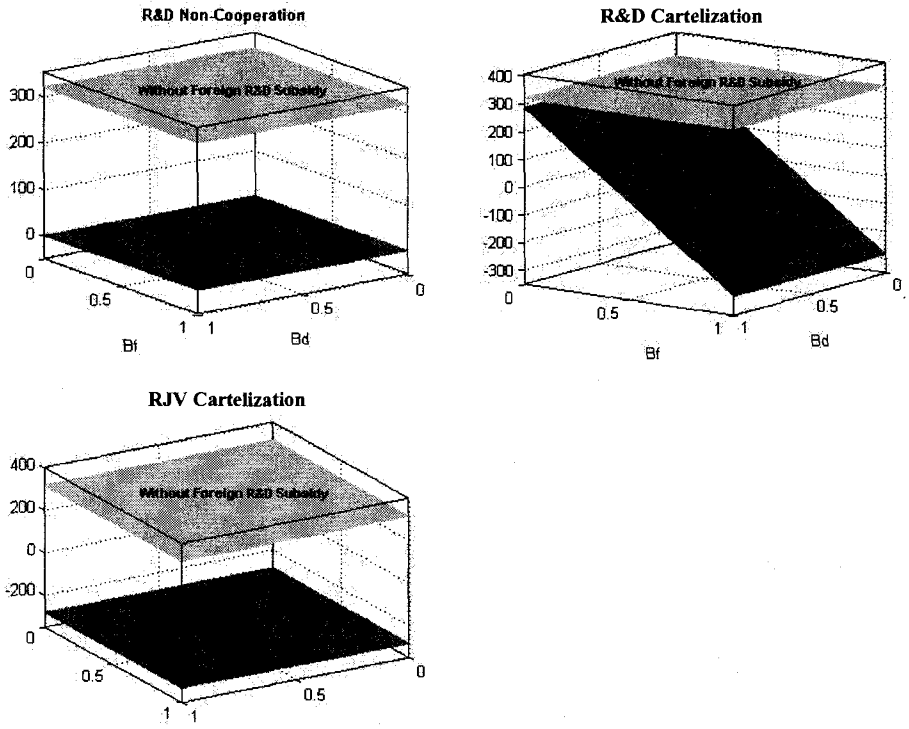
R&D Cartelization

RJV Cartelization

v) Optimal tariff:

The optimal tariff is always higher when there is no foreign R&D subsidy. An interesting result is that the optimal tariff becomes negative when there is RJV cartelization and for a large parameter range under R&D cartelization. This means that the benefit from obtaining higher consumer surplus by importing cheaper goods outweighs the loss of profit of the domestic firm due to imports, as well as the cost of the negative tariff. As a result, it will be optimal for the domestic government to encourage imports. Figure 16 presents the optimal tariff.

Figure 16- Optimal tariff; foreign R&D subsidy vs. no foreign R&D subsidy



6- Domestic and foreign R&D subsidies

It is interesting to see what happens if the home country uses two policy instruments, the tariff and the R&D subsidy, and the foreign country uses one policy instrument, the R&D subsidy, to maximize their welfare. In this section, we will see how the domestic R&D, domestic profit, consumer surplus, and domestic welfare will change. We modify the model of sections 3 and 6 to show these changes. The profit of the domestic firm will be as follows:

$$\pi_d = (p - c_d)y_d - \gamma x_d^2 + s_d x_d ,$$

where s_d is the subsidy of the home country to the R&D of the domestic firm. Also, the welfare of the home country will change as follows:

$$W_d = CS + \pi_d + ty_f - s_d x_d .$$

The rest of the model is as before. In the first stage, the domestic government sets the level of the tariff, t, on foreign output and the level of R&D subsidy, s_d, on the domestic firm. Simultaneously, the government of the foreign country sets the level of R&D subsidy, s_f, on the foreign firm. Given the levels of domestic R&D subsidy, foreign R&D subsidy, and the tariff, the domestic and foreign firms will decide on the levels of their R&D, $x_i(s_d, s_f, t),\ i = d, f$, in the second stage. R&D can be performed cooperatively or noncooperatively as in section 3. Given the domestic tariff, domestic and foreign subsidies, and the levels of foreign and domestic R&D, firms will compete a la Cournot in the third stage, $y_i(x_d, x_f, s_d, s_f, t),\ i = d, f$. We assume the same values for the parameters of A, α_d, α_f, and γ as before.

Figure 17 presents the optimal R&D subsidy to the domestic firm. The R&D subsidy is very low when there is full information. The reason is that when there is full information, R&D subsidy does not increase welfare of the domestic country as much as the situations in which there is no R&D cooperation or there is R&D cartelization.

Figure 17- Optimal domestic R&D subsidy

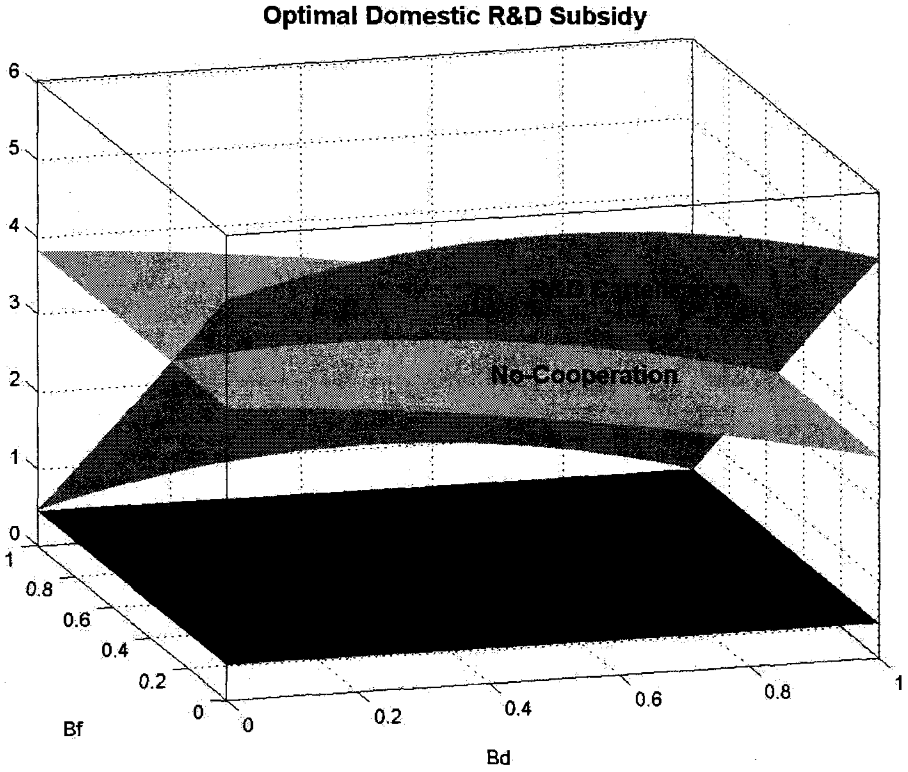
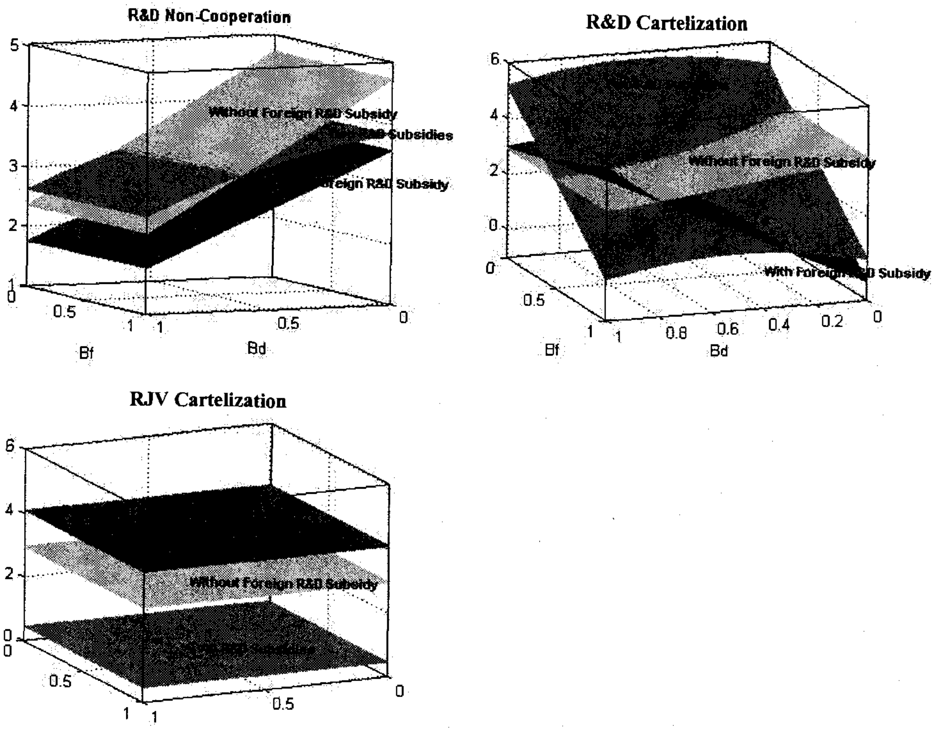


Figure 18 compares domestic R&D under the three scenarios of only domestic tariff (without foreign R&D subsidy); domestic tariff and foreign R&D subsidy (with foreign R&D subsidy); and domestic tariff, domestic R&D subsidy, and foreign R&D subsidy (two R&D subsidies).

Figure 18- Domestic R&D


R&D Non-Cooperation

R&D Cartelization

RJV Cartelization

Figure 19 presents domestic profits under the three scenarios. This figure suggests that the domestic firm may achieve a higher profit if the home country uses an R&D subsidy. As expected, domestic profit is lowest when the foreign firm receives an R&D subsidy. Under RJV cartelization, the domestic firm attains the highest profit when the domestic firm receives the subsidy. Under non-cooperation, the profit of the domestic firm with two R&D subsidies is highest when β_d is high.

Figure 19- Domestic profit

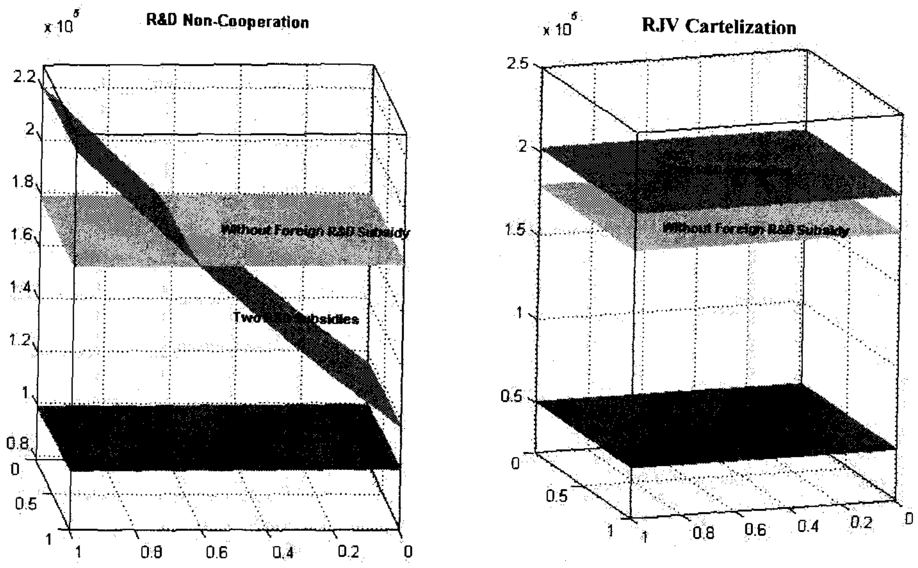
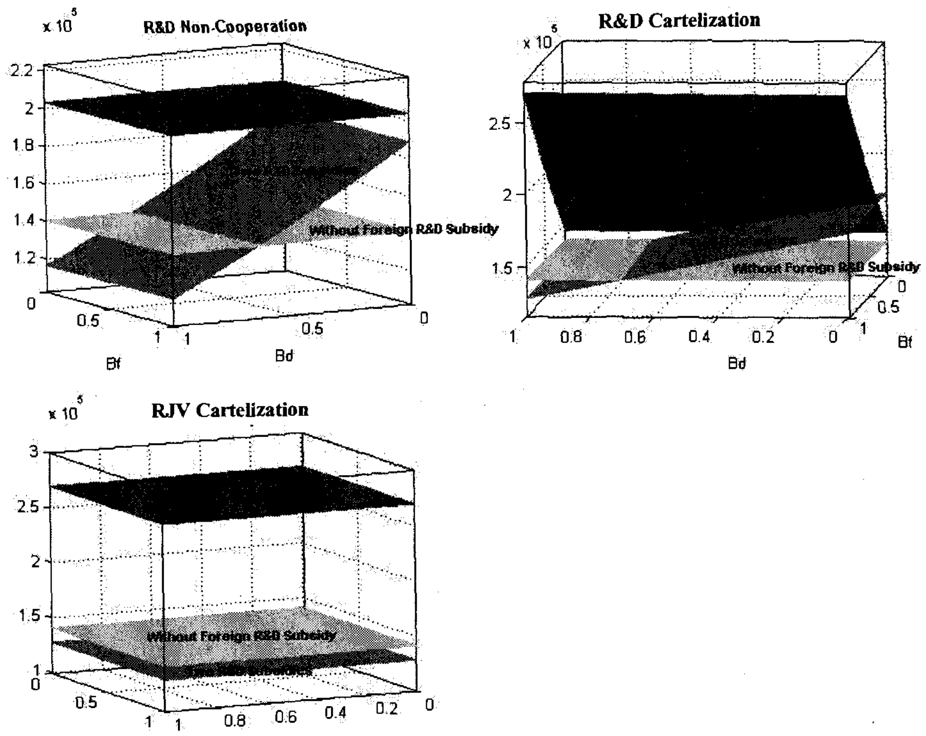


Figure 20 shows consumer surplus under the three scenarios. This figure suggests that consumer surplus is highest when the foreign firm receives an R&D subsidy. In other words, domestic consumers benefit the most from trade when the foreign firm receives an R&D subsidy. Consumer surplus is sometimes very low when the domestic firm receives an R&D subsidy. This is due to the market power that the domestic firm possesses in this case. Figures 19 and 20 suggest that the government of the domestic country may help the domestic firm increase its profit by granting an R&D subsidy, but this will be at the expense of domestic consumers.

Figure 20- Domestic consumer surplus



R&D Non-Cooperation

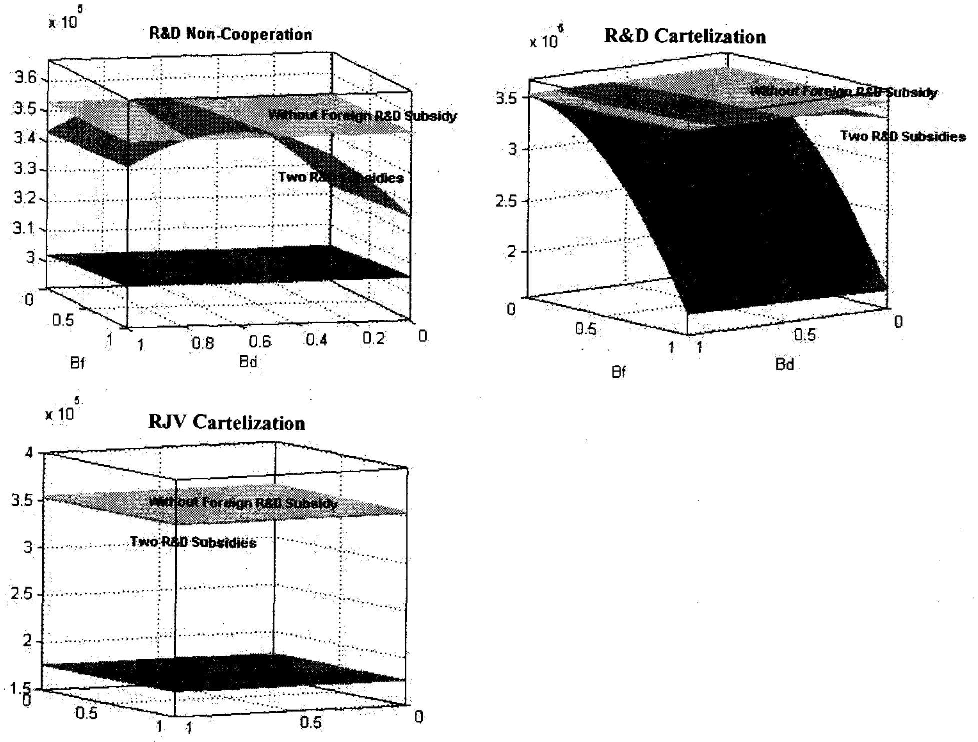
R&D Cartelization

RJV Cartelization

Figure 21 presents domestic welfare under the three scenarios. Welfare is always lowest when there is only a foreign R&D subsidy. This means the gain in consumer surplus due to the foreign R&D subsidy is less than the loss in the domestic firm's profit. As a result, a domestic R&D subsidy will be beneficial in this case.

These results suggest that the home country can recover partially or totally the profit and welfare loss due to the introduction of the foreign R&D subsidy by giving an R&D subsidy to the domestic firm. In other words, if the foreign country uses an R&D subsidy, the home country has to use two policy instruments to achieve higher welfare.

Figure 21- Domestic welfare


R&D Non-Cooperation

R&D Cartelization

RJV Cartelization

Appendix 2 shows analytically the impact of an exogenous tariff on the variables of interest in all models. It proves that these results do not depend critically on the parameters of the model.

7 – Special cases: β_d and β_f are very low or very high

In this section, we study four special cases where there are very high or very low technology diffusions between the domestic and foreign countries. We will analyze what the best R&D policies are in terms of R&D cartelization or non-cooperation under each scenario for the domestic firm and the government regarding the values of the profit, consumer surplus and welfare in each case. The goal of this section is to find out what will be the optimal scenario that the government of the domestic should pursue in each case and what will be the reaction of the firms in each case with respect to the government's decision. The government implements its policies by using the tariff and R&D subsidy. The firms react by cooperating or non-cooperating in R&D. The four cases are as follows:

Case 1- Both spillovers are very high ($\beta_d = \beta_f = 1$)

This resembles the case where both countries are developed or technologically advanced.

i) The profit of the domestic and foreign firms in each scenario is as follows:

Domestic profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.7851e+005	**1.0143e+005**	**2.2271e+005**
R&D cartelization	**1.7938e+005**	5.0227e+004	2.0168e+005

The dominant strategy of each firm in terms of R&D cooperation or non-cooperation under each scenario has been presented in **bold**. The results suggest that there is no natural equilibrium for the firms: Non-cooperation or R&D cartelization strategies will not be the firms' mutual best choices under any of the scenarios. This means that the bargaining between the firms on R&D cartelization and transferring part of the benefits will be probable. The domestic firm attains the maximum possible profit under the "foreign and domestic R&D subsidies" scenario and when it chooses the non-cooperation strategy. The foreign firm will have the maximum profit when there is only a foreign R&D subsidy and firms cooperate on R&D.

Foreign profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	**1.1459e+004**	1.0176e+005	528.7151
R&D cartelization	1.1058e+004	**2.5761e+005**	**3.2432e+003**

ii) Consumer surplus is as follows. The consumer surplus is the highest when only the foreign firm receives an R&D subsidy and firms cooperate on R&D.

Consumer surplus	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.4047e+005	2.0314e+005	1.1663e+005
R&D cartelization	1.4139e+005	**2.6972e+005**	1.2836e+005

iii) The welfare is presented in the following table:

Welfare	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	3.5282e+005	3.0461e+005	3.4423e+005
R&D cartelization	**3.5483e+005**	1.7675e+005	*3.5267e+005*

This table suggests that when both countries have high spillover rates, domestic welfare is highest when there is no R&D subsidy and the firms cooperate on R&D. This is the best policy that the government of the domestic country should consider in this case. However, if the foreign country decides to use an R&D subsidy, the domestic country should grant an R&D subsidy to the domestic firm; otherwise, there will be a welfare loss. This policy will be second best.

iv) The tariff is as follows:

Tariff	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	315.7506	0.1325	461.7575
R&D cartelization	316.5260	-281.7982	391.8119

When both countries have high spillover rates, the lowest tariff happens when there is only a foreign R&D subsidy. This is because consumers can benefit from the higher outputs of the foreign firm. The negative sign means the government of the domestic firm may even promote imports. However, due to the major losses in the profit of the domestic firm, this strategy is not optimal. If the foreign country uses an R&D subsidy, the home country increases both tariff protection and R&D subsidies to attain higher welfare.

Case 2- Domestic spillovers are very high, but foreign spillovers are very low ($\beta_d = 1$, $\beta_f = 0$)

This resembles the case where the home country is a developed country or more technologically advanced compared to the foreign country.

i) The profit of the domestic and foreign firms in each scenario is as follows:

Domestic profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	**1.7862e+005**	9.9125e+004	**2.2075e+005**
R&D cartelization	1.7860e+005	**1.6841e+005**	2.0042e+005

This is similar to the previous case where both countries had high spillovers. Again, the firms may not agree on a common R&D strategy. The domestic firm has the highest profit when it does not cooperate under the "Foreign and domestic R&D subsidies" scenario and the foreign firm attains its highest profit under non-cooperation strategy and "Foreign R&D subsidy" scenario.

Foreign profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.1216e+004	**1.0301e+005**	566.4796
R&D cartelization	**1.1261e+004**	1.7516e+004	**3.7616e+003**

ii) Consumer surplus is highest when there is only a foreign R&D subsidy.

Consumer surplus	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.4009e+005	**2.0264e+005**	1.1632e+005
R&D cartelization	1.4030e+005	1.4686e+005	1.2870e+005

iii) Welfare is highest when there is no R&D subsidy. However, the second best solution is when there is only a foreign R&D subsidy. This means, contrary to the previous case, it will be optimal for the home country not to give an R&D subsidy if the foreign country does it.

Welfare	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	3.5250e+005	3.0172e+005	3.4263e+005
R&D cartelization	**3.5251e+005**	3.5219e+005	3.5080e+005

iv) The tariff is as follows. The explanation is the same as in case 1.

Tariff	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	317.9084	-0.1315	461.0104
R&D cartelization	315.5519	281.9290	389.1640

Case 3- The home country has low spillovers, but the foreign country has high spillovers ($\beta_d = 0$, $\beta_f = 1$)

This resembles the case where the foreign country is a developed country or more technologically advanced compared to the home country.

i) The profit of the domestic and foreign firms in each scenario is as follows.

Domestic profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.7912e+005	**1.0190e+005**	1.1760e+005
R&D cartelization	**1.8061e+005**	5.0242e+004	**1.3422e+005**

The domestic firm attains the highest profit when there are no R&D subsidies and the firms cooperate on R&D. This is different from the previous two cases where the highest profit for the domestic firm occurred when there were R&D subsidies. The reason is that when there is no spillover from the domestic firm, it prefers to rely only on tariff protection. The foreign firm attains the highest profit when there is a foreign R&D subsidy, as expected.

Foreign profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	**1.1153e+004**	1.0079e+005	**7.2923e+004**
R&D cartelization	1.0442e+004	**2.5754e+005**	4.9612e+004

ii) Consumer surplus is maximized when there is only a foreign R&D subsidy and R&D cartelization.

Consumer surplus	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.4072e+005	2.0322e+005	1.8833e+005
R&D cartelization	1.4093e+005	**2.6807e+005**	1.7394e+005

iii) Welfare is maximized when there is only tariff protection and firms choose R&D cartelization.

Welfare	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	3.5307e+005	3.0504e+005	3.2503e+005
R&D cartelization	**3.5477e+005**	1.7425e+005	3.4018e+005

iv) As usual, the tariff is minimized when there is a foreign R&D subsidy in order for consumers to enjoy a higher surplus. However, this does not attain the optimal welfare for the home country because of the loss in the domestic firm's profit.

Tariff	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	314.3731	-0.2630	70.8512
R&D cartelization	317.3313	-283.5542	142.8405

Case 4- Both spillovers are very low ($\beta_d = \beta_f = 0$)

This resembles the case where none of the countries is a technologically advanced country.

i) The profit of the domestic and foreign firms under each scenario is as follows. Domestic maximal profit occurs when there is only tariff protection and the firms cooperate on R&D.

Domestic profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.7924e+005	9.9770e+004	1.1537e+005
R&D cartelization	**1.7983e+005**	**1.6985e+005**	**1.3377e+005**

As usual, the foreign firm has maximum profits when there is only a foreign R&D subsidy.

Foreign profit	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	**1.0910e+004**	**1.0171e+005**	**7.3812e+004**
R&D cartelization	1.0641e+004	1.6609e+004	5.0266e+004

ii) Consumer surplus is as follows. It is maximized when there is only a foreign R&D subsidy.

Consumer surplus	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	1.4033e+005	**2.0256e+005**	1.8780e+005
R&D cartelization	1.3985e+005	1.4615e+005	1.7360e+005

iii) Welfare is maximized when there is only tariff protection and there is R&D competition.

Welfare	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	**3.5276e+005**	3.0241e+005	3.2244e+005
R&D cartelization	3.5245e+005	3.5216e+005	3.3729e+005

iv) The tariff is as follows:

Tariff	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Non-Cooperation	316.5421	0.2608	70.8746
R&D cartelization	316.3439	283.6862	140.5403

By comparing the four cases, we realize that welfare is always maximized when there is no R&D subsidy. While domestic R&D subsidies without a foreign R&D subsidy would be socially beneficial, competition on R&D subsidies between countries would be socially harmful. The benefit to domestic producers of a domestic R&D subsidy tends to "cancel out" when a foreign R&D subsidy is introduced. Moreover, under the three cases of extreme spillovers, where at least one spillover is not very low, maximum welfare is obtained under R&D cartelization. The reason is that there will be less waste of resources under this strategy. The only exception is when both firms have zero spillovers. In this case, maximum welfare is obtained under R&D competition, probably because firms cannot benefit from the R&D spillovers that occur due to higher joint R&D expenditures. This suggests that the government of the home country should pursue policies that avoid competition on R&D subsidies, and in most cases, encourage R&D cooperation between firms.

Consumer surplus is always highest when there is only a foreign R&D subsidy. The foreign profit is always highest when there is only a foreign R&D subsidy, and the firms choose the R&D cartelization strategy. The only exception is when both countries have low spillovers, in which, R&D cooperation is not beneficial for the foreign firm. When there are high domestic spillovers, it is optimal for the domestic firm to receive an R&D subsidy and choose the non-cooperation strategy. However, when there are high foreign spillovers, the domestic firm attains the highest profit when it relies only on tariff protection and cooperates with the foreign firm on R&D.

The first best scenarios in each case for the government to follow, and the reaction strategies of each firm are summarized in the following table:

Case	$\beta_d = 1$, $\beta_f = 1$	$\beta_d = 1$, $\beta_f = 0$	$\beta_d = 0$, $\beta_f = 1$	$\beta_d = \beta_f = 0$
Best scenario for the domestic government to attain highest welfare	No R&D subsidy – *R&D cartelization*	No R&D subsidy – *R&D cartelization*	No R&D subsidy – *R&D cartelization*	No R&D subsidy – *non-cooperation*
Domestic firm's reaction under this scenario	*R&D cartelization*	*non-cooperation*	*R&D cartelization*	*R&D cartelization*
Foreign firm's reaction under this scenario	*non-cooperation*	*non-cooperation and/or R&D cartelization*	*non-cooperation*	*non-cooperation*

The government should target the "No R&D subsidy" scenario with R&D cartelization in three cases and with non-cooperation in one case because the highest welfare will be attained under these scenarios. However, given the "No R&D subsidy" scenario, the above table suggests that the domestic and foreign firms' optimal strategies are not the same as what the domestic government may wish. In fact, firms may fail to agree to cooperate. Therefore, the optimal welfare will not be attained without further government enforcements or mutual agreements between the firms. Calculating the optimal transfer between firms to agree on a common strategy will be an interesting question.

Keeping in mind that the highest profit for the foreign firm always occurs when it receives the foreign R&D subsidy, we may assume that the foreign government will choose the "Foreign R&D subsidy" scenario. In this case, the scenario that the home country's government will target is as follows. We call these scenarios "second-best". The second-best scenarios have been presented for each case as follows:

Case	$\beta_d = 1$, $\beta_f = 1$	$\beta_d = 1$, $\beta_f = 0$	$\beta_d = 0$, $\beta_f = 1$	$\beta_d = \beta_f = 0$
Second-best scenario for the domestic government to attain highest welfare	Foreign and domestic R&D subsidies – *R&D cartelization*	**Foreign and domestic R&D subsidies –** ***non-cooperation***	Foreign and domestic R&D subsidies – *R&D cartelization*	Foreign R&D subsidies – *R&D cartelization*
Domestic firm's reaction under this scenario	*non-cooperation*	***non-cooperation***	*R&D cartelization*	*R&D cartelization*
Foreign firm's reaction under this scenario	*R&D cartelization*	***non-cooperation***	*non-cooperation*	*non-cooperation*

This table suggests that the only case where a pure equilibrium without further government intervention or mutual firm agreements may occur is when the domestic spillover is high and the foreign spillover is low. In this case, the government targets the "Foreign and domestic R&D subsidies" scenario with non-cooperation strategy to achieve the highest welfare. After the government chooses this scenario, both firms' reaction will be the non-cooperation strategy, and equilibrium occurs. When the foreign spillover is high, the government targets the "Foreign and domestic R&D subsidies" scenario; however, it should later encourage the foreign firm to choose the "R&D cartelization" strategy. The same is true when both spillovers are low: the government targets the "Foreign R&D subsidies" scenario, but it should later encourage the foreign firm to choose the "R&D cartelization" strategy.

Appendix 1 presents the analytical solutions of the models of this section under the "No R&D subsidy" scenario when β_d and β_f are equal to 1 or 0 to see how sensitive the results are to the parameters of the model. As the equations prove, the results are independent of the values of A and α. Only the value of γ may affect the results. Regarding the second-order-conditions and other equations, all results sustain if $\gamma>2$.

8- Conclusion

In this paper, we studied the effect of tariffs on R&D expenditures when there are R&D spillovers between firms. The firms are located in the home and foreign countries and compete in the home country's market. We considered a three-stage game, where the government determines the amount of the tariff in the first stage, firms choose their R&D expenditures in the second stage, and the outputs are determined in the third stage based on Cournot competition. Firms can choose their optimal R&D expenditures in the second stage cooperatively or non-cooperatively. We used simulation techniques to solve this model, where the objective of the government is to maximize welfare. Also, we analyzed how spillovers affect the equilibrium.

We showed that the results depend critically on R&D spillovers. Domestic unit cost is always lower under RJV cartelization than R&D cartelization, and both are lower under non-cooperation. However, if both domestic and foreign spillovers are low, non-cooperation gives a lower domestic unit cost than R&D cartelization. Also, when the domestic spillover is low and the foreign spillover is high, R&D cartelization yields a lower domestic unit cost than RJV cartelization, and both of them give a lower domestic unit cost than non-cooperation. Domestic R&D is higher under R&D cartelization than under RJV cartelization and non-cooperation when the domestic spillover is high, and it is higher under non-cooperation when the domestic spillover is low. This confirms the results of D'Aspremont and Jacquemin (1988) two-stage model, where symmetric R&D spillovers exist, but no tariff or R&D subsidy is involved. Domestic firm's profits are always higher under R&D cartelization than under RJV cartelization, and both of them are higher than under non-cooperation. However, if the domestic spillover is high and the foreign spillover is low, the domestic firm's profits are lower under R&D cartelization than under RJV cartelization. Consumer surplus and welfare are always higher under RJV cartelization. Welfare is higher under R&D cartelization than under non-cooperation when the foreign spillover is high.

We extended the model to study the effect of foreign and domestic R&D subsidies. We showed that if the foreign government gives an R&D subsidy to the foreign firm, foreign R&D will increase and the domestic firm's profit and domestic welfare will decrease. However, domestic consumer surplus will increase. For certain levels of spillovers, it will be optimal for the home country to encourage imports (through a negative tariff) to reach higher welfare. We also showed that the home country can recover this profit and welfare loss, partially or totally, through the simultaneous use of a tariff and an R&D subsidy. This result is similar to Spencer and Brander (1983) where the government uses both export and R&D subsidies, but there are no R&D spillovers.

To obtain more concrete analytical results, we considered four special cases where domestic and spillovers are very high or very low. These cases resemble the interaction between two developed countries, one developed and one underdeveloped country, and two underdeveloped countries. The results suggest that the home country always attains higher welfare when none of the countries gives R&D subsidies. However, if the foreign firm receives an R&D subsidy, the domestic government should also support R&D. The other result is that the foreign and domestic firms will never choose the same strategy in terms of R&D cartelization or non-cooperation. More government enforcement or mutual agreements between firms may be needed to attain higher welfare. The only case where there will be a pure strategy equilibrium, is when the domestic spillover is high and the foreign spillover is low. In this case, the government will target the "Foreign and domestic R&D subsidies" scenario and both firms will choose the non-cooperation strategy. This is the best strategy in terms of domestic profit, foreign profit, and welfare.

Appendixes 1 and 2 show that the results of this paper do not depend critically on the parameters of the model. Reitzes (1991) and Bouet (2001) show that in a two-stage model with no R&D spillovers, imposing tariffs will increase R&D expenditures. Appendix 2 proves the same results in a three-stage game with asymmetric R&D spillovers. On the other hand, this paper extends the results of DeCourcy (2005), where the spillovers are symmetric and the only policy tools by the home and foreign countries are R&D subsidies. This paper suggests that if we relax this assumption that R&D spillovers are symmetric, we will get quite different results from DeCourcy (2005).

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Appendix 1- Solutions at β_d and β_f equal to 1 or 0

In this appendix, we confirm analytically the results of section 7. First, we see which values of γ are required to satisfy the second-order-conditions with respect to the tariff. Then, we analyze the difference between domestic profits, consumer surplus, and welfare at different values of spillovers between R&D cartelization and non-cooperation strategies.

The second order conditions are as follows. We will assume γ >0.8158 based on the following second-order-conditions (SOC). The equations are independent of A and α. In the following equations, W stands for welfare, t for tariff, π for profit, CS for consumer surplus, NOC for R&D non-cooperation, and RDC for R&D cartelization.

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{NOC}_{(\beta_d=1,\beta_f=1)} = -\frac{729\gamma^3-252\gamma^2+6\gamma+2}{\gamma(9\gamma-2)^2} <0 \quad \Rightarrow \quad \gamma > 0.282$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{NOC}_{(\beta_d=1,\beta_f=0)} = -\frac{3\gamma(243\gamma^3-210\gamma^2+51\gamma-4)}{(27\gamma^2-15\gamma+2)^2} <0 \Rightarrow \quad \gamma > 0.5232$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{NOC}_{(\beta_d=0,\beta_f=1)} = -\frac{\gamma(81\gamma-16)}{(9\gamma-2)^2} <0 \quad \Rightarrow \quad \gamma > 0$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{NOC}_{(\beta_d=0,\beta_f=0)} = -\frac{3\gamma(243\gamma^3-336\gamma^2+132\gamma-16)}{(27\gamma^2-24\gamma+4)^2} <0 \quad \Rightarrow \quad \gamma > 0.8158$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{RDC}_{(\beta_d=1,\beta_f=1)} = -\frac{81\gamma^2-58\gamma+8}{(9\gamma-4)^2} <0 \quad \Rightarrow \quad \gamma > 0.5295$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{RDC}_{(\beta_d=1,\beta_f=0)} = -\frac{\gamma(81\gamma^3-88\gamma^2+24\gamma-2)}{(9\gamma^2-7\gamma+1)^2} <0 \quad \Rightarrow \quad \gamma > 0.7245$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{RDC}_{(\beta_d=0,\beta_f=1)} = -\frac{\gamma(81\gamma^3-88\gamma^2+29\gamma-4)}{(9\gamma^2-7\gamma+1)^2} < 0 \quad \Rightarrow \quad \gamma > 0.6548$$

$$\left[\frac{\partial^2 W}{\partial t_2}\right]^{RDC}_{(\beta_d=0,\beta_f=0)} = -\frac{\gamma(81\gamma^2-37\gamma+4)}{(9\gamma-1)^2(\gamma-1)} < 0 \quad \Rightarrow \quad \gamma > 0.2811$$

The differences between profits, consumer surplus, and welfare are as follows. As we see, the signs of all equations depend only on the value of γ and are independent of A and α. All equations have the expected sign (positive) as explained in section 7 as long as $\gamma > 2$. This condition is also valid for the foreign profit. We did our simulations under γ = 60.

i) Domestic profits:

$$\left[\pi_d^{RDC} - \pi_d^{NOC}\right]_{(\beta_d=1,\beta_f=1)} =$$

$$\frac{\gamma(A-\alpha)^2(199290375\gamma^8-373878585\gamma^7+271311201\gamma^6-98918172\gamma^5+19176480\gamma^4-1861272\gamma^3+65724\gamma^2+1120\gamma-64)}{(729\gamma^3-252\gamma^2+6\gamma+2)^2(81\gamma^2-58\gamma+8)^2} > 0$$

$$\left[\pi_d^{NOC} - \pi_d^{RDC}\right]_{(\beta_d=1,\beta_f=0)} =$$

$$\frac{\gamma^2(A-\alpha)^2(531441\gamma^9+1751787\gamma^8-6725106\gamma^7+8028711\gamma^6-4912749\gamma^5+1753464\gamma^4-380803\gamma^3+49751\gamma^2-3608\gamma+112)}{(243\gamma^3-210\gamma^2+51\gamma-4)^2(81\gamma^3-88\gamma^2+24\gamma-2)^2} > 0$$

$$\left[\pi_d^{RDC} - \pi_d^{NOC}\right]_{(\beta_d=0,\beta_f=1)} =$$

$$\frac{\gamma(A-\alpha)^2(37732311\gamma^8-84695949\gamma^7+81174717\gamma^6-44294247\gamma^5+15217248\gamma^4-3376604\gamma^3+471084\gamma^2-37440\gamma+1280)}{(81\gamma^3-88\gamma^2+29\gamma-4)^2(81\gamma-16)^2(3\gamma-1)^2} > 0$$

$$\left[\pi_d^{RDC} - \pi_d^{NOC}\right]_{(\beta_d=0,\beta_f=0)} =$$

$$\frac{\gamma^2(A-\alpha)^2(15057495\gamma^8-50672790\gamma^7+72480663\gamma^6-57553488\gamma^5+27787752\gamma^4-8367168\gamma^3+1536688\gamma^2-157568\gamma+6912)}{(243\gamma^3-336\gamma^2+132\gamma-16)^2(81\gamma^2-37\gamma+4)^2(\gamma-1)} > 0$$

ii) Consumer surplus:

$$\left[CS_d^{RDC} - CS_d^{NOC}\right]_{(\beta_d=1,\beta_f=1)} =$$

$$\frac{18\gamma^2(A-\alpha)^2(10935\gamma^4-7749\gamma^3+1356\gamma^2+13\gamma-12)(1053\gamma^3-258\gamma^2-7\gamma+4)}{(729\gamma^3-252\gamma^2+6\gamma+2)^2(81\gamma^2-58\gamma+8)^2} > 0$$

$$\left[CS_d^{RDC}-CS_d^{NOC}\right]_{(\beta_d=1,\beta_f=0)}=$$

$$\frac{9\gamma^3(A-\alpha)^2(7290\gamma^5-12780\gamma^4+8113\gamma^3-2329\gamma^2+312\gamma-16)(81\gamma^2-35\gamma+4)(2\gamma-1)}{2(81\gamma^3-88\gamma^2+24\gamma-2)^2(243\gamma^3-210\gamma^2+51\gamma-4)^2}>0$$

$$\left[CS_d^{RDC}-CS_d^{NOC}\right]_{(\beta_d=0,\beta_f=1)}=$$

$$\frac{18\gamma^2(A-\alpha)^2(3645\gamma^4-4689\gamma^3+2165\gamma^2-452\gamma+36)(81\gamma^3-20\gamma^2+18\gamma-4)}{(81\gamma^3-88\gamma^2+29\gamma-4)^2(81\gamma-16)^2(3\gamma-1)^2}>0$$

$$\left[CS_d^{NOC}-CS_d^{RDC}\right]_{(\beta_d=0,\beta_f=0)}=$$

$$\frac{18\gamma^2(A-\alpha)^2(3645\gamma^4-6066\gamma^3+3368\gamma^2-776\gamma+64)(27\gamma^2-34\gamma+8)(7\gamma-2)}{(81\gamma^2-37\gamma+4)^2(243\gamma^3-336\gamma^2+132\gamma-16)^2}>0$$

iii) Welfare:

$$\left[W_d^{RDC}-W_d^{NOC}\right]_{(\beta_d=1,\beta_f=1)}=$$

$$\frac{\gamma(A-\alpha)^2(7776\gamma^3-2097\gamma^2+123g-4)}{(81\gamma^2-58\gamma+8)(729\gamma^3-252\gamma^2+6\gamma+2)}>0$$

$$\left[W_d^{RDC}-W_d^{NOC}\right]_{(\beta_d=1,\beta_f=0)}=$$

$$\frac{\gamma(A-\alpha)^2(6\gamma-1)(2\gamma-1)(11\gamma-4)}{2(81\gamma^3-88\gamma^2+24\gamma-2)(243\gamma^3-210\gamma^2+51\gamma-4)}>0$$

$$\left[W_d^{RDC}-W_d^{NOC}\right]_{(\beta_d=0,\beta_f=1)}=$$

$$\frac{\gamma(A-\alpha)^2(6561\gamma^4-6498\gamma^3+2652\gamma^2-520\gamma-40)}{(81\gamma-16)(3\gamma-1)^2(81\gamma^3-88\gamma^2+29\gamma-4)}>0$$

$$\left[W_d^{NOC}-W_d^{RDC}\right]_{(\beta_d=0,\beta_f=0)}=$$

$$\frac{\gamma(A-\alpha)^2(405\gamma^4-1299\gamma^3+1220\gamma^2-420\gamma-48)}{(\gamma-1)(81\gamma^2-37\gamma+4)(243\gamma^3-336\gamma^2+132\gamma-16)}>0$$

Appendix 2 – Finding the effect of tariffs on variables

This appendix analyzes analytically the impact of tariffs on the variables of the model. For this purpose, we assume that the tariff is exogenous. In other words, we solve the model only for the third and second stages. This way, the optimal level of all variables of interest can be obtained as a function of the exogenous tariff t, spillover rates β_d and β_f, and the parameters of the model A, α, and γ. Then, we determine the impact of tariffs on these variables. Due to complexity of some the equations, we may use graphs to sign the equations. Equations suggest that all results are independent of the parameters A and α. Moreover, all results hold for $\gamma > 2$.

Case 1- Basic model

In this case, there is only tariff protection, and no domestic or foreign R&D subsidies are involved.

i) Non-cooperation

i-1) Domestic R&D; For all $\gamma > 1$:

$$\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{NOC} = \frac{(2-\beta_d)(3\gamma+\beta_f^2-2\beta_f)}{4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2}>0$$

i-2) Domestic output; For all $\gamma > 1$:

$$\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{NOC} = \frac{3\gamma(3\gamma+\beta_f^2-2\beta_f)}{4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2}>0$$

i-3) Domestic profit; For all γ:

$$\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{NOC} = \frac{2\gamma(A-\alpha)(9\gamma+4\beta_d-\beta_d^2-4)(3\gamma+\beta_f^2-2\beta_f)(3\gamma+3\beta_f-\beta_f^2-2)}{(4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2)^2}>0$$

i-4) Consumer surplus; For all $\gamma > 1$:

$$\left[\frac{\partial CS}{\partial t}\right]_{t=0}^{NOC}=\frac{-9\gamma^2(A-\alpha)(6\gamma+3\beta_f+3\beta_d-\beta_f^2-\beta_d^2-4)}{(4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2)^2}<0$$

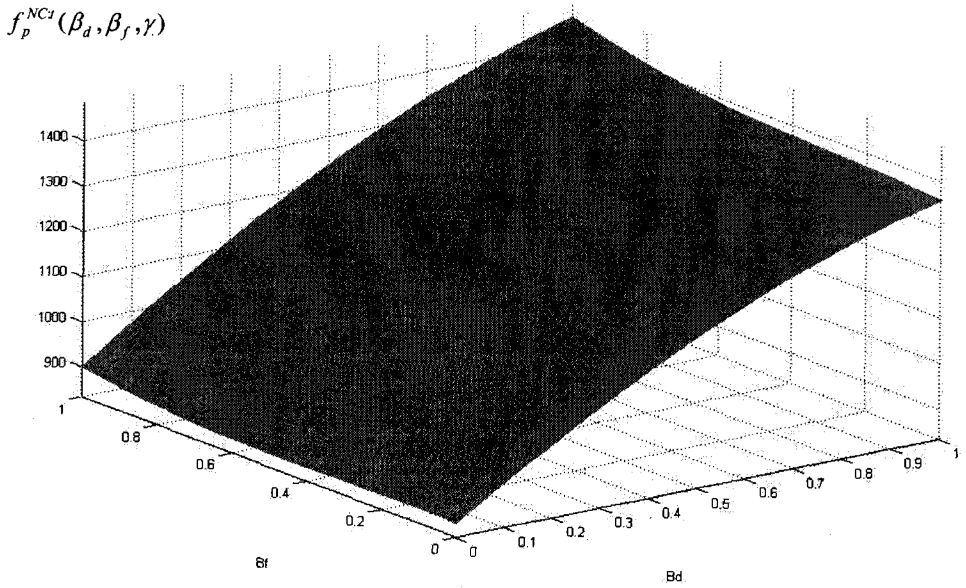
i-5) Welfare; For all $\gamma > 2$:

$$\begin{aligned}\left[\frac{\partial W}{\partial t}\right]_{t=0}^{NOC}&=\frac{2\gamma(A-\alpha)(9\gamma+4\beta_d-\beta_d^2-4)(3\gamma+\beta_f^2-2\beta_f)(3\gamma+3\beta_f-\beta_f^2-2)}{(4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2)^2}\\&-\frac{9\gamma^2(A-\alpha)(6\gamma+3\beta_f+3\beta_d-\beta_f^2-\beta_d^2-4)}{(4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2)^2}\\&+\frac{3\gamma(A-\alpha)(3\gamma+3\beta_d-\beta_d^2-2)}{(4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2)}\\&=\frac{\gamma(A-\alpha)f_w^{NCt}(\beta_d,\beta_f,\gamma)}{(4+27\gamma^2+12\gamma\beta_d+12\gamma\beta_f+2\beta_d\beta_f^2+2\beta_f\beta_d^2-24\gamma-3\gamma\beta_f^2-3\gamma\beta_d^2-2\beta_f-2\beta_d-3\beta_f\beta_d-\beta_f^2\beta_d^2)^2}>0,\end{aligned}$$

where $f_w^{NCt}(\beta_d,\beta_f,\gamma)$ is a function of β_d, β_f, and γ.

For the equations that are too complicated to be signed analytically, we assign different values to γ and will draw the equation for different β_d and β_f to see if the value of the function is positive or negative. For example, for $\left[\frac{\partial W}{\partial t}\right]_{t=0}^{NOC}$, we know the sign of all variables except $f_w^{NCt}(\beta_d,\beta_f,\gamma)$. To find the sign of this equation, we draw its graph with respect to β_d and β_f for $\gamma=2$. We start from $\gamma=2$ because we need $\gamma \geq 2$ for first order and second order conditions to hold our results of section 7 (appendix 1). As we see, this equation is positive for all values of β_d and β_f. Also, since this equation is of order of γ^3 (positive), the sign of the equation will always be positive for large values of γ. This means $\left[\frac{\partial W}{\partial t}\right]_{t=0}^{NOC}>0$ for $\gamma \geq 2$. The graph of $f_p^{NCt}(\beta_d,\beta_f,\gamma)$ at $\gamma=2$ is presented in figure 22.

Figure 22 - The graph of $f_p^{NCt}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$



These results suggest that when there are R&D spillovers between countries, the introduction of tariffs increases output and profit of the domestic firm and decreases consumer surplus. However, contrary to the trade literature, this will lead to higher welfare for the home country. In other words, when there is no R&D cooperation between countries and in the presence of R&D spillovers, the increase in profits due to tariffs is greater than the loss of consumer surplus, and the net result is an increase in welfare.

ii) R&D Cartelization

ii-1) Domestic R&D; For all $\gamma \geq 2$:

$$\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} = \frac{4\gamma + \beta_d \beta_f^2 - 5\gamma\beta_d - \beta_f}{1 + 9\gamma^2 + 8\gamma\beta_d + 8\gamma\beta_f + \beta_f^2\beta_d^2 - 10\gamma - 5\gamma\beta_f^2 - 5\gamma\beta_d^2 - 2\beta_f\beta_d} > 0$$

ii-2) Domestic output; For all $\gamma > 1$:

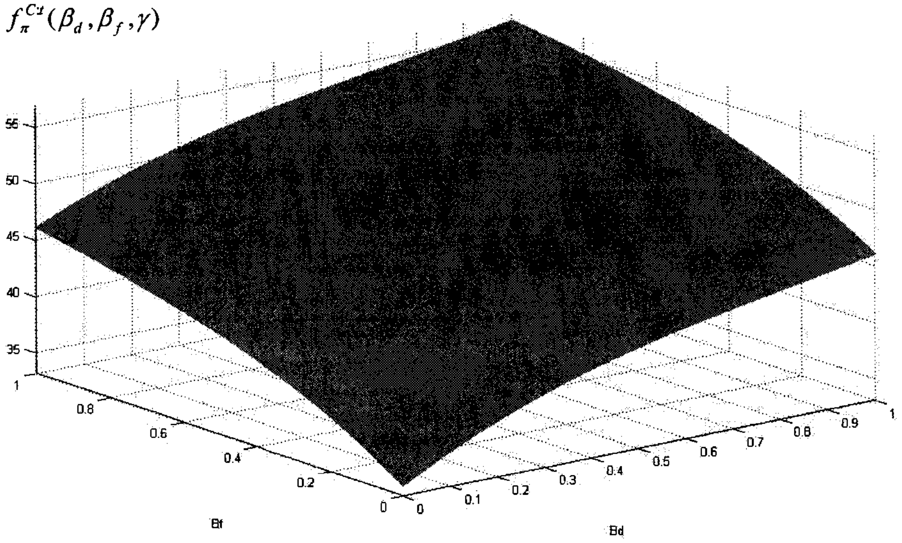
$$\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{C} = \frac{3\gamma^2 + \gamma + \gamma\beta_f^2 - 2\gamma\beta_d - 2\gamma\beta_f}{1 + 9\gamma^2 + 8\gamma\beta_d + 8\gamma\beta_f + \beta_f^2\beta_d^2 - 10\gamma - 5\gamma\beta_f^2 - 5\gamma\beta_d^2 - 2\beta_f\beta_d} > 0$$

ii-3) Domestic profit; For all $\gamma > 2$:

$$\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{C} = \frac{2\gamma(A-\alpha) f_\pi^{C_1}(\beta_d, \beta_f, \gamma)}{(1 + 9\gamma^2 + 8\gamma\beta_d + 8\gamma\beta_f + \beta_f^2\beta_d^2 - 10\gamma - 5\gamma\beta_f^2 - 5\gamma\beta_d^2 - 2\beta_f\beta_d)^2} > 0,$$

where $f_\pi^{C_1}(\beta_d, \beta_f, \gamma)$ is of order γ^3. The graph of $f_\pi^{C_1}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$ is presented in figure 23. Therefore, $\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{C} > 0$ for all $\gamma > 2$.

Figure 23 - The graph of $f_\pi^{C_1}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$



ii-4) Consumer surplus; For all $\gamma > 1$:

$$\left[\frac{\partial CS}{\partial t}\right]_{t=0}^{C} = \frac{-9\gamma^2(A-\alpha)(2\gamma + 2\beta_f + 2\beta_d - \beta_f^2 - \beta_d^2 - 2)(\gamma + \beta_f + \beta_d - \beta_f^2 - 1)}{(1 + 9\gamma^2 + 8\gamma\beta_d + 8\gamma\beta_f + \beta_f^2\beta_d^2 - 10\gamma - 5\gamma\beta_f^2 - 5\gamma\beta_d^2 - 2\beta_f\beta_d)^2} < 0$$

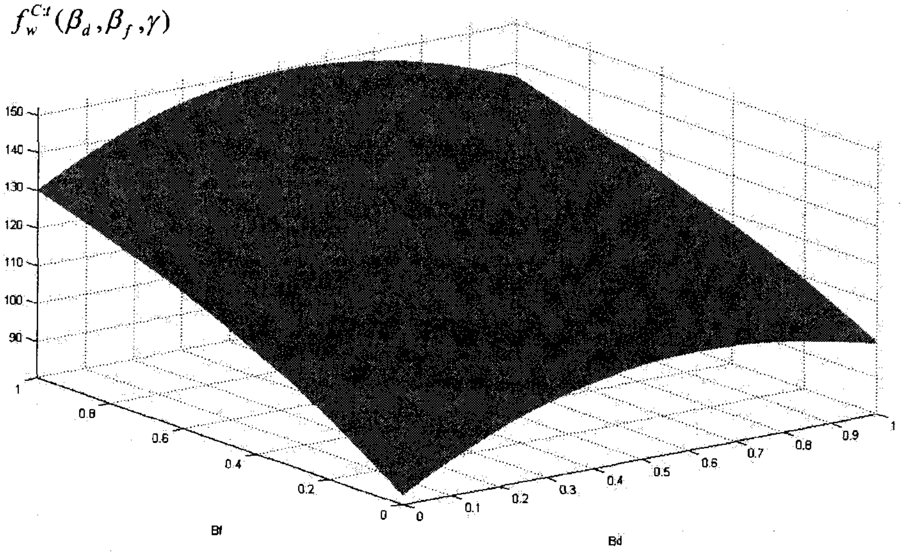
ii-5) Welfare; For all $\gamma > 2$:

$$\left[\frac{\partial W}{\partial t}\right]_{t=0}^{C} = \frac{\gamma(A-\alpha) f_w^{C:t}(\beta_d,\beta_f,\gamma)}{(1+9\gamma^2+8\gamma\beta_d+8\gamma\beta_f+\beta_f^2\beta_d^2-10\gamma-5\gamma\beta_f^2-5\gamma\beta_d^2-2\beta_f\beta_d)^2} > 0$$

$f_w^{C:t}(\beta_d,\beta_f,\gamma)$ is of order of γ^3. Its graph at $\gamma = 2$ is presented in figure 24.

Graphs of this equation for $\gamma \geq 2$ suggest that $\left[\frac{\partial W}{\partial t}\right]_{t=0}^{C} > 0$ for all $\gamma \geq 2$.

Figure 24 - The graph of $f_w^{C:t}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



The results of section (ii) confirm that in the presence of R&D spillovers, imposing tariffs will increase welfare regardless whether the countries cooperate on R&D or not. This result is in contrast with the trade literature that suggest tariffs always reduce the welfare of a small open economy. These results also explain why the optimal tariff is always positive in Figure 9. The spillover rates determine when the optimal tariff is highest among the three scenarios of non-cooperation, R&D cartelization, and RJV cartelization.

Case 2- Foreign R&D subsidy model

In this case, the foreign country grants an R&D subsidy to the foreign firm. The home country may use tariff protection to increase welfare. The following equations show the impact of a tariff on the variables when the foreign country grants an R&D subsidy.

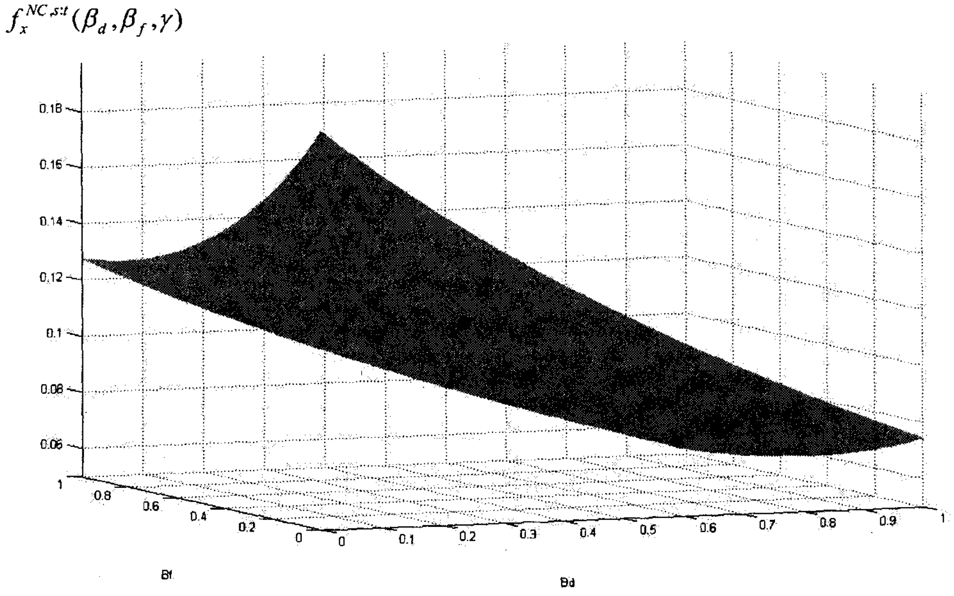
i) Non-cooperation

i-1) Domestic R&D; For all $\gamma > 2$:

$$\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{NOC} = f_x^{NC,st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_x^{NC,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 25. Since $\frac{\partial f_x^{NC,st}(\beta_d,\beta_f,\gamma)}{\partial \gamma} > 0$ for $\gamma > 2$, we can say that $\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma > 2$.

Figure 25 - The graph of $f_x^{NC,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

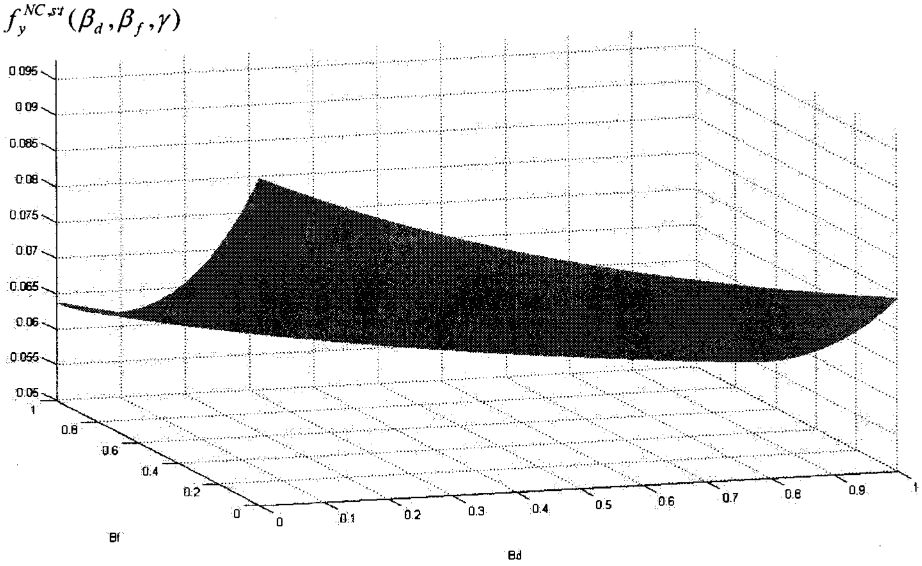


i-2) Domestic output; For all γ >2:

$$\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{NOC} = 3\gamma . f_y^{NC,st}(\beta_d, \beta_f, \gamma) > 0$$

The graph of $f_y^{NC,st}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$ is presented in figure 26. Graphs of this equation for $\gamma \geq 2$ suggest that $\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma \geq 2$.

Figure 26 - The graph of $f_y^{NC,st}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$



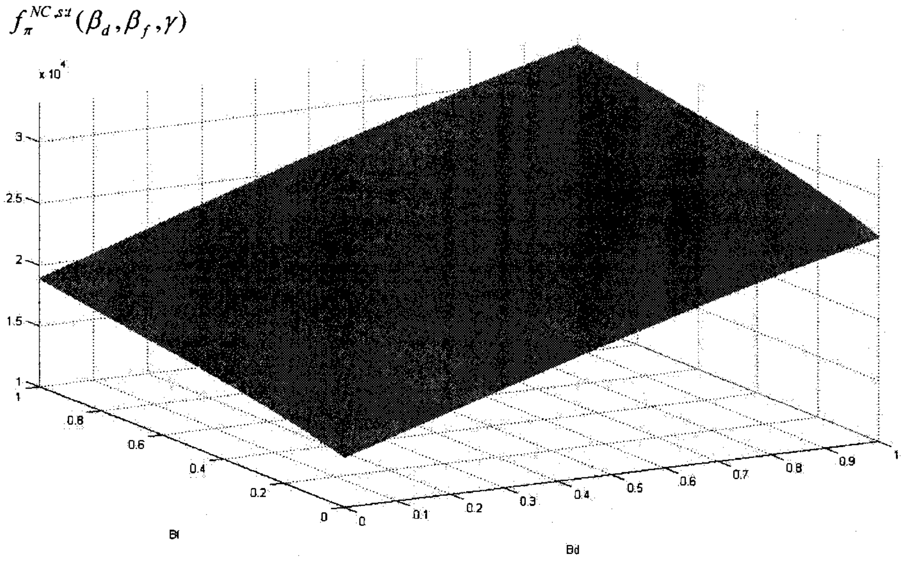
i-3) Domestic profit; For all γ >2:

$$\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{NOC} = \frac{2\gamma(A-\alpha) f_\pi^{NC,st}(\beta_d, \beta_f, \gamma)}{(g^{NC}(\beta_d, \beta_f, \gamma))^2} > 0$$

$f_\pi^{NC,st}(\beta_d, \beta_f, \gamma)$ is of order of γ^4 and its graph at γ =2 is presented in figure 27.

Graphs of this equation for $\gamma \geq 2$ suggest that $\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma \geq 2$.

Figure 27 - The graph of $f_{\pi}^{NC,s:t}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



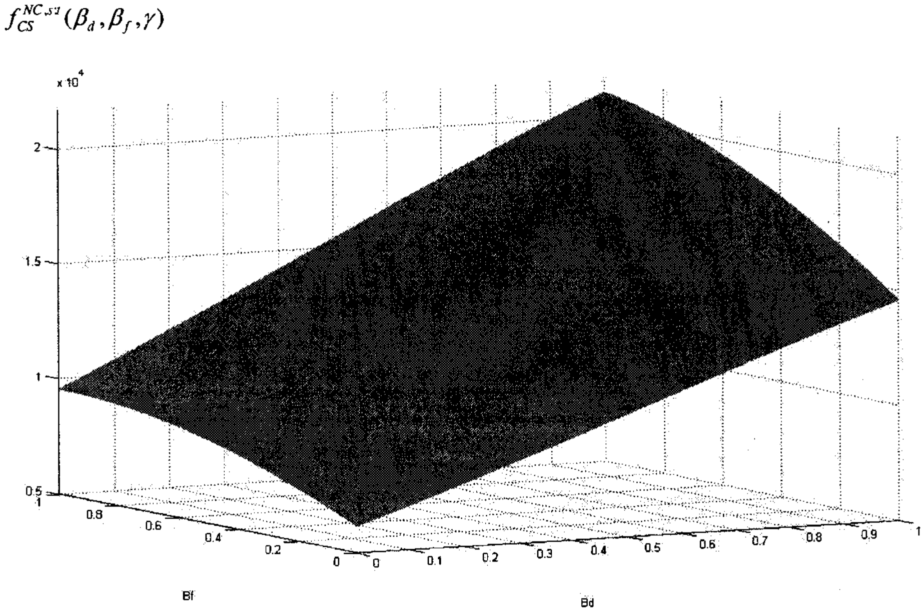
i-4) Consumer surplus; For all γ >2:

$$\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{NOC} = \frac{-2\gamma^2(A-\alpha)f_{CS}^{NC,s:t}(\beta_d,\beta_f,\gamma)}{(g^{NC}(\beta_d,\beta_f,\gamma))^2} < 0$$

$f_{CS}^{NC,s:t}(\beta_d,\beta_f,\gamma)$ is of order of γ^4 and its graph at $\gamma = 2$ is presented in figure 28.

Graphs of this equation for $\gamma > 2$ suggest that $\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{NOC} < 0$ for $\gamma > 2$.

Figure 28 - The graph of $f_{CS}^{NC,s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



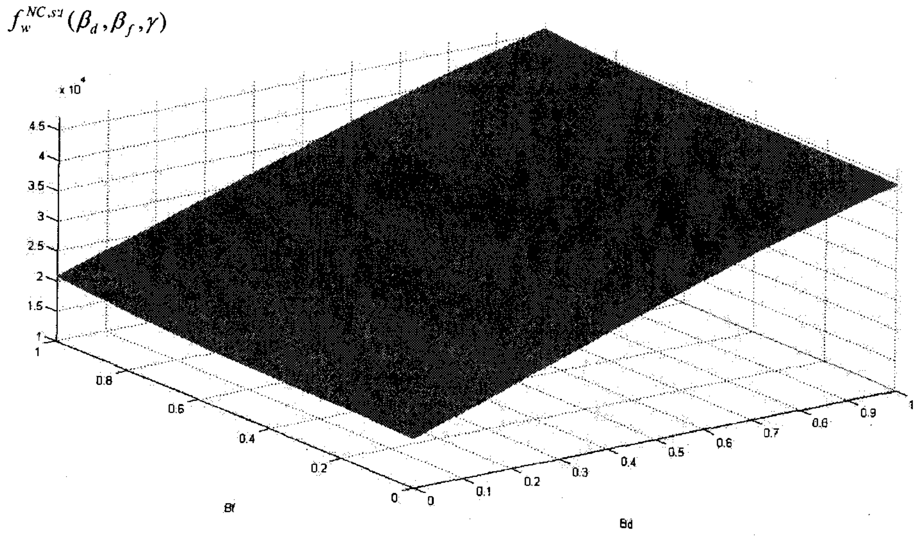
i-5) Welfare; For all $\gamma > 2$:

$$\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{NOC} = \frac{\gamma(A-\alpha) f_w^{NC,s1}(\beta_d,\beta_f,\gamma)}{(g^{NC}(\beta_d,\beta_f,\gamma))^2} > 0$$

$f_w^{NC,s1}(\beta_d,\beta_f,\gamma)$ is of order of γ^5 and its graph at $\gamma = 2$ is presented in figure 29.

Graphs of this equation for $\gamma > 2$ suggest that $\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma > 2$.

Figure 29 - The graph of $f_w^{NC,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



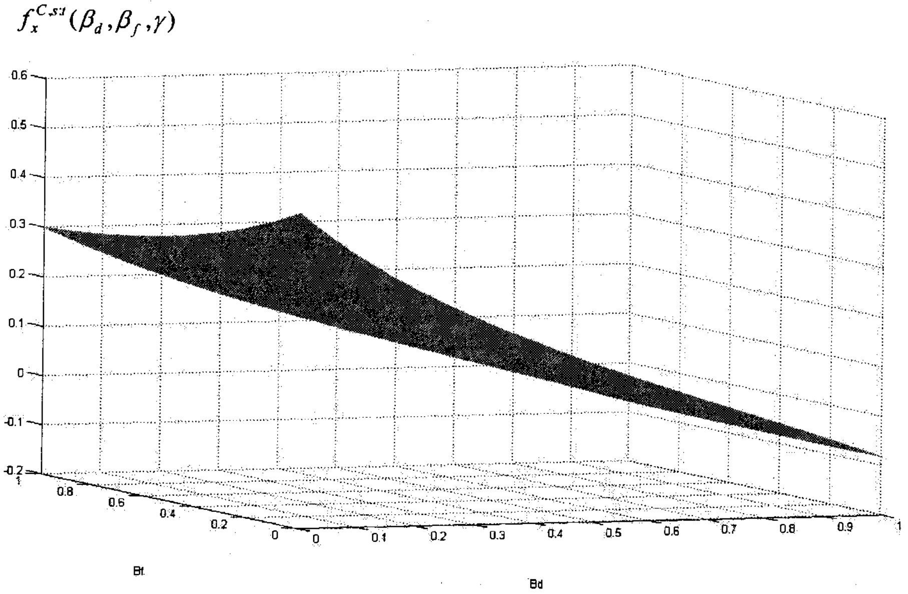
ii) R&D Cartelization

ii-1) Domestic R&D:

$$\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} = f_x^{C,st}(\beta_d,\beta_f,\gamma)$$

The graph of $f_x^{C,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 30. Analyzing $f_x^{C,st}(\beta_d,\beta_f,\gamma)$ at different values of γ >2 suggests that $\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} < 0$ when β_d is close to 1, and $\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} > 0$ in other cases. In other words, imposing tariffs will reduce domestic R&D under R&D cartelization when domestic spillovers are high. The reason is that the domestic firm wants to deter R&D free riding of the foreign firm when its R&D spillover is high. Imposing tariffs will increase domestic R&D in other cases.

Figure 30 - The graph of $f_x^{C,st}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$

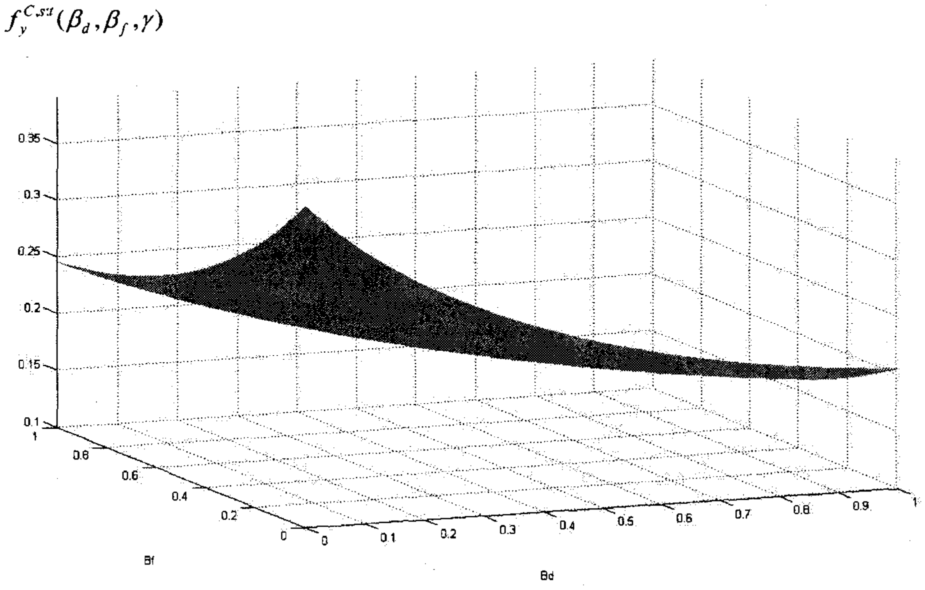


ii-2) Domestic output; For all $\gamma > 2$:

$$\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{C} = \gamma . f_y^{C,st}(\beta_d, \beta_f, \gamma) > 0$$

The graph of $f_y^{C,st}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$ is presented in figure 31. Graphs of $f_y^{C,st}(\beta_d, \beta_f, \gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{C} > 0$ for $\gamma > 2$.

Figure 31 - The graph of $f_y^{C,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

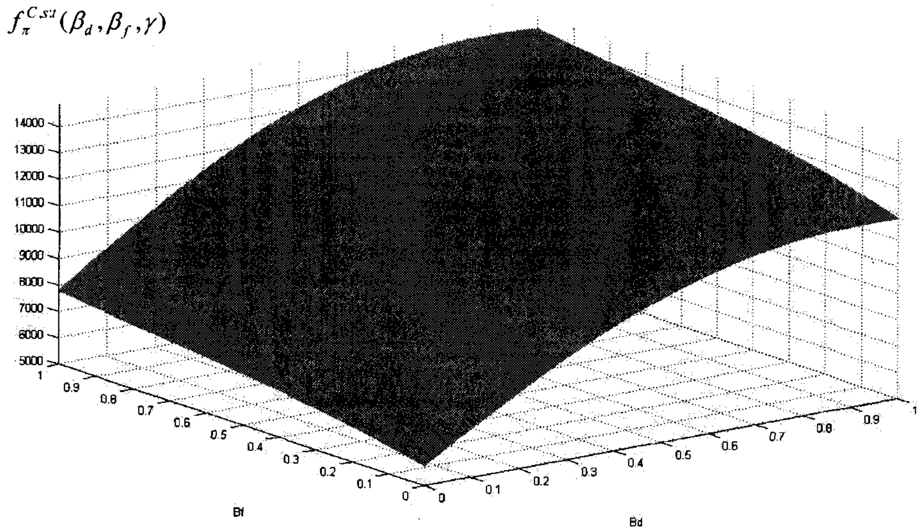


ii-3) Domestic profit; For all $\gamma > 2$:

$$\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{C} = \frac{2\gamma(A-\alpha) f_\pi^{C,st}(\beta_d,\beta_f,\gamma)}{(g^C(\beta_d,\beta_f,\gamma))^2} > 0$$

The graph of $f_\pi^{C,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 32. Graphs of $f_\pi^{C,st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{C} > 0$ for $\gamma > 2$.

Figure 32 - The graph of $f_{\pi}^{C,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

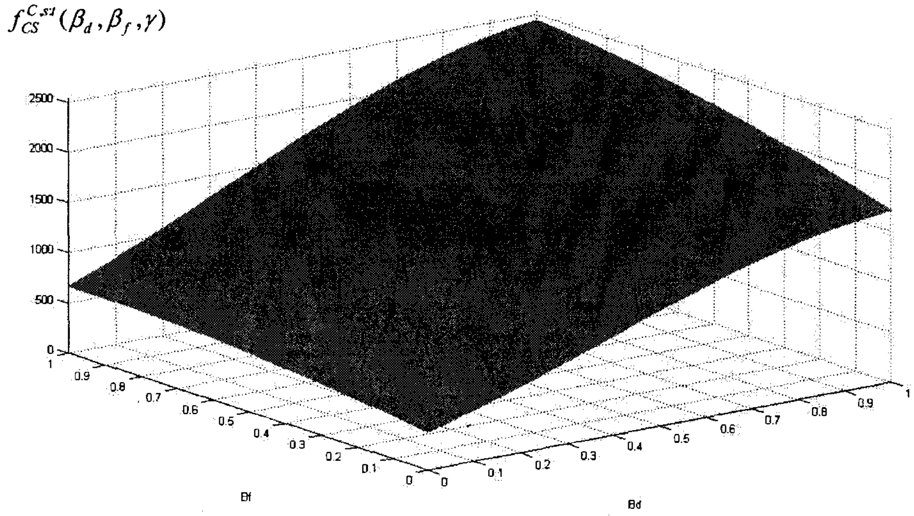


ii-4) Consumer surplus; For all $\gamma > 2$:

$$\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{C} = \frac{-9\gamma^2(A-\alpha)f_{CS}^{C,st}(\beta_d,\beta_f,\gamma)}{(g^C(\beta_d,\beta_f,\gamma))^2} < 0$$

The graph of $f_{CS}^{C,st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 33. Graphs of $f_{CS}^{C,st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{C} < 0$ for $\gamma > 2$.

Figure 33 - The graph of $f_{CS}^{C,s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

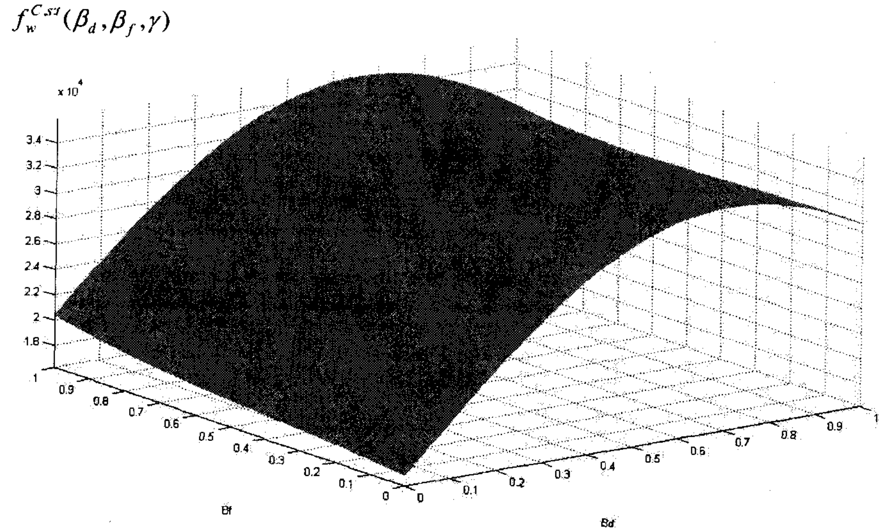


ii-5) Welfare; For all $\gamma > 2$:

$$\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{C} = \frac{\gamma(A-\alpha) f_w^{C,s1}(\beta_d,\beta_f,\gamma)}{(g^C(\beta_d,\beta_f,\gamma))^2} > 0$$

The graph of $f_w^{C,s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 34. Graphs of $f_w^{C,s1}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{C} > 0$ for $\gamma > 2$.

Figure 34 - The graph of $f_w^{C,s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



The analysis of this section suggests that imposing tariffs does not necessarily increase domestic R&D spillovers when there is a foreign R&D subsidy. However, in the presence of a foreign R&D subsidy, imposing tariffs still increases the welfare of the domestic country.

Case 3- Domestic and foreign R&D subsidy model

In this case, both countries grant R&D subsidies to their firms. The home country may also use tariff protection to increase welfare. The following equations show the impact of a tariff on the variables when there are domestic and foreign R&D subsidies.

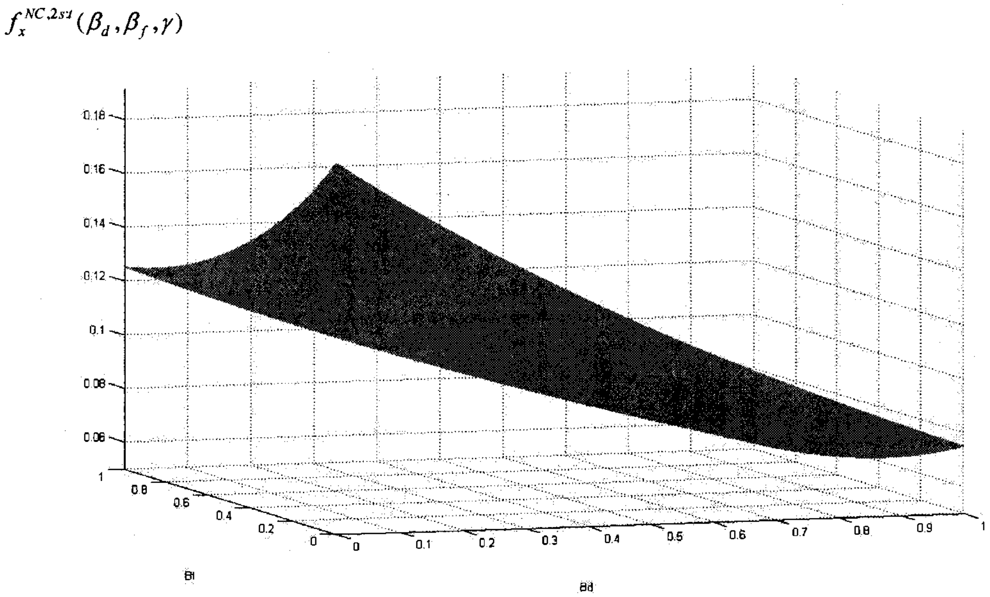
i) Non-cooperation

i-1) Domestic R&D; For all γ >2:

$$\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{NOC} = f_x^{NC,2st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_x^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 35. Graphs of $f_x^{NC,2st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma > 2$.

Figure 35 - The graph of $f_x^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

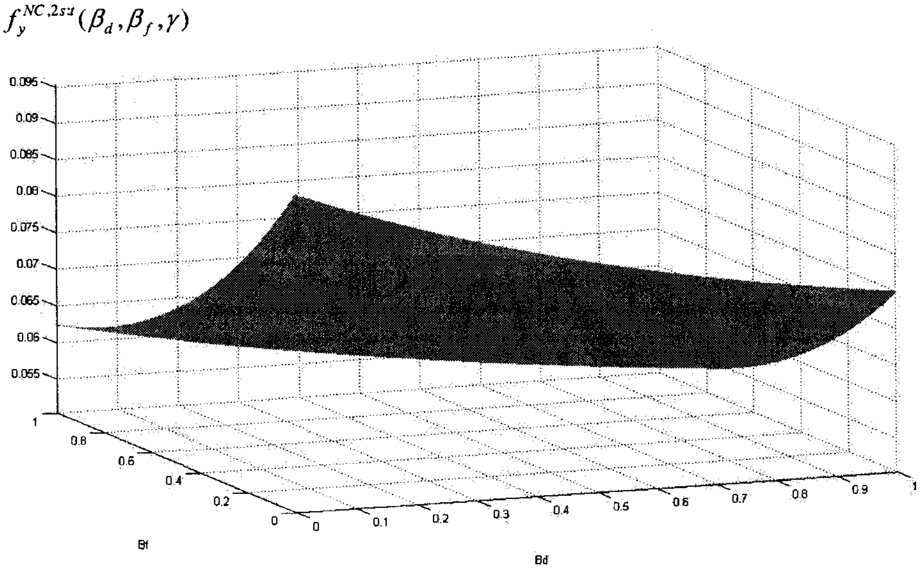


i-2) Domestic output; For all γ >2:

$$\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{NOC} = 3\gamma . f_y^{NC,2st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_y^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 36. Graphs of $f_y^{NC,2st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\dfrac{\partial y_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma > 2$.

Figure 36 - The graph of $f_y^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

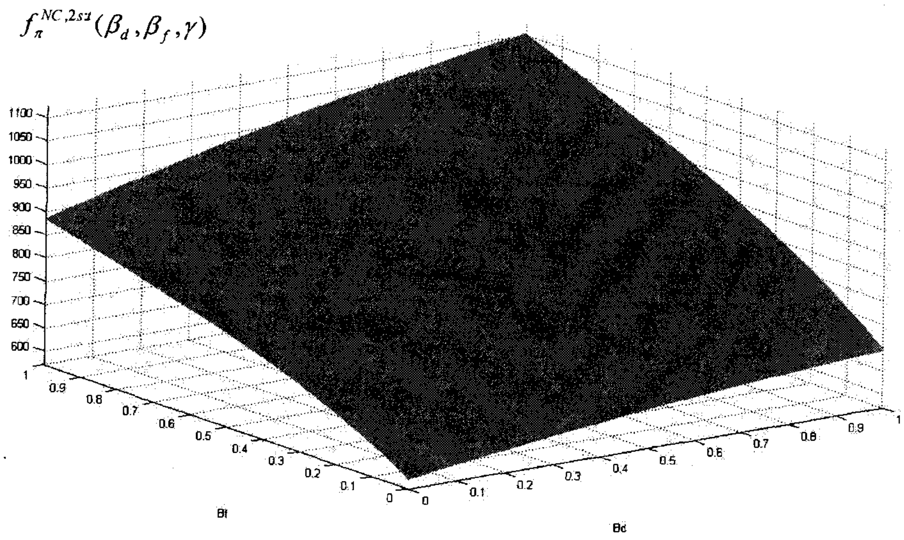


i-3) Domestic profit; For all $\gamma > 2$:

$$\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{NOC} = \gamma(A-\alpha) f_\pi^{NC,2st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_\pi^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 37. Graphs of $f_\pi^{NC,2st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\dfrac{\partial \pi_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma > 2$.

Figure 37 - The graph of $f_{\pi}^{NC,2s1}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$

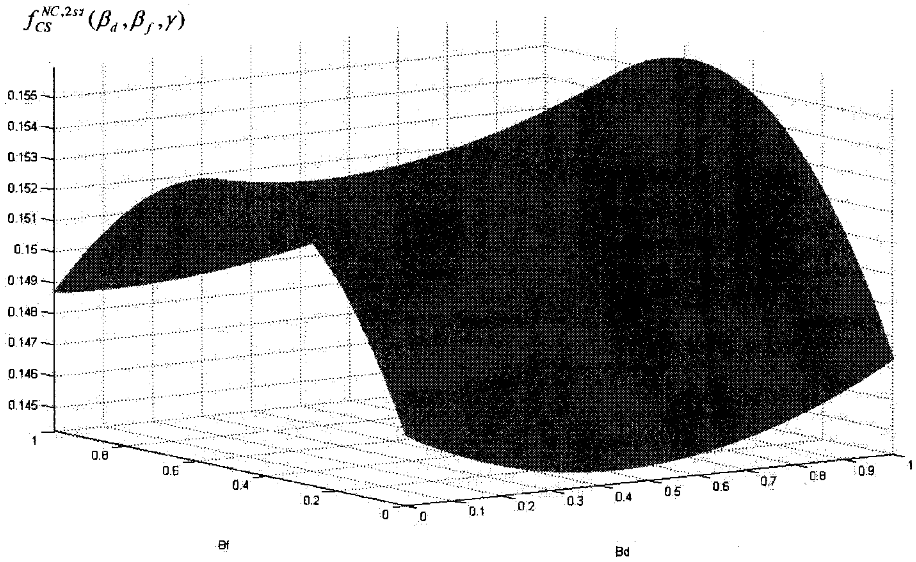


i-4) Consumer surplus; For all $\gamma > 2$:

$$\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{NOC} = -\gamma(A-\alpha) f_{CS}^{NC,2s1}(\beta_d, \beta_f, \gamma) < 0$$

The graph of $f_{CS}^{NC,2s1}(\beta_d, \beta_f, \gamma)$ at $\gamma = 2$ is presented in figure 38. Graphs of $f_{CS}^{NC,2s1}(\beta_d, \beta_f, \gamma)$ for $\gamma \geq 2$ suggest that $\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{NOC} < 0$ for $\gamma \geq 2$.

Figure 38 - The graph of $f_{CS}^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

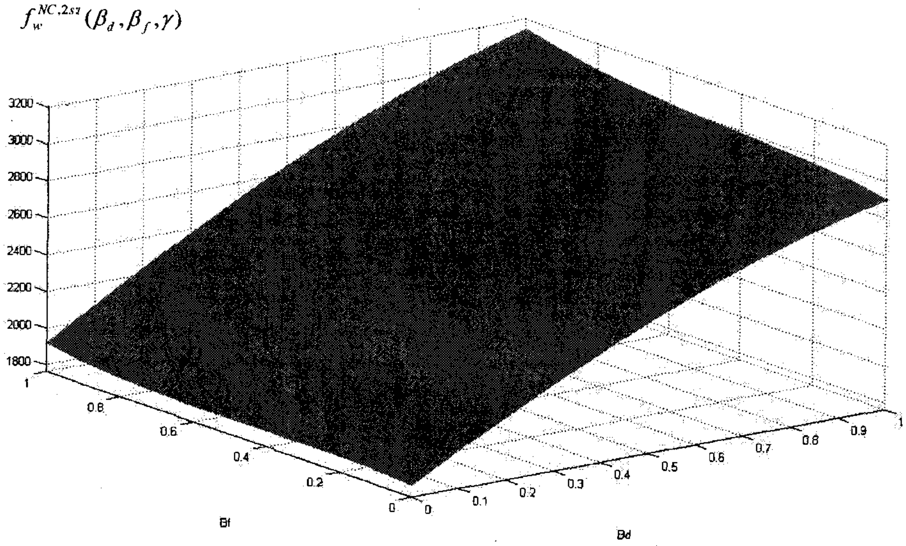


i-5) Welfare; For all $\gamma > 2$:

$$\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{NOC} = (A-\alpha) f_w^{NC,2st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_w^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 39. Graphs of $f_w^{NC,2st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{NOC} > 0$ for $\gamma > 2$.

Figure 39 - The graph of $f_w^{NC,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



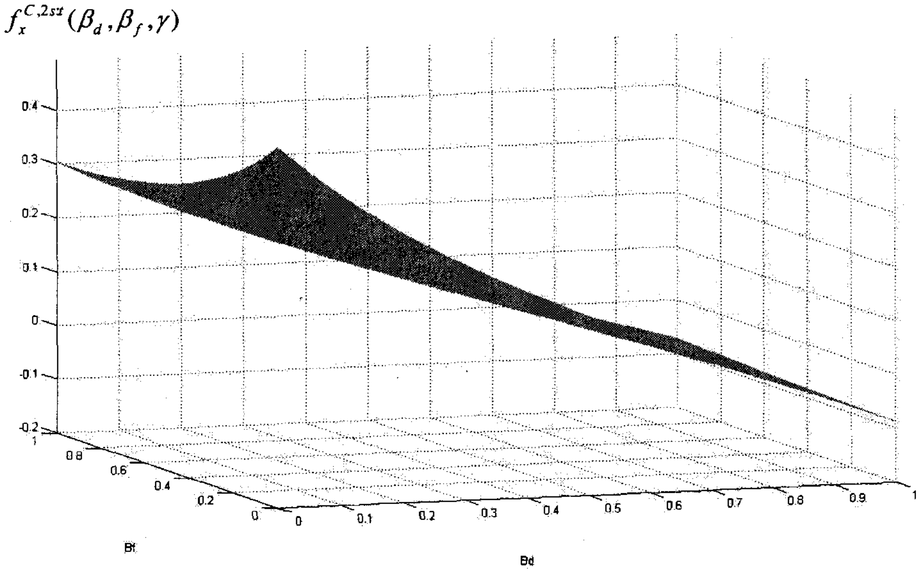
ii) R&D Cartelization

ii-1) Domestic R&D:

$$\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} = f_x^{C,2st}(\beta_d,\beta_f,\gamma)$$

The graph of $f_x^{C,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 40. Analyzing $f_x^{C,st}(\beta_d,\beta_f,\gamma)$ at different values of $\gamma > 2$ suggests that $\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} < 0$ when β_d is close to 1, and $\left[\frac{\partial x_d}{\partial t}\right]_{t=0}^{C} > 0$ in other cases. In other words, imposing tariffs will reduce domestic R&D under R&D cartelization when the domestic spillover is high. Imposing tariffs will increase domestic R&D in other cases. This is similar to the R&D cartelization when there is only a domestic tariff and a foreign R&D subsidy.

Figure 40 - The graph of $f_x^{C,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

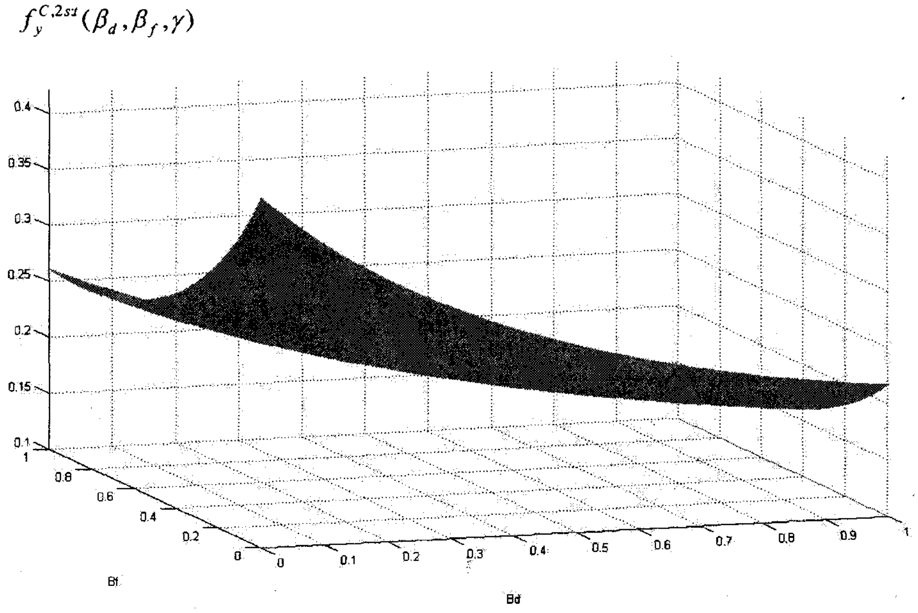


ii-2) Domestic output; For all $\gamma > 2$:

$$\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{C} = \gamma . f_y^{C,2st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_y^{C,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 41. Graphs of $f_y^{C,2st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial y_d}{\partial t}\right]_{t=0}^{C} > 0$ for $\gamma > 2$.

Figure 41 - The graph of $f_y^{C,2s1}(\beta_d,\beta_f,\gamma)$ at γ= 2

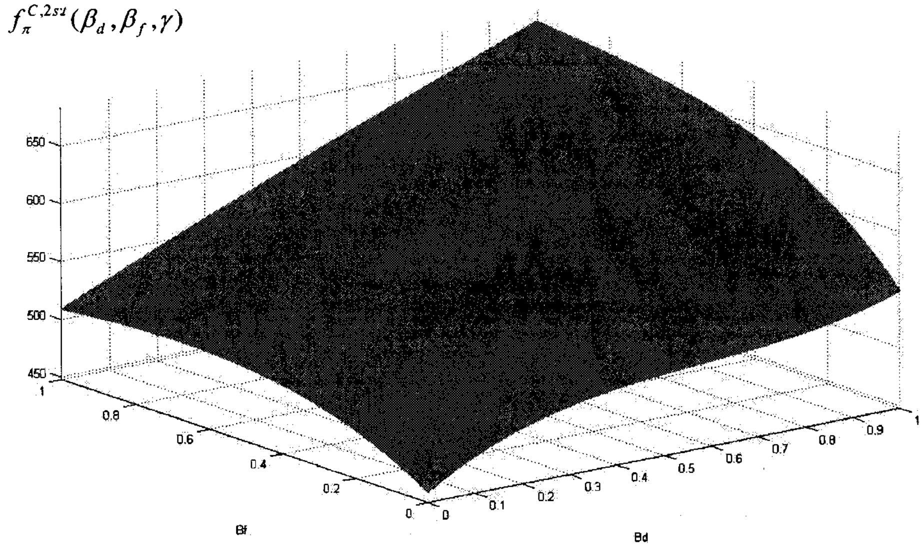


ii-3) Domestic profit; For all γ >2:

$$\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{C} = \gamma(A-\alpha)f_\pi^{C,2s1}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_\pi^{C,2s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 42. Graphs of $f_\pi^{C,2s1}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial \pi_d}{\partial t}\right]_{t=0}^{C} > 0$ for $\gamma > 2$.

Figure 42 - The graph of $f_{\pi}^{C,2s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

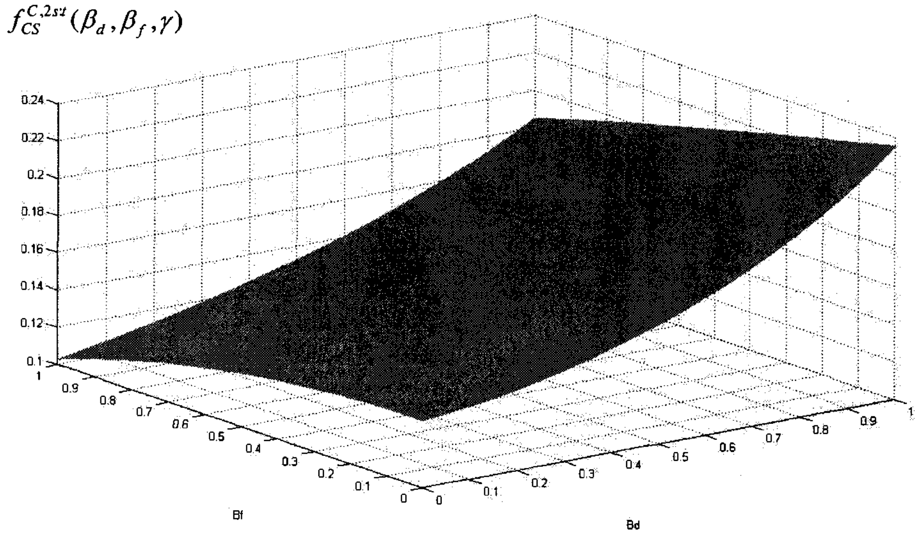


ii-4) Consumer surplus; For all γ >2:

$$\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{C} = -\gamma(A-\alpha) f_{CS}^{C,2s1}(\beta_d,\beta_f,\gamma) < 0$$

The graph of $f_{CS}^{C,2s1}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 43. Graphs of $f_{CS}^{C,2s1}(\beta_d,\beta_f,\gamma)$ for $\gamma \geq 2$ suggest that $\left[\frac{\partial CS_d}{\partial t}\right]_{t=0}^{C} < 0$ for $\gamma \geq 2$.

Figure 43 - The graph of $f_{CS}^{C,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$

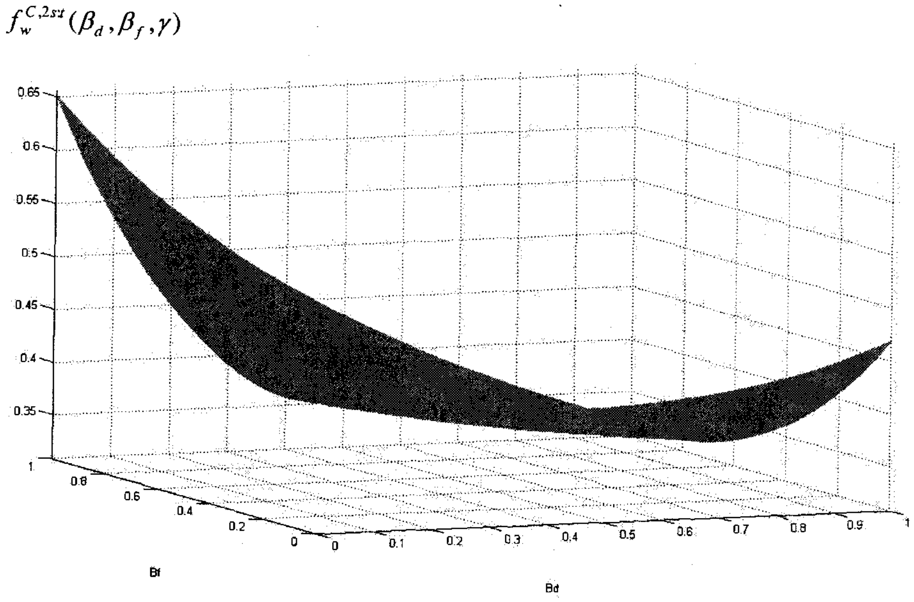


ii-5) Welfare; For all $\gamma > 2$:

$$\left[\frac{\partial w_d}{\partial t}\right]_{t=0}^{C} = (A-\alpha) f_w^{C,2st}(\beta_d,\beta_f,\gamma) > 0$$

The graph of $f_w^{C,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$ is presented in figure 44. Graphs of $f_w^{C,2st}(\beta_d,\beta_f,\gamma)$ for $\gamma > 2$ suggest that $\left[\frac{\partial W_d}{\partial t}\right]_{t=0}^{C} > 0$ for $\gamma > 2$.

Figure 44 - The graph of $f_w^{C,2st}(\beta_d,\beta_f,\gamma)$ at $\gamma = 2$



Analyzing the impact of tariffs when there are domestic and foreign R&D subsidies shows that the results of sections (i) and (ii) of this appendix still hold: introducing tariffs increases the domestic output, profit, and welfare, and decreases consumer surplus. Domestic R&D expenditures always increase because of the tariff if the firms do not cooperate on R&D. Sections 4, 5, and 6 of the paper compare the optimal values of these variables under different scenarios.

Chapter 2

Revisiting the Impacts of Domestic and Foreign Technology Spillovers on Canadian Industries

Abstract

This chapter studies the impacts of domestic and international technology spillovers on the growth rate of Canadian manufacturing industries. It is assumed that Canada is a small open economy, which obtains a large extent of its technology from abroad. This paper examines whether different types of industries have different technology spillover rates. To test these hypotheses, Canadian industries are categorized into three groups based on their characteristics as low-tech, medium-tech, and high-tech. It is expected that more advanced technologies have higher spillover rates. The study is done on 14 Canadian industries for the period 1978-1997. According to the empirical results, only foreign R&D has a positive and significant impact on productivity. Domestic R&D is not significant under any of the specifications; however, it helps industries absorb foreign R&D.

1- Introduction

One of the main goals of governments is to achieve a higher economic growth. Technology growth has been the main source of economic growth in the last decades. Furthermore, technology is critical for the economic success and survival of a firm in a highly competitive environment that appeared in the new integrated economy. One way of capturing new technology is to import it from more advanced countries. This issue is especially important now a day, where there are greater knowledge spillovers among countries, and national borders are less barriers to technology transfer as they used to be.

This paper studies the roles of domestic and foreign technology spillovers through importing goods on the growth rate of Canadian manufacturing industries. It is assumed that Canada is a small open economy, which obtains an extensive part of its technology from abroad. Moreover, the paper assumes that there are different technology diffusion rates for different sectors of the economy. Examining this hypothesis is important because most empirical studies on technology spillovers implicitly assume that different industries have the same technology spillover and technology absorption rates.

The paper is based on the endogenous growth models developed by Grossman and Helpman (1990, 1991a, 1991b, 1991c), Romer (1990), and Barro and Sala-i-Martin (2004). In these models, technology grows with investment in R&D and with the increase in the stock of general knowledge. Grossman and Helpman, and Barro and Sala-i-Martin assume symmetric technology improvement in all sectors and solve their models under this assumption. However, some researchers suggest that different sectors of the economy may have different technology diffusion rates due to their natures (e.g. Grossman and Helpman, 1991a; Link and Siegel, 2003; Comin et al., 2006). If we assume different technology spillover rates, we may draw different results from previous models of technology growth in a small open economy in terms of trade and technology policies.

The contributions of this paper to the literature are as follows: (i) To the author's best knowledge, this is the first study that breaks down total domestic and foreign R&D into the domestic and foreign R&D's of industries with similar characteristics. This means that we will have industrial groups that are different in terms of their R&D spillovers. This helps us study the spillovers rate of each group separately. (ii) This study uses a different methodology to construct domestic and foreign R&D capital and to capture the impacts of R&D expenditures on productivity from other studies for Canada. According to the empirical results, only foreign R&D has a positive and significant impact on productivity. Domestic R&D is not significant under any of the specifications; however, it helps industries absorb foreign R&D.

The structure of the paper is as follows. The next section reviews the theoretical and empirical papers that address the impact of R&D spillovers on economic growth. Section 3 introduces the theoretical background and econometric models that will be used to examine the hypotheses of this study. Section 4 introduces data sources. Section 5 presents the estimation results. Section 6 concludes.

2- Literature Review

This section presents some of the studies on R&D spillovers and technological growth. The first part of this section presents the theoretical papers on the effects of R&D spillovers on economic growth. These papers are based on endogenous growth models and have been extended to capture technological growth and technology spillovers from other countries. The second part of this section presents empirical studies. In these studies, productivity growth is considered as a measure of the final benefits of innovations. Moreover, R&D expenditures are generally considered the best available proxy for knowledge investment.

Grossman and Helpman (1990a, 1991a), Rivera-Batiz and Romer (1991), Devereux and Lapham (1994), and Barro and Sala-i-Martin (2004) develop economic growth models that link domestic and international knowledge accumulation to economic growth. Most models assume that international knowledge is transferred into the home country through international trade. Yet, some authors consider foreign investment as the other major vehicle for technology transfer (e.g. Globerman, 1979; Saggi, 2002; Saggi and Glass, 2002; Keller, 2004; Keller and Yeaple, 2005; Xu and Chiang, 2005). Other models that relate economic growth to international technology diffusion include Brecher et al. (2002) and Findlay (1995).

There are two approaches to model technological changes in the literature (Barro and Sala-i-Martin, 2004). In the first approach, technological progress is shown by increasing the number of varieties of products. This way, producing a new variety is synonym to making a new innovation or opening up a new technology. It is assumed that increasing the number of varieties needs purposive R&D effort by firms. The second approach for showing technological changes is the Schumpeterian model of quality ladders, in which the quality or productivity of each type of products will improve. In this approach, we assume that the new product has a higher quality and substitutes out the same product with a lower quality.

A major empirical contribution on the relationship between domestic and foreign R&D expenditures and productivity growth is done by Coe and Helpman (1995), where they split knowledge into domestic knowledge and foreign knowledge received by international trade. Other empirical studies on the relationship between R&D expenditures and economic growth include Coe, Hoffmaiser, and Helpman (1997), Bayoumia, Coe, and Helpman (1999), Diao, Roe, and Yeldan (1999), Smith (1999), Choudhri and Hakura (2000), Bouet (2001), Mayer and Blaas (2002), Keller (2002a), Schiff and Wang (2003, 2006), Keller and Yeaple (2005), Kneller (2005), Cameron, Proudman, and Redding (2005), and Acharya and Keller (2006). Most of these studies find a positive relationship between R&D expenditures and economic growth.

With respect to the role of foreign R&D, Eaton and Kortum (1996) conclude that in 1988, around 85% of the productivity growth in France, Germany, and the United Kingdom and 40% of the productivity growth in the United States were due to foreign R&D. The model is further developed in Eaton and Kortum (1999, 2001). Meanwhile, Keller (2002b) concludes that own-industry R&D accounts for about 50% of the total effect on productivity, domestic inter-industry for 30%, and foreign technology spillovers for 20%.

A few studies have been conducted on the relationship of R&D expenditures and productivity growth in Canada. Industry level studies by Globerman (1972), Postner and Wesa (1983), and Leung and Zheng (2008) do not find a significant relationship between industrial R&D expenditures and productivity growth in Canada. While, Bernstein (1986, 1988, 1989, and 1996), Bernstein and Yan (1997) firm-level studies, and Hanel (2000) find that domestic R&D spillovers are positive and significant for Canadian industries.

Also, Bernstein finds that the social rate of return to R&D exceeds the private rate of return by a factor of two or more in most cases. This means that there will be underinvestment in R&D if R&D decisions are made by the market.

Table 1- Summary of R&D spillover rates of some studies

Author	Method	Country	R&D spillover rates
Bernstein (1988)	translog cost function; Firm level	Canada	elasticies to R&D vary from 0.077 to 0.148 for different industries, with median equal to 0.089
Bernstein (1989)	translog cost function; Firm level	Canada	elasticies to R&D vary from 0 to 0.70 for different industries, with median equal to 0.16
Bernstein (1996)	translog cost function; Firm level	Canada	elasticies to R&D vary from 0.189 to 0.495 for different industries, with median equal to 0.383
Bernstein and Yan (1997)	translog cost function; Firm level	Canada	elasticies to R&D vary from 0.175 to 1.640 for different industries, with median equal to 1.250
Guellec (2001)	TFP based on Cobb-Douglas production function; Industry level; 1980-1998	OECD	elasticities of TFP to business R&D from 0.022 to 0.029 (long-run effects) depending on the method of estimation
Keller (2002b)	TFP; Industry level; 1970-1991	G7 + Sweden	TFP growth is 50% due to its own R&D, 30 due to other industries R&D, and 20% due to foreign R&D
Acharya and Keller (2006)	TFP based on Cobb-Douglas production function; Industry level; 1973-2002	OECD	elasticities of TFP to R&D for Canada from 0.134 to 0.249 depending on the method of estimation
Schiff and Wang (2006)	TFP based on Cobb-Douglas production function; Industry level; 1976-1998	OECD + developing dountries	elasticity of TFP to R&D is equal to 0.16 for developed countries

Table 1 presents the summary of R&D spillover rates for some of the foresaid studies. These studies have either concentrated on Canadian industries or use a similar approach to this paper to estimate industrial R&D spillover.

More studies have been done by Bernstein and Nadiri (1988) on the effects of inter-industry R&D spillovers in five US high-tech industries; by Denny et al. (1992) on estimating the TFP growth of manufacturing industries of Japan, Canada, and the United

States; and by Bernstein and Mohnen (1998) on the mutual effects of R&D investments in the United States and Japan on production costs, factor intensities and productivity growth of these countries. One of the issues in the Bernstein studies is that the estimated R&D spillovers vary widely in his different studies[1]. Also, the ranking of industries are different from one study to another in terms of their R&D spillovers.

Studies conducted in Canadian industries at the micro level show that a number of factors may influence the adoption rate of technology in Canadian industries (Baldwin, 1995; Baldwin and Sabourin, 1995, 1998; Baldwin, J., B. Diverty, and D. Sabourin, 1995; Baldwin, Sabourin and Rafiquzzaman, 1996; Baldwin and Rafiquzzaman, 1996; Baldwin, Rama and Sabourin, 1999; and Sabourin and Beckstead, 1999; Gu and Tang, 2003; Baldwin and Gu, 2004). The results of these studies are as follows. First of all, ideas for the adoption of technology come from both inside and outside the firm. In other words, both internal and external sources are important. R&D is an important input into the innovation process. Firms engage in R&D both to create new products and processes and also to be more receptive to the technological advances of others. Research and development, either done within the enterprise or contracted out, increases the probability of technology adoption. Moreover, R&D that is carried out within the enterprise has the strongest effect on the probability of technology adoption. Secondly, the use of advanced technology increases with establishment size (in terms of employee number). In fact, it seems that establishment size is the single most important characteristic related to both technological incidence and intensity in Canada (Baldwin and Sabourin, 1995; Baldwin, Rama and Sabourin, 1999). The reason could be the access to more developed

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[1] The median of the external rate of return on R&D for the Canadian economy varies in his studies from 0.089 in Bernstein (1988) to 1.250 in Bernstein and Yan (1997).

information networks, superior financial and technical resources, and economies of scale. Education is another important factor in technology use. Firms lacking workers with necessary skills to effectively operate and maintain the new technology may choose to introduce training programs for their current workforce, or they may search for and recruit new employees with necessary skills.

This paper brings a new insight to the impact of foreign and domestic R&D spillovers in Canadian manufacturing industries, assuming that different industries have different spillover rates. The paper examines whether this assumption draws different results from other studies.

3- Model

This section summarizes some of the main theoretical backgrounds of the models that examine the effects of domestic and foreign R&D spillovers on technological growth and productivity of a small open economy. The theoretical model is based on Grossman and Helpman (1990a, 1990b, 1991a, 1991b, 1991c) and Barro and Sala-i-Martin (2004). The empirical model of this section extends the model to include asymmetric technology diffusion in a small open economy.

The basic model is as follows. Assume there are two sectors in the economy with the following production functions:

$$Y = A_Y D_Y^{\beta} K_Y^{1-\beta} ,$$

$$Z = A_Z D_Z^{\beta} L_Z^{1-\beta} .$$

There are two primary factors as capital, K, and labor, L. A_Y and A_Z are the levels of technology in the country or government policies. D_i is an index of intermediate goods used in sector i, $i = Y, Z$. D_i is defined as follows:

$$D_i = \sum_{j=1}^{N} (X_{ij})^{\alpha} ,$$

where X_{ij} is the amount of intermediate good j that is used in sector i. The model assumes that the country is small and a price taker. Also, it assumes that the two final goods are tradable, but the intermediate goods are non-tradable[1]. In this case, if both final goods are produced, each one must have a unit cost equal to its world price.

In this type of R&D modeling, technological progress is measured by the increase in the number of known intermediate goods, N, rather than the productivity parameter A. It is assumed that the increase of N needs purposive effort in the form of R&D. R&D firms face a two-stage decision process. In the first stage, they decide if they want to invest in R&D to invent a new product. They will devote resources to R&D if the net present value of their future expected profits is more than their R&D expenditures. In the second stage, the firms decide on the optimal sale price of the newly invented good.

Grossman and Helpman (1991) assume that new intermediate goods are produced with two inputs, capital and general knowledge. The greater the stock of general knowledge among inventors and the greater the stock of capital, the greater the number of newly invented intermediate goods will be. In other words, the number of available intermediates grows as follows:

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[1] This is an assumption to simplify the model.

$$\dot{n} = \frac{H.K_R}{a_{KR}},$$

where H is the stock of general knowledge, K_R is the capital used in R&D to develop new intermediates, and a_{KR} is the productivity parameter.

The stock of general knowledge grows in two ways. First, in the process of R&D to develop a new intermediate good, inventors generate discoveries that have wider applicability and can increase general knowledge. In other words, in the process of inventing a new variety of an intermediate good, two types of outputs are generated. The first type is an appropriable output that can be protected by patents or other means of R&D protection. The second part is an inappropriable output that other inventors may benefit of freely. This part adds to the stock of general knowledge. This property is due to the public good nature of R&D and the fact that R&D has positive externalities on other sectors. The stock of general knowledge is non-rival, i.e. the same idea can be used in different applications and in different locations at the same time. Also, knowledge is usually non-excludable. This means that the inventors of knowledge cannot easily get compensation from other agents who use their generated ideas.

The second channel through which a small country can accumulate its stock of general knowledge is the interaction with the outside world. International trade, foreign direct investment, and attending seminars and workshops are some of the methods that may increase capital knowledge. It is assumed that the more a small country has interactions with the outside world, the more it can benefit from the accumulated knowledge of the world. This paper assumes that interaction of the small country with the world takes place only through international trade.

Under these assumptions, the stock of knowledge in the small country at time t is a function of the accumulated amount of domestic research, which can be represented by the number of available intermediate goods, $n(t)$, and the volume of trade, $T(t)$:

$$H(t) = F[n(t), T(t)],$$

where F is increasing in both n and T. Both Grossman and Helpman (1990a, 1991a, 1991b, 1991c) and Barro and Sala-i-Martin (2004) assume symmetric technology improvement and solve their models under this assumption.

To test this model empirically, this paper uses an approach similar to Coe and Helpman (1995). This approach has been widely used in the recent literature to model the effect of foreign R&D on domestic TFP when international trade is the main carrier of foreign technology. Coe and Helpman's (1995) model is as follows. Suppose the aggregate production function for country i at time t is as follows:

$$Y_{it} = F_{it}(L_{it}, K_{it}, S_{it}), \qquad (1)$$

where Y, L, K, and S are GDP, labor, capital, and knowledge capital of country i. If we assume F exhibits a Cobb-Douglas form, we will have the following equation after applying logarithm:

$$\log TFP_{it} = \alpha_S \log S_{it-1}, \qquad (2)$$

where

$$\log TFP_{it} = \log Y_{it} - \alpha_L \log L_{it} - \alpha_K \log K_{it}, \qquad (3)$$

where α_S, α_L, and α_K are the elasticities to knowledge capital, labor, and capital. Suppose that the knowledge capital, S, consists of domestic knowledge, RD, and foreign knowledge, FRD:

$$\log S_{it} = \alpha_D \log RD_{it} + \alpha_F \log FRD_{it}. \qquad (4)$$

In Coe and Helpman (1995), *RD* is the stock of domestic R&D expenditures, and *FRD* is the stock of foreign R&D embodied in imported goods. The final equation Coe and Helpman derive is as follows:

$$\log TFP_{it} = \alpha_i + \alpha_t + \alpha_d \log RD_{it-1} + \alpha_f \log FRD_{it-1} + \varepsilon_{it}\,, \qquad (5)$$

where TFP_{it} is the total factor productivity of industry i at time t, α_i is the industry effect, α_t is the time effect, RD_{it-1} is the domestic R&D in industry i at time t-*1*, FRD_{it-1} is the foreign R&D received by industry i at time t-*1*, and ε_{it} is the error term. We use the R&D variables with one lag because it takes time for R&D expenditures to affect the productivity.

We assume that the R&D of industry i is the R&D expenditures in industry i (intra-industry spillovers) plus a weighted sum of R&D's of all other industries (inter-industry spillovers):

$$RD_{it} = RD\_own_{it} + RD\_others_{it} = RD\_own_{it} + \sum_{j=1}^{I} w_{ij} RD_{jt}\,, \qquad (6)$$

where the weights, w_{ij}, are the input-output coefficients. Similarly, we assume that the foreign R&D for industry i of the country, FRD_{it}, is the sum of the foreign R&D received directly from the industry i's of other countries and the weighted sum of the R&Ds of other foreign industries[1]:

$$\begin{aligned} FRD_{it} &= FRD\_own_{it} + FRD\_others_{it} = FRD\_own_{it} + \sum_j w_{ij} \overline{FRD}_{jt} \\ &= FRD\_own_{it} + \sum_j w_{ij} \left[\sum_k \left(\frac{M_{jkt}}{Output_{jt} + \sum_q M_{jqt} - \sum_q X_{jqt}} \right) RD_{jkt} \right], \qquad (7) \end{aligned}$$

---

[1] The second term for R&D has been adapted Schiff and Wang (2006).

where t indexes time, k and q index developed countries, i and j index industries, M_{jkt} is the country's imports from industry j in country k, X_{jkt} is the country's exports of industry j in country k, RD_{jkt} is the R&D stock of industry j in country k, and w_{ij} is the import's input-output coefficient, which measures the share of industry j's output that is sold to industry i of the country. Since the data on import input-outputs are not available, import input-outputs are proxied by domestic input-output flows. Also, $Output_{jt}$ is the country's total output of industry j, $\sum_q M_{jqt}$ is the country's total import in industry j, and $\sum_q X_{jqt}$ is the country's total export in industry j. The equation $FRD_{it} = \sum_j w_{ij} \overline{FRD}_{jt}$ states that the foreign R&D in industry i is the sum over all industries j, of $\overline{FRD}_{jt}$, the industry j's forign R&D obtained through trade, adjusted by w_{ij}, the share of output of industry j that is sold to industry i.

This paper extends equation (5) to examine whether different industries have different spillover and absorption rates. First, we estimate the impacts of domestic and foreign R&D on the total factor productivity (TFP) by using the base equation (5). Since the data series of equation (5) are non-stationary, the first difference of the variables are used (Model 1):

$$\begin{aligned} \Delta \log TFP_{it} = \alpha_i + \alpha_t + \alpha_d^w \Delta \log RD\_own_{it-1} + \alpha_d^t \Delta \log RD\_others_{it-1} + \\ + \alpha_f^w \Delta \log FRD\_own_{it-1} + \alpha_f^t \Delta \log FRD\_others_{it-1} + \varepsilon_{it}, \end{aligned} \tag{8}$$

where Δ in front of a variable means the first difference of that variable, α_d^w is the impact of the R&D of each industry in itself, α_d^t is the impact of the R&D of other industries,

α_f^w is the impact of the foreign R&D of each industry in itself, and α_f^t is the impact of the foreign R&D of other industries.

Model 1 is the general model that is usually used in empirical studies to estimate the effects of R&D on total factor productivity. As explained earlier, this model implicitly assumes that all industries have the same domestic and foreign R&D spillover rates. This unique rate is determined by α_d for the domestic R&D and α_f for the foreign R&D. This paper examines if this assumption is valid by using the data of Canadian industries.

First, we allow having different foreign spillover rates for different industries. If we assume that each industry has a unique R&D spillover rate, we can rewrite equation (5) as follows:

$$\log TFP_{it} = \alpha_i + \alpha_t + \sum_{j=1}^{I} \alpha_d^j w_{ij} \log RD_{jt-1} + \sum_{j=1}^{I} \alpha_f^j w_{ij} \log FRD_{jt-1} + \varepsilon_{it}, \qquad (9)$$

where $w_{ij} = 1$ if $i = j$, $i = 1, \ldots, \mathrm{I}$. Under this specification, α_d^i estimates the impact of the R&D of industry *i* and α_f^i estimates the impact of the foreign R&D of industry *i*. This way, we estimate *i* different coefficients for *i* industries instead of having just one coefficient for all industries as in equation (5). This specification is analogous to Coe and Helpman (1995), where total R&D is split into domestic and foreign R&D, and Guellec and van Pottelsberghe (2003) and Acharya and Coulombe (2006), where total R&D is split into public R&D (government and university) and business R&D. However, since we do not have enough observations to estimate this model, we categorize industries into three groups according to their similarities and specifications based on the OECD classification of the Low-Tech, Medium-Tech, and High-Tech technologies. Section 5 explains this classification in more details. To be able to compare the results with the base model, we break down *R&D_own*, *R&D_Others*, and *Foreign R&D_own* one at a time. First, we assume that the foreign R&D of different industry groups have different spillover rates on the domestic industries. To test this hypothesis, we separate the impacts of the Low-Tech, Medium-Tech, and High-Tech industries in equation (5) by using dummy variables as follows (Model 2):

$$\begin{aligned}\Delta \log TFP_{it} = \alpha_i + \alpha_t + \alpha_d^w \Delta \log RD\_own_{it-1} + \alpha_d^t \Delta \log RD\_others_{it-1} \\ + \alpha_f^L D_L * \Delta \log FRD\_own_{it-1} + \alpha_f^M D_M * \Delta \log FRD\_own_{it-1} \\ + \alpha_f^H D_H * \Delta \log FRD\_own_{it-1} + \alpha_f^t \Delta \log FRD\_others_{it-1} + \varepsilon_{it},\end{aligned} \tag{10}$$

where α_f^L, α_f^M, and α_f^H are the impacts of the foreign R&D of Low-Tech, Medium-Tech, and High-Tech industries. This way, we will examine if there is any significant difference among the impacts of different classes of industries in terms of their foreign R&D's.

Similarly, we can separate the impacts of the R&D's of the Low-Tech, Medium-Tech, and High-Tech industries on own industries (Model 3):

$$\begin{aligned}\Delta \log TFP_{it} = \alpha_i + \alpha_t + \alpha_d^{wL} D_L * \Delta \log RD\_own_{it-1} + \alpha_d^{wM} D_M * \Delta \log RD\_own_{it-1} \\ + \alpha_d^{wH} D_H * \Delta \log RD\_own_{it-1} + \alpha_d^t \Delta \log RD\_others_{it-1} \\ + \alpha_f^w \Delta \log FRD\_own_{it-1} + \alpha_f^t \Delta \log FRD\_others_{it-1} + \varepsilon_{it},\end{aligned} \tag{11}$$

where α_d^{wL}, α_d^{wM}, and α_d^{wH} are the intra-industry impacts of the R&D of Low-Tech, Medium-Tech, and High-Tech industries. To examine whether there are different inter-industry spillover rates, we break down *R&D_Others* into three groups of Low-Tech, Medium-Tech, and High-Tech industries. The result will be as follows (Model 4):

$$\begin{aligned}\Delta \log TFP_{it} &= \alpha_i + \alpha_t + \alpha_d^w \Delta \log RD\_own_{it-1} + \alpha_d^{tL} \Delta \log RD\_oth\_Low_{it-1} \\ &+ \alpha_d^{tM} \Delta \log RD\_oth\_Medium_{it-1} + \alpha_d^{tH} \Delta \log RD\_oth\_High_{it-1} \qquad (12) \\ &+ \alpha_f^w \Delta \log FRD\_own_{it-1} + \alpha_f^t \Delta \log FRD\_others_{it-1} + \varepsilon_{it},\end{aligned}$$

where α_d^{tL}, α_d^{tM}, and α_d^{tH} are the inter-industry impacts of the R&D of Low-Tech, Medium-Tech, and High-Tech industries. Similarly, we distinguish among the inter-industry foreign spillover rates by breaking down *Foreign R&D_Others* into three groups of Low-Tech, Medium-Tech, and High-Tech industries. The result will be as follows (Model 5):

$$\begin{aligned}\Delta \log TFP_{it} &= \alpha_i + \alpha_t + \alpha_d^w \Delta \log RD\_own_{it-1} + \alpha_d^t \Delta \log RD\_others_{it-1} \\ &+ \alpha_f^w \Delta \log FRD\_own_{it-1} + \alpha_f^{tL} \Delta \log FRD\_oth\_Low_{it-1} \qquad (13) \\ &+ \alpha_f^{tM} \Delta \log FRD\_oth\_Medium_{it-1} + \alpha_f^{tH} \Delta \log FRD\_oth\_High_{it-1} + \varepsilon_{it},\end{aligned}$$

where α_f^{tL}, α_f^{tM}, and α_f^{tH} are the inter-industry impacts of the foreign R&D of Low-Tech, Medium-Tech, and High-Tech industries. Examining these models with Canadian data shows whether domestic and foreign R&D spillovers in Canada support the hypothesis of the paper.

4- Data

R&D expenditures have been retrieved from ANBERD dataset in SourceOECD in ISIC revision 2 for 1973-1997. Since the R&D expenditures are in current PPP US dollars, they have been made constant by using the US GDP deflator. The R&D stocks have been constructed by using the R&D expenditures. The depreciation rate for R&D is assumed to be 25%. The data consists of R&D expenditures of Canada and 14 advanced

OECD countries[1]. To keep the data of the model consistent, labor, investment, value added, human capital, and the number of enterprises have also been retrieved from SourceOECD. The import shares of Canadian industries and the input-output coefficients have been obtained from World Bank database "Trade and Production 1976-1998" (Nicita and Olarreaga, 2001). These data series are available in ISIC revision 2. The input-output coefficients are constant over time. The industrial imports are available from 1978. All data sets have accordingly been aggregated to match with the import and input-output coefficients. The total factor productivity has been calculated by using the following equation:

$$\log TFP_{it} = \log VA_{it} - w_{it} \log L_{it} - (1 - w_{it}) \log K_{it},$$

where *TFP* is the total factor productivity, *VA* is the value added, *L* is labor, and *K* is the capital stock. *w* is the share of the wage bill in value added[2]. The source of all of these variables is STAN database of the SourceOECD. The capital stocks are calculated from investment series by using the perpetual inventory model with a 10% depreciation rate. Appendix 1 presents the list of the industries used in this study. Appendix 2 explains how the foreign R&D variable has been constructed.

5- Results

This section presents the empirical results and main findings of the models. First , we present the results of the base model. Then, we present the results of extended models.

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[1] Australia, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom, and United States.

[2] Some w's have to be adjusted because the share of labor in value added becomes greater than one for some industries in some years. This happens when the industries receive subsidies. In this case, the w was set to the average of the former and previous years.

5- 1- Baseline results

Table 2 presents the results of Model 1, in which the impacts of domestic and foreign R&D on TFP of Canadian industries are identified under different specifications.

Table 2- The estimation results for Model 1

ΔTFP	**FE**	**GLS**	**PCSE**	**GMM**	**Sys GMM**	**LDPD**	**IV 2SLS**	**VEC**
ΔRD_own	0.879	0.812	0.137	0.756	0.175	0.876	2.322	0.290
	(0.965)	(0.769)	(1.119)	(1.188)	(1.194)	(0.912)	(2.698)	(0.234)
ΔRD_others	1.301	1.009	0.722	2.040	3.230	0.582	0.614	-0.104
	(2.772)	(2.100)	(2.405)	(4.092)	(3.210)	(4.617)	(3.368)	(0.524)
ΔFRD_own	0.429^{e}	0.460^{c}	0.582^{c}	0.592^{c}	0.654^{c}	0.500^{c}	0.559^{c}	0.240^{e}
	(0.311)	(0.263)	(0.359)	(0.328)	(0.381)	(0.273)	(0.358)	(0.177)
ΔFRD_others	-0.014	0.045	0.374	0.176	0.191	0.269	0.013	-0.088
	(0.647)	(0.554)	(0.513)	(0.609)	(0.420)	(0.656)	(0.658)	(0.491)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; FE: Fixed-effects regression; GLS: Cross-sectional Time-series Generalized Least Squares; PCSE: Linear regression with panel-corrected standard errors; GMM: Arellando-Bond linear dynamic panel-data estimation; System GMM: Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation; LDPD: Linear Dynamic Panel-Data Estimation; IV 2SLS: Instrumental variables and two-stage least squares; VEC: Vector Error Correction Model (long-run coefficents); All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

According to table 2, only the coefficient of the foreign R&D is significant. This result is consistent with other industry-level studies on Canadian R&D, in which the effect of domestic R&D is either insignificant or close to zero and the foreign R&D is the main contributor to the TFP (e.g. Mohnen, 1992; Globerman 1972; Postner and Wesa, 1983; Leung and Zheng, 2008). Though, this result is in contrast with firm-level studies in Canada and cross-country studies countries.

The impact of the foreign R&D is positive and significant under all specifications. This result is consistent with other Canadian and cross-country studies that suggest the foreign R&D is the main contributor to TFP. The average elasticity of TFP to foreign R&D is 55%. This is more than 20% in Keller (2002b), but less than 85% in Eaton and

Kortum (1996). In what follows, we split domestic and foreign R&D's into different industrial groups and compare the results with the baseline model.

5- 2- Breaking down foreign R&D

To further explore the role of foreign R&D in Canada and also test the hypothesis of the paper, suggesting that different industrial groups have different spillover rates, we estimate the impacts of the Low-tech, Medium-Tech, and High-Tech industries separately as suggested in Model 2. For this purpose, the 14 industries are broken down into 3 groups based on the OECD classification. OECD classifies manufacturing industries into 4 groups as low technology, medium-low technology, medium-high technology, and high technology industries. Due to the level of data integration of this study, it is more convenient to merge medium-high and high technologies into one group. The 3 groups of this study and their OECD equivalents are as follows:

- Low-Tech industries (equivalent to OECD low technology):
    - Food, Beverages & Tobacco
    - Textiles, Apparel & Leather
    - Wood Products & Furniture
    - Paper, Paper Products & Printing
    - Other Manufacturing
- Medium-Tech industries (equivalent to OECD medium-high technology):
    - Petroleum Refineries & products
    - Non-Metallic Mineral Products
    - Iron & Steel

  - Non-Ferrous Metals
  - Metal Products
  - Chemicals & Rubber +Plastic Products
- High-Tech industries (equivalent to OECD medium-high and high technologies):
  - Machinery & Equipment, nec
  - Manufacture of transport equipment
  - Manufacture of electrical machinery apparatus, appliances and supplies + Professional Goods

Under this classification of industries, Table 3 presents the impacts of Low-tech, Medium-Tech, and High-Tech foreign R&D's (Model 2). Under most specifications, the coefficients of the foreign R&D in Low-Tech and High-Tech industries are significant; though the coefficient of High-Tech industries is more significant and almost twice the coefficient of Low-Tech industries.

The coefficient of the foreign R&D of High-Tech industries becomes greater than one when we use dynamic specifications like GMM and System GMM. This result shows the importance of foreign R&D for the High-Tech sector. The coefficient of Medium-Tech industries is not significant except under System GMM specification. There might be several reasons for that. First of all, these industries are dependent on natural resources and need rather low technologies for their productions. As a result, they might not be dependent on advanced foreign technology to maintain their markets. The other reason might be that these industries depend on FDI or other methods of technology transfer to receive their required technologies, while the foreign R&D measure of this study is defined based on imports and cannot reflect this.

Table 3- The estimation results for Model 2: different foreign R&D impacts

ΔTFP	FE	GLS	PCSE	GMM	Sys GMM	LDPD	IV 2SLS
ΔRD_own	0.924	0.831	0.102	0.914	0.605	0.944	2.591
	(0.974)	(0.769)	(1.124)	(1.185)	(1.052)	(0.913)	(2.695)
ΔRD_others	1.545	1.301	0.737	3.118	4.145	-1.141	1.115
	(2.814)	(2.124)	(2.228)	(4.076)	(3.361)	(4.531)	(3.541)
ΔFRD_own_LowTech	0.510	0.382	0.469[d]	0.616[e]	0.645[e]	0.637[c]	0.717[d]
	(0.462)	(0.373)	(0.314)	(0.465)	(0.498)	(0.361)	(0.520)
ΔFRD_own_MedTech	0.239	0.367	0.672	0.542	0.690[c]	0.336	0.219
	(0.463)	(0.405)	(0.633)	(0.516)	(0.411)	(0.403)	(0.543)
ΔFRD_own_HighTech	0.688	0.891[d]	0.706[b]	1.020[d]	1.169[b]	1.114[b]	0.790
	(0.673)	(0.584)	(0.370)	(0.693)	(0.600)	(0.582)	(0.680)
ΔFRD_others	0.035	0.122	0.387	0.247	0.271	0.157	0.053
	(0.660)	(0.560)	(0.511)	(0.617)	(0.408)	(0.657)	(0.671)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; FE: Fixed-effects regression; GLS: Cross-sectional Time-series Generalized Least Squares; PCSE: Linear regression with panel-corrected standard errors; GMM: Arellando-Bond linear dynamic panel-data estimation; System GMM: Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation; LDPD: Linear Dynamic Panel-Data Estimation; IV 2SLS: Instrumental variables and two-stage least squares; All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

5-3- Does breaking down domestic R&D make any changes?

The coefficient of the domestic R&D is not significant in table 2. We can take a similar approach to distinguish the impacts of the R&D expenditures of the Low-Tech, Medium-Tech, and High-Tech industries on their own.

This way, we can examine whether there is a significant difference among different industrial groups with respect to own R&D effects (Model 3). Table 4 presents the results of this specification. The coefficient of the R&D of none of the industry groups is significant. Also, the coefficients are not consistent across different specifications. This result suggests that separating R&D's based on industry specifications cannot explain why the impact of domestic R&D in Canada is not significant.

Table 4- The estimation results for Model 3: different intra-industry R&D impacts

ΔTFP	FE	GLS	PCSE	GMM	Sys GMM	LDPD	IV 2SLS
ΔRD_own_LowTech	1.037	1.068	0.542	1.277	0.529	1.316	2.856
	(1.176)	(0.956)	(0.731)	(1.502)	(1.164)	(0.935)	(2.774)
ΔRD_own_MedTech	0.664	0.516	-0.214	-0.986	-1.199	-0.775	2.506
	(1.442)	(1.089)	(1.766)	(2.048)	(1.725)	(1.781)	(3.791)
ΔRD_own_HighTech	0.363	0.172	0.070	4.149	-0.181	1.934	1.336
	(3.111)	(2.347)	(1.161)	(5.456)	(4.116)	(3.815)	(2.965)
ΔRD_others	1.070	0.710	0.457	2.067	1.877	-0.545	-0.065
	(2.942)	(2.221)	(2.461)	(4.534)	(2.976)	(5.105)	(3.686)
ΔFRD_own	0.434^{e}	0.471^{c}	0.600^{c}	0.579^{c}	0.616^{c}	0.488^{c}	0.545^{b}
	(0.313)	(0.264)	(0.354)	(0.335)	(0.369)	(0.275)	(0.366)
ΔFRD_others	-0.030	0.019	0.356	0.126	0.173	0.164	-0.050
	(0.653)	(0.557)	(0.514)	(0.631)	(0.375)	(0.673)	(0.671)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; FE: Fixed-effects regression; GLS: Cross-sectional Time-series Generalized Least Squares; PCSE: Linear regression with panel-corrected standard errors; GMM: Arellando-Bond linear dynamic panel-data estimation; System GMM: Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation; LDPD: Linear Dynamic Panel-Data Estimation; IV 2SLS: Instrumental variables and two-stage least squares; All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

An important question is the interaction of domestic and foreign R&D. Some theories suggest that doing R&D in an industry increases the ability of that industry to absorb and use new technologies that are developed elsewhere, e.g. foreign technologies. As tables 2, 3, and 4 suggest, domestic R&D does not have a significant effect on the productivity of Canadian industries, while foreign R&D does. Therefore, it will be important to examine whether R&D spending by industries helps them to be better recipients of foreign technologies. Appendix 3 shows that the interaction between the foreign and domestic R&D is positive for all industries and quite significant for High-Tech industries. This is a rationale for R&D spending in these industries even though it does not have a direct impact on the TFP.

Table 5- The estimation results for Model 4: different inter-industry R&D impacts

ΔTFP	FE	GLS	PCSE	GMM	Sys GMM	LDPD	IV 2SLS
ΔRD_own	0.888	0.795	0.210	0.831	-0.188	0.402	3.164
	(1.009)	(0.801)	(1.019)	(1.299)	(1.086)	(0.910)	(3.104)
ΔRD_oth_LowTech	-0.618	-2.055	-2.355	-2.092	-2.689	-3.058	-22.209
	(4.572)	(3.711)	(2.952)	(5.112)	(5.516)	(5.042)	(22.808)
ΔRD_oth_MedTech	1.193	1.474	1.651	-1.062	-4.568	-6.646	1.183
	(3.387)	(2.561)	(2.606)	(5.068)	(4.171)	(5.430)	(7.002)
ΔRD_oth_HighTech	1.163	-0.362	0.649	5.261	5.479	1.921	0.979
	(7.549)	(5.899)	(5.132)	(9.006)	(6.312)	(8.121)	(13.433)
ΔFRD_own	0.435^{e}	0.483^{c}	0.588^{c}	0.713^{b}	0.725^{b}	0.567^{b}	0.499
	(0.318)	(0.267)	(0.351)	(0.338)	(0.345)	(0.282)	(0.420)
ΔFRD_others	-0.041	0.025	0.400	0.222	0.227	0.076	0.098
	(0.649)	(0.552)	(0.508)	(0.612)	(0.351)	(0.642)	(0.726)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; FE: Fixed-effects regression; GLS: Cross-sectional Time-series Generalized Least Squares; PCSE: Linear regression with panel-corrected standard errors; GMM: Arellando-Bond linear dynamic panel-data estimation; System GMM: Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation; LDPD: Linear Dynamic Panel-Data Estimation; IV 2SLS: Instrumental variables and two-stage least squares; All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

Tables 5 and 6 present the results of Models 4 and 5 in which the inter-industry impacts of domestic and foreign R&D's have been split into Low-Tech, Medium-Tech, and High-Tech impacts. The econometrics results suggest that none of these industries has a significant inter-industry impact at the industry level.

5- 4- Policy implications

Empirical results of tables 2-6 suggest that industrial R&D in Canada does not have a significant impact on productivity, while foreign R&D, especially in High-Tech industries, does. This issue has been expressed by many researchers. One reason for the low impact of domestic R&D in Canada can be that firms do not spent enough on R&D in the first place. Canada enjoys one of the most generous R&D incentive programs, but at the same time, it has one of the lowest R&D to GDP ratios among the OECD countries. According to the Department of Finance, only 0.3% of Canadian firms performed research in 1980. A justification for these low ratios is that a high proportion of Canadian firms are controlled by foreign companies, which do most of their research in the home country (Dagenais, Mohnen, and Therrien (1997).

Table 6- The estimation results for Model 5: different intra-industry foreign R&D impacts

ΔTFP	FE	GLS	PCSE	GMM	Sys GMM	LDPD	IV 2SLS
ΔRD_own	0.868	0.806	0.181	0.720	0.186	0.919	2.001
	(0.962)	(0.761)	(1.124)	(1.193)	(1.251)	(0.916)	(2.729)
ΔRD_others	1.755	1.353	0.661	1.677	2.529	0.571	0.922
	(2.789)	(2.102)	(2.325)	(4.251)	(3.105)	(4.447)	(3.608)
ΔFRD_own	0.435 ^{e}	0.460 ^{c}	0.533 ^{d}	0.636 ^{c}	0.680 ^{c}	0.576 ^{c}	0.551 ^{d}
	(0.323)	(0.273)	(0.337)	(0.355)	(0.391)	(0.316)	(0.384)
ΔFRD_oth_LowTech	1.519	1.340 ^{e}	0.720	1.009	1.014	1.285	0.966
	(1.182)	(0.973)	(0.980)	(1.195)	(0.826)	(1.704)	(1.516)
ΔFRD_oth_MedTech	-1.814	-1.613	-0.701	-0.450	-0.691	-0.045	-1.408
	(1.544)	(1.351)	(1.354)	(1.760)	(1.605)	(1.697)	(1.867)
ΔFRD_oth_HighTech	0.479	0.476	0.856	0.585	0.661	0.864	0.429
	(1.475)	(1.249)	(1.157)	(1.403)	(0.958)	(1.384)	(1.494)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; FE: Fixed-effects regression; GLS: Cross-sectional Time-series Generalized Least Squares; PCSE: Linear regression with panel-corrected standard errors; GMM: Arellando-Bond linear dynamic panel-data estimation; System GMM: Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation; LDPD: Linear Dynamic Panel-Data Estimation; IV 2SLS: Instrumental variables and two-stage least squares; All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

Based on the results of this study, there should be more attention to adopting innovations generated abroad, especially in the High-Tech industries. This policy has been suggested by other researchers too. For example, Brean and Leonard (1998) criticize the R&D policy of Canada in the sense that it counts too much on the ability of new Canadian innovations: "Canada has long offered generous supply-based subsidies designed to increase the stock of new discoveries, but productivity and competitiveness have not improved (p.28)." According to them, tax policy should not be limited exclusively to increasing the supply of domestic R&D, instead "R&D policy should therefore focus on developing the infrastructure and know-how necessary for adapting innovations, regardless of their origin, into profitable products and processes (p.28)." They emphasize that the ultimate objective is economic growth not R&D per se.

6- Conclusion

This paper studies the roles of domestic technology spillovers and foreign technology spillovers through importing goods on the growth rate of Canadian industries. The paper assumes that there are different technology diffusion rates for different sectors of the economy. To test this hypothesis, the domestic and foreign R&D's were decomposed into three groups as Low-Tech, Medium-Tech, and High-Tech.

According to the empirical results, only foreign R&D has a positive and significant impact on productivity. Contrary to the theory and cross-country empirical studies, domestic R&D of Canada does not have a significant impact on TFP under any of the specifications. However, it helps industries absorb foreign R&D. These results suggest that innovation policies should focus more on receiving and absorbing foreign innovations.

Since the primary emphasis of this study was to examine the impacts of domestic and foreign R&D through trade, we did not include variables such as FDI and human capital in the model. Also, linking these results to the firm-level studies will enrich the study if firm-level data is accessible.

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Appendix 1 – Industries used in the study

The list of the industries used in this study is as follows:

No	ISIC code (rev. 2)	Industry name
1	31	Food, Beverages & Tobacco
2	32	Textiles, Apparel & Leather
3	33	Wood Products & Furniture
4	34	Paper, Paper Products & Printing
5	353, 354	Petroleum Refineries & products
6	36	Non-Metallic Mineral Products
7	371	Iron & Steel
8	372	Non-Ferrous Metals
9	381	Metal Products
10	382	Machinery & Equipment, nec.
11	384	Manufacture of transport equipment
12	39	Other Manufacturing
13	351, 352, 355, 359	Chemicals +Rubber & Plastic Products
14	383, 384	Manufacture of electrical machinery apparatus, appliances and supplies +Professional Goods

Appendix 2 – Constructing the foreign R&D

This appendix explains how the foreign R&D variable for Canadian industries has been constructed. The industrial R&D expenditures of 14 major industrial countries have been retrieved from ANBERD. The name and ISIC codes of industries have been presented in appendix 1. The 14 selected countries are as follows: Australia, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom, and United States. The data is in current PPP dollars in ISIC revision 2 from 1973 to 1997. Then, the data series have been merged into 14 industries to match with the trade and input-output coefficients of Nicita and Olarreaga (2001). The R&D expenditures have been made constant by diving them by the US GDP deflator (year 2002 =100). The R&D stocks of industry i, i =1, .., 14, of country j, j = 1, …, 14, at time t, t = 1974, …, 1997, have been calculated as follows:

$$RD\_Stock_{ijt} = (1-d)RD\_Stock_{ijt-1} + RD\_Expenditures_{ijt-1},$$

where the depreciation rate, d, is assumed to be 25% for R&D. The initial R&D stock of industry i in 1973 has been calculated as follows:

$$RD\_Stock_{ij1973} = \frac{RD\_Expenditures_{ij1973}}{g+d},$$

where g is the average growth rate of R&D expenditures of industry i of country j from 1973 to 1977. These R&D stocks should be weighted by industrial imports of Canada and aggregated over countries to make the foreign R&D of Canada:

$$FRD_{it} = \sum_j w_{ij}\overline{FRD}_{jt} = \sum_j w_{ij}\left[\sum_k \left(\frac{M_{jkt}}{Output_{jt} + \sum_q M_{jqt} - \sum_q X_{jqt}}\right) RD_{jkt}\right].$$

The industrial imports to Canada have been obtained from Nicita and Olarreaga (2001). The updated version of this data set is available at the website of the World Bank. The data is in thousand current US dollars in ISIC revision 2 for 1978 - 2005. The data has been converted to Canadian dollars by using respective annual US-Canada exchange rates. The result is the industrial imports to Canada in Canadian dollars. Then, these imports have been aggregated into the 14 industries of the study (M_{jkt}). By dividing the industrial imports by (Output + Exports – Imports) of Canadian industry j in year t in current prices, the import shares are obtained. The other method is to make the import data constant by dividing them by the US GDP deflator (year 2002 $= 100$), and then convert it to Canadian dollars by using the exchange rate of 2002. This gives the imports to Canada in 2002 constant prices in Canadian dollars. Then, the data is aggregated into 14 industries and is divided by (Output $+$Exports – Imports) in 2002 constant prices to give the import share of Canadian industry j from country k. The shares obtained by these methods are slightly different, but the final results of this paper are independent of the method used. The import shares obtained by this method are used to weigh the diffusion of the R&D's of other countries to Canada.

Appendix 3- Interaction between the foreign R&D and own R&D and the robustness of the foreign R&D impacts per industry group

i) PCSE: Linear regression with panel-corrected standard errors

ΔTFP	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔRD_own	0.275 (1.139)	0.111 (1.123)	0.246 (1.137)	0.118 (1.125)	0.261 (1.139)	0.092 (1.122)	0.102 (1.124)	0.086 (1.128)	-0.092 (1.181)
ΔRD_others	1.236 (2.620)	0.255 (2.252)	0.964 (2.579)	0.619 (2.263)	1.339 (2.577)	0.336 (2.222)	0.737 (2.228)	0.733 (2.235)	0.594 (2.220)
ΔFRD_own_LowTech			0.421 ^{d} (0.293)		0.442 ^{d} (0.302)	0.446 ^{d} (0.304)	0.469 ^{d} (0.314)	0.470 ^{d} (0.316)	-0.014 (0.473)
ΔFRD_own_MedTech		0.640 (0.623)		0.659 (0.625)		0.653 (0.630)	0.672 (0.633)	0.676 (0.631)	0.690 (0.631)
ΔFRD_own_HighTech	0.623 ^{c} (0.366)			0.677 ^{c} (0.365)	0.651 ^{c} (0.367)		0.706 ^{b} (0.370)	0.508 (0.472)	0.720 ^{b} (0.367)
ΔFRD_others	0.332 (0.515)	0.259 (0.482)	0.153 (0.487)	0.414 (0.512)	0.299 (0.511)	0.224 (0.482)	0.387 (0.511)	0.361 (0.521)	0.400 (0.511)
ΔRD_own * ΔFRD_own_HighTech								3.524 (4.450)	
ΔRD_own * ΔFRD_own_LowTech									5.265 ^{d} (4.033)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

ii) System GMM: Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation

ΔTFP	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ΔRD_own	0.236 (1.309)	0.412 (1.106)	0.194 (1.346)	0.577 (1.082)	0.332 (1.306)	0.457 (1.085)	0.605 (1.052)	0.487 (1.090)	0.391 (1.337)	0.551 (0.936)
ΔRD_others	4.109 (3.884)	4.352 (3.422)	4.311 (3.700)	4.230 (3.536)	4.147 (3.756)	4.345 (3.237)	4.145 (3.361)	4.711 (3.590)	5.450 (4.177)	4.269 (3.371)
ΔFRD_own_LowTech			0.600 (0.515)		0.677 ^{e} (0.534)	0.577 (0.486)	0.645 ^{e} (0.498)	0.610 (0.514)	0.598 ^{e} (0.469)	0.406 (0.529)
ΔFRD_own_MedTech		0.624 ^{c} (0.386)		0.655 ^{c} (0.396)		0.653 ^{c} (0.395)	0.690 ^{c} (0.411)	0.697 ^{c} (0.414)	0.524 (0.588)	0.686 ^{c} (0.408)
ΔFRD_own_HighTech	1.190 ^{c} (0.665)			1.089 ^{c} (0.615)	1.276 ^{b} (0.662)		1.169 ^{b} (0.600)	0.455 (0.497)	1.195 ^{b} (0.626)	1.156 ^{b} (0.601)
ΔFRD_others	0.065 (0.385)	0.049 (0.396)	-0.112 (0.459)	0.216 (0.368)	0.101 (0.414)	0.087 (0.436)	0.271 (0.408)	0.191 (0.423)	0.428 (0.530)	0.261 (0.408)
ΔRD_own * ΔFRD_own_HighTech								10.496 ^{c} (5.828)		
ΔRD_own * ΔFRD_own_MedTech									6.819 (17.085)	
ΔRD_own * ΔFRD_own_LowTech										2.631 (5.619)

a: significant at 1 percent level; b: significant at 5 percent level; significant at 10 percent level; d: significant at 15 percent level; e: significant at 20 percent level; All models include time and industry dummies. There are 224 observations for 14 industries in 20 years (1978-1997).

Appendix 4- Panel estimation techniques

The followings section explains various econometric techniques that have been used in chapters two and three of this dissertation. The contexts have been extracted from Baltagi, B.H., "Econometric Analysis of Panel Data", Third Edition, 2005, Stata 10 Reference Manual, and http://dss.princeton.edu/online_help/analysis/panel.htm.

1- The Fixed Effects Model (FE)

Fixed effects regression is the model to use when you want to control for omitted variables that differ between cases but are constant over time. It lets you use the changes in the variables over time to estimate the effects of the independent variables on your dependent variable, and is the main technique used for analysis of panel data. A panel regression has this format:

$$y_{it} = \alpha + X_{it}^{'}\beta + u_{it} \qquad i = 1,\ldots,N; \quad t = 1,\ldots,T$$

Most of the panel data applications utilize a one-way error component model for the disturbances, with $u_{it} = \mu_i + v_{it}$, where μ_i denotes the unobservable individual-specific effect and v_{it} denotes the remainder disturbance i.e. the usual disturbance. In this case, the μ_i are assumed to be fixed parameters to be estimated and v_{it} are $IID(0,\sigma_v^2)$. The X_{it} are assumed to be independent of v_{it} for all i and t.

The fixed effects model is an appropriate specification if we are focusing on a specific set of N firms, industries, or countries. We may add cross-section dummy variables for this model:

$$y_{it} = \alpha + \beta x_{it} + \mu_i + v_{it}$$

However, keeping all μ_i dummies in the model will decrease the degrees of freedom when N is very large and too many dummies may worsen the problem of multicollinearity among the regressors. If T is large, the FE least square estimator is consistent. But if T is small and N is large, the OLS estimator is biased.

Similarly, we can define the two-way error component regression model, in which the disturbances are of the form $u_{it} = \mu_i + \lambda_t + v_{it}$, where μ_i denotes the unobservable individual effect, λ_i denotes the unobservable time effect, and v_{it} denotes the remainder disturbance. Note that λ_i is individual-invariant and it accounts for any time-specific effect that is not included in the regression.

In a fixed effects two-way error component regression model, the μ_i and λ_i are assumed to be fixed parameters to be estimated, v_{it} are $IID(0,\sigma_v^2)$, and the X_{it} are independent of v_{it} for all *i* and *t*.

If N or T is large, there will be too many dummy variables in the regression, which causes loss in degrees of freedom. We may transform the data to get rid of μ_i and λ_i by averaging over time and individuals, but this process will eliminate all time and individual invariant variables (missing variable problem). Then the estimates will be biased and inconsistent.

If μ_i are $IID(0,\sigma_\mu^2)$, λ_i are $IID(0,\sigma_\lambda^2)$, v_{it} are $IID(0,\sigma_v^2)$, independent of each other, and X_{it} are assumed independent of μ_i, λ_i, and v_{it} for all i and t, we will have a two-way random effects model. The two-way random effects model is an appropriate specification a sample is randomly chosen from a large population.

For the random two-way error component model, Breusch-Pagan Test derives a Lagrangian multiplier to test $H_0 : \sigma_\mu^2 = \sigma_\lambda^2 = 0$. We may also test for one-way error component model $H_0 : \sigma_\mu^2 = 0$ or $H_0 : \sigma_\lambda^2 = 0$. Hausman's Specification Test can be used to choose between fixed or random effects.

2- Generalized least squares (GLS)

GLS fits panel-data linear models by using feasible generalized least squares. This method allows estimation in the presence of AR(1) autocorrelation within panels (common to all the panels or specific to each the panels) and cross-sectional correlations and heteroskedasticity across panels.

3- Linear regression with panel-corrected standard errors (PCSE)

PCSE calculates panel-correlated standard error estimates for linear cross-sectional time-series models where the parameters are estimated by either OLS or Prais-winsten regression. When computing the standard errors and the variance-covariance estimates, PCSE assumes that the disturbances are, by default, heteroskedastic and contemporaneously correlated across panels.

4- Arellando-Bond linear dynamic panel-data estimation (GMM)

Arellando-Bond linear dynamic panel-data models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. This estimate is designed for datasets with many panels and few periods, and it requires that there be no autocorrelation in the idiosyncratic errors. If this condition does not hold, you may use linear dynamic panel-data estimation or Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation.

Sargan test should be used after this regression to examine over-identifying restrictions. Also, the first and second autocorrelation in the first-differenced error should be examined. Serial correlation in the first-differenced errors at an order higher than 1 implies that the moment conditions used by Arellando-Bond linear dynamic panel-data estimation are not valid; the alternative in this case is linear dynamic panel-data estimation.

5- Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation (System GMM)

Linear dynamic panel-data models include *p* lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. Blunedell and Bond (1998) extend the work of Arelano and Bover (1995) to develop a system estimator that uses additional moment conditions. This estimator is used when the autoregressive parameters in the GMM estimator are too large or the ratio of the panel-level effect to the variance of idiosyncratic error is too large.

This estimator is designed for datasets with many panels and few periods. This method assumes that there is no autocorrelation in the idiosyncratic errors and requires the initial condition that the panel-level effects be uncorrelated with the first difference of the first observation of the dependent variable.

6- Linear dynamic panel-data estimation (LDPD)

Linear dynamic panel-data models include *p* lags of the dependent variables as covariates. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. Linear dynamic panel-data estimation can fit models with low-order moving-average correlation in the idiosyncratic errors or predetermined variables with a more complicated structure than allowed for Arellando-Bond linear dynamic panel-data estimation or Arellano-Bover/Blundell-Bond linear dynamic panel-data estimation.

7- Instrumental variables and two-stage least squares for panel-data models (IV 2SLS)

IV 2SLS offers different estimators for fitting panel-data models in which some of the right-hand-side covariates are endogenous. These estimators are two-stage least-squares generalizations of simple panel-data estimators for exogenous variables.

8- Vector error correction model (VEC)

Vector error correction models are reduced form time series models that are commonly used to empirically analyze the dynamic behavior of a set of *I(1)* variables. A vector error correction model may be written as follows:

$$Y_{i,t} - Y_{i,t-1} = -\beta(Y^{*}_{i,t} - Y_{i,t-1})$$

In this formulation – also known as a partial adjustment scheme – there is adjustment of Y toward a target Y^{*}, where $-\beta$ is the speed of convergence toward the steady state. In a convergent model, we expect that $1 > \beta > 0$. A set of exogenous variables Z can be used as proxies for the steady state Y^*. In this case, the vector error correction model with two-way error components can be presented as follows (for example, see Guellec and van Pottelsberghe, 2003; Acharya and Coulombe, 2006; and Islam, 1995):

$$\Delta Y_{i,t} = \beta Y_{i,t-1} + \alpha Z_{i,t} + \gamma \Delta Z_{i,t} + u_i + \delta_t + \varepsilon_{i,t}$$

γ represents the short-run effect of exogenous variables Z, and $-\alpha / \beta$ represents their long-run effects.

9- Heteroskedasticity and Serial Correlation in the Error Component Model

The standard error component models assume that regression disturbances are homoskedastic with the same variance across time and individuals. This may be a restrictive assumption for panels, where the cross-sectional units may be of varying size and as a result may exhibit different variation.

Assuming homoskedastic disturbances when heterskedasticity is present will still result in consistent estimates of the regression coefficients, but these estimates will not be efficient. Also, the standard errors of these estimates will be biased and one should compute robust standard errors correcting for the possible presence of heteroskedasticity. Also, ignoring serial correlation when it is present results in consistent but inefficient estimates of the regression coefficients and biased standard errors.

10- Nonstationary Panels

To test whether a panel is stationary or not, we may use Levin, Lin and Chu Test or Im, Pesaran and Shin Test. This way, we can understand if the panel is an I(0) process or a process of higher degrees. If the panel is not I(0), we can either transform it into an I(0) process or use VEC models if possible.

10-1- Levin, Lin and Chu Test

The null hypothesis is that each individual time series contains a unit root against the alternative that each time series is stationary. This test is suggested for panels of moderate size with N between 10 and 250 and T between 25 and 250. The test has two limitations: (i) the test crucially depends on the independence assumption across cross-sections and is not applicable if cross-sectional correlation is present. (ii) the assumption that all cross-sections have or do not have a unit root is restrictive. For very large N and very small T, Levin, Lin and Chu (2002) and Baltagi, 2005 recommend the usual panel data procedure.

10-2- Im, Pesaran and Shin Test

The null hypothesis in this test is that each series in the panel contains a unit root, i.e., $H_0 : \rho_i = 0$ for all i and the alternative hypothesis allows for some (but not all) of the individual series to have unit roots, i.e.,

$$H_1 : \begin{cases} \rho_i < 0 & for \quad i = 1,2,3,\ldots,N_1 \\ \rho_i = 0 & for \quad i = N_1 + 1,\ldots,N \end{cases}$$

You should have a large enough order of lags in the test.

Chapter 3

Measuring the Transfer of Foreign Technology to Canadian Industries by Using Patent Applications

Abstract

This chapter estimates the diffusion rate of foreign technology into Canadian industries at the industry level by using the patent database of the Canadian Intellectual Property Office. The paper suggests that the patent activity of foreign countries is the most important factor for receiving foreign patents in Canada. Moreover, imports and foreign direct investments are important vehicles for technology transfer. The distance between countries has a negative impact on receiving foreign patents. The impacts of R&D intensity and human capital on receiving foreign patents are mixed and insignificant, but industries with a higher R&D intensity may be better recipients of foreign patents. Moreover, the paper empirically tests the propensity to patent of different industries and shows that there is a great difference among industries with this respect.

1- Introduction

Innovation is increasingly becoming an indicator for the success of an economy. Public policy is concerned about promoting innovation in order to stimulate economic growth (Kleinknecht, et al., 2002). Measuring innovation is challenging, and measuring the success of public policy decisions designed to increase innovation can be even more difficult. Patent statistics have long been identified as interesting in spite of all the difficulties that arise in their use and interpretation (Griliches, 1990).

A patent is a set of exclusive rights granted by a patent office to an inventor or his assignee for a fixed period of time in exchange for a disclosure of an invention. The goal of all patent offices is to stimulate innovation. This task is undertaken in two ways. First, patents stimulate R&D expenditures and innovation by granting a monopolistic power to inventors. Second, patent systems help worldwide diffusion of inventions through publications of patent applications.

This paper addresses the diffusion of knowledge to Canada by using the number of foreign patent applications. The paper consists of two sections. The first section presents the patent applications in Canada for the period 1977-2003. The main source of data for this analysis is TECHSOURCE, the patent database of the Canadian Intellectual Property Office (CIPO). CIPO is responsible for the administration and processing of patents and other intellectual products in Canada. The patent database at CIPO covers all patent applications from 1869 to the present time. However, due to different policies and administrative decisions, different types of information were kept in the database in different periods of time. Since this dataset is more complete for the period 1977-2003, we paid more attention to retrieving and polishing the data of this period. Some of the variables of interest that are presented in the paper include: patent applications in Canada and worldwide, patents by country of origin, and patent applications per industry based on ISIC revision 3[1].

The second part of this paper presents a model that can be used to estimate the number of foreign patent applications in Canada. Since foreign patenting is one of the channels of technology transfer to a country (e.g. Eaton and Kortum, 1996; Kortum and Lerner, 1997; Rafiquzzaman and Whewell, 1998; Hanel and Zorgati, 2001), this model also estimates the diffusion rate of foreign technology into Canadian industries. One of the policy implications of identifying the determinants of foreign patenting will be to direct resources toward attracting new technologies into the country.

The contribution of this study to the literature is as follows. Firstly, this is one of few studies on patents at the industry level. Mapping patents to industry classifications was always an issue in empirical studies on patents. The author assigned an industry classification to all patent applications in Canada based on the OECD Technology concordance. Secondly, some new explanatory variables will be examined to find their impacts on technology diffusion into Canadian industries. Thirdly, the difference in patent propensity of industries is examined empirically. Finally, the model will be examined with a new patent data set that has been extracted and modified by the author from the CIPO databases. The results suggest that the patent activities of other countries, imports, FDI, and distance between countries are important determinants of the number of foreign patent applications in Canada. Also, industries with a higher R&D intensity seem to be better recipients of foreign patents.

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[1] For more information on Canadian patents in Canada, readers may refer to Nikzad and Collette (2008).

The next section surveys the literature on patents and innovation. Section 3 overviews patent applications in Canada. Section 4 presents the model that we will use to estimate the number of foreign patent applications in Canada. Section 5 describes the sources of data. Section 6 presents the empirical results. Section 7 concludes.

2- Literature review

Patents are considered as one of the outputs of innovative activities. Therefore, they can show the innovativeness of firms, regions, or countries. Using patents as a measure of innovation has advantages and disadvantages compared to other measures of innovation, e.g. R&D expenditures, which are regarded as inputs of innovation. As Trajtenberg, Jaffe, and Hall (2000) mention, patents are a very rich source of data for the study of innovation and technical change. Some advantages include:

- each patent contains highly detailed information on the innovation itself, the technological area to which it belongs, the inventors, etc.
- there is a very large number of patents, which is very useful for research. Moreover, there is more than 100 years of continuous patent data for some countries.
- in contrast to other types of economic information, applicants provide patent data voluntarily, and the incentives to provide this piece of information are plain and clear.

One of the major drawbacks of simple patent count as an indicator of innovative output is that innovations vary enormously in their technological and economic value and importance (Trajtenberg, Jaffe, and Hall, 2000). Secondly, only a subset of all research outcomes is patentable. Thirdly, not all patentable innovations will be patented. The reason is that patenting is a strategic decision and firms may choose other forms of protection for their innovations. A study by Hanel (2001) suggests that Canadian firms rely less on patents and more on trade secrets to protect their innovations. Finally, the propensity to patent changes greatly from one industry to another. This means that some economic sectors use IP rights more intensively than other industries. Industries in which innovation is costly, requires long periods of time, or generates substantial income are more willing to use IP rights. The pharmaceutical and biotechnology industries are examples of this group (Putnam, 2001; Charles, Mcdougall, and Tran, 2001). Therefore, we cannot compare the innovativeness of industries by simply using the number of their patents (Griliches, 1990; Jaffe, Trajtenberg, and Trajtenberg, 2000; Cantwell, 2000).

There are a few methods to overcome these problems. We may use industry dummy variables to solve the last three problems. For the first problem, we benefit from the law of large numbers: "The economic significance of any sample patent can also be interpreted as a random variable with some probability distribution." (Griliches, 1990). Moreover, some researchers have tried to measure the significance and value of a patent by counting the number of citations to that patent or the number of claims of that patent (Jaffe, Trajtenberg, and Henderson, 1993; Trajtenberg, Jaffe, and Hall, 2000). A problem with using citations and claims is that this piece of information may not be available for all patents. For example, CIPO does not currently capture citation data electronically. Therefore, these models cannot be used for patent applications in Canada without significant effort. Both patent applications and patent grants can be considered as indicators of inventive activities. However, patent applications are used more frequently in research because the related procedures are more hamronized internationally (Soete 1987; Eto and Lee, 1993; Rafiquzzaman and Whewell, 1998).

Many researchers have used patents to measure the geographical localization of innovations. Jaffe, Trajtenberg, and Henderson (1993), Henderson, Jaffe and Trajtenberg, (2004), McFetridge (1997), Cantwell and Kosmopoulou (2001), Cantwell and Piscitello (2003), Cantwell, and Glac and Harding (2004) are some examples of this type of research. Cantwell (2000) suggests that foreign penetration is highest in the chemicals, pharmaceuticals, oil, and food product industries. Here are some explanations for the internationalization of innovation activities, which result in the diffusion of technology: (i) use of locally-specific resources and competencies that help entering local markets, (ii) transfer of technology, skills and assets across national borders to build a sustainable competitive advantage for the multinational company, and (iii) adaptation of products to local consumer preferences.

A few studies have been done on the structure of the patenting system in Canada. Rafiquzzaman and Whewell (1998), Trajtenberg (2000), Vaver (2001), Putnam (2001), Charles, Mcdougall, and Tran (2001), Rafiquzzaman and Ghosh (2001), Hanel (2001), Pazderka and Stegemann (2001), Gallini, Putnam and Tepperman (2001), Rafiquzzaman and Mahmud (2001), and Rafiquzzaman (2002) are among them. Hanel (2001) concludes that two thirds of Canadian firms that apply for a patent in Canada apply also in the United Stated. Also, less than 10 percent of firms apply only in the United States, around 20 percent apply only in Canada, and around 5 percent apply elsewhere. He also suggests that the tendency to apply for a patent in the United States increases with the size of firms. Firms with more than 10 patents tend to patent more in the United States than in

Canada. Moreover, he concludes that firms that introduced mainly Canada–first innovations seem to rely somewhat less on patents and almost equally on trade secrets. Gallini, Putnam, and Tepperman (2001) suggest that an increase in foreign patenting in Canada may be due to an increase in innovative activity of the foreign countries that spills over into Canada regardless of the incentives provided in Canada.

Since most researchers use R&D expenditures as a measure of innovation, it is worth mentioning the relationship between patents and R&D expenditures. R&D expenditures are generally considered as inputs of innovative activities, and patents as output of innovative activities. However, not all R&D expenditures will result in innovative outputs, and, as discussed earlier, not all innovative outcomes are patented. Therefore, it will be interesting to look at the ratio of patents to R&D expenditures of each sector. Griliches (1990) suggests that the relationship between R&D expenditures and patents is quite strong at the cross-sectional level (order of 90% in median), but rather weaker at time-series dimension (order of 30% in median). Moreover, he suggests that when firms change their R&D expenditures, parallel changes happen in their patent numbers with a very short lag.

3- Description of patent data of Canada

This section describes the patent dataset of CIPO. CIPO's database covers patents in Canada from 1869 to the present time. The database contains the information for more than 1.9 million patent applications. Moreover, it contains valuable information on the name and address of applicants, the classification of the patent according to the International Patent Classification (IPC) or the Canadian Patent Classification (CPC), and the filing date, examination request date, and grant date of the patent. However, the type of information that is kept in the database varies greatly over time. For example, only the grant date of patents used to be kept in the database, or for a few years, the industry that produced the patent and the industry that was supposed to use the patent were also kept in the database. CIPO stopped assigning industries to patents in the 1990s; however, this piece of information later became the main source of patent-industry concordance in the United States and Europe. The change in patent policies and the type of information that was kept in each period limits the use of the database. For this reason, we focus only on the patent applications from 1977 to 2003 in this paper.

Figure 1 – Annual patent applications in Canada (1990-2003)

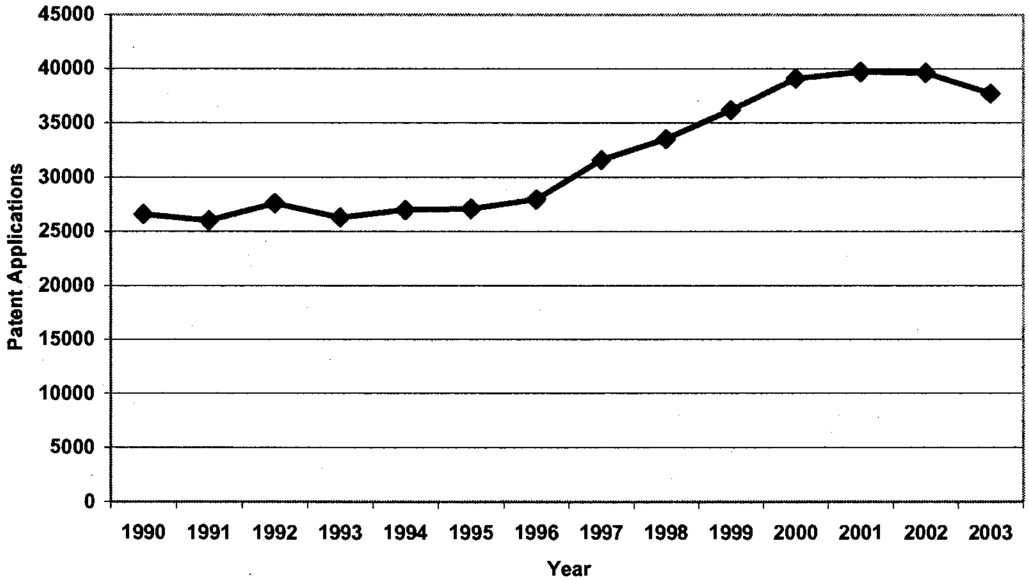
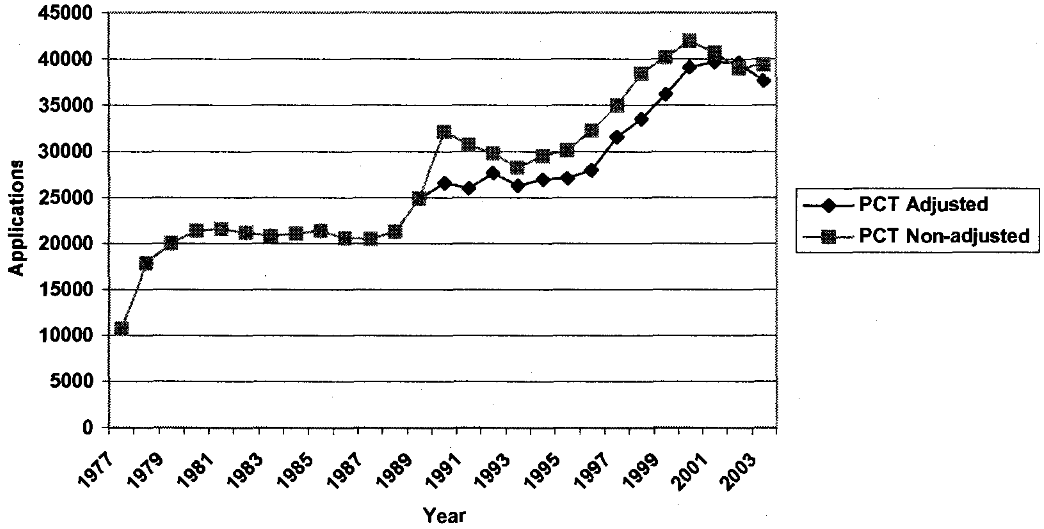


Figure 1 presents the annual number of patent applications in Canada from 1990 to 2003. The filing date of applications was captured only after 1977. Applications that failed to receive a grant were removed from the database until 1989. This means, the data of 1977-1989 consists only of the application dates of files that have been granted. As a result, only the application numbers of 1990-2003 are presented in figure 1. The annual number of patent applications was almost constant between 1990 and 1995. It started increasing afterward until 2001, when it reached its peak. Then, it decreased in 2003.

It is important to know that CIPO keeps the filing date of applications that file under the Patent Cooperation Treaty (PCT) differently. The application date of PCT patents in the CIPO database is the original date the application was filed internationally. Since most PCT patents in Canada are foreign patents, their filing date is the date they open an application in a foreign patent office, not at CIPO. These patents have another piece of information that shows their filing date in Canada[1]. Figure 2 shows the adjusted filing dates. There were no PCT applications before 1989. The number of PCT-adjusted applications is similar to the number of PCT-unadjusted applications with one lag.

Figure 2 – Annual patent applications in Canada: PCT versus non-PCT



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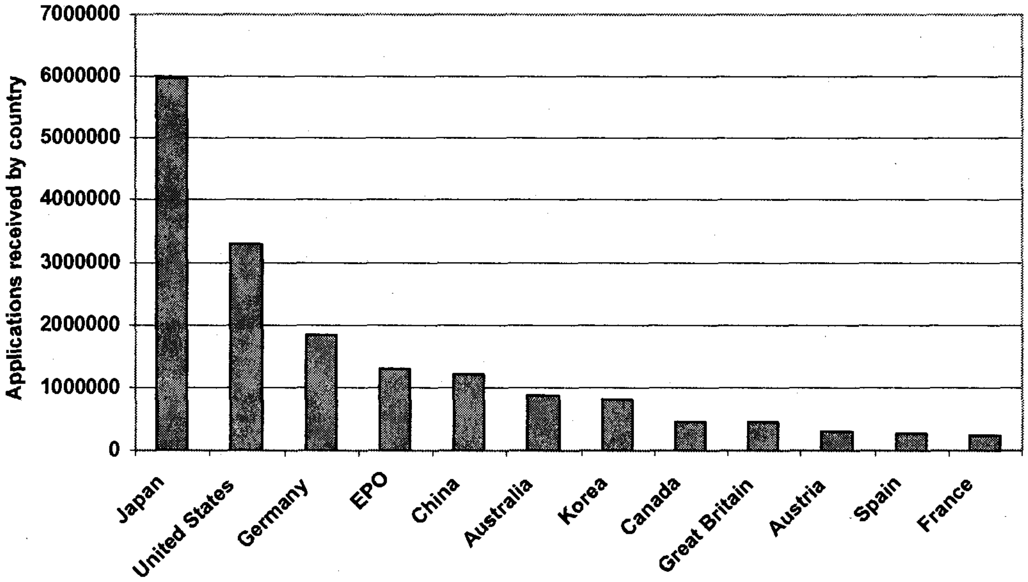
[1] National Entry Date.

Figure 3 compares the number of patent applications received by different countries from 1990 to 2003. It is important to note that IP offices use different procedures, and these can have an effect on application levels. For example, one of the reasons that Japan has the highest number of patent applications is that it uses a different patenting procedure, e.g. the extensions on one invention might be considered as parts of the original invention in the United States or Canada; but the same extensions are eligible for a separate patent in Japan.

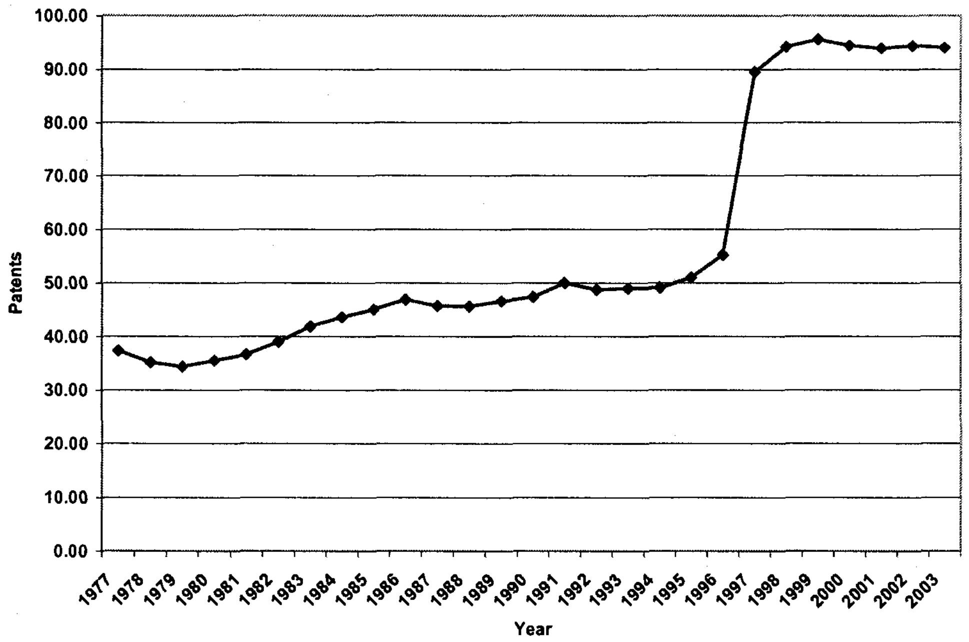
Figure 3 - The number of patent applications received by different countries (1990-2003)



Source: EPO and CIPO patent database

Another important issue with respect to innovation is the location of the innovation, the diffusion of spillovers, and the agglomeration of innovations in certain areas. Patent applications can be used for this purpose. On one hand, the increase in the number of patent applications originating from a region means that region is becoming a center of innovation, or an agglomeration of innovation is happening. On the other hand, attracting foreign patent applications can be considered as technology spillovers from a foreign country to the home country. Therefore, studying the location of applicants is of great importance. CIPO keeps a corresponding address for the applicant and one address for the inventor or owner. Almost all patents have a corresponding address, which is, in most cases, the address of the agent who applies for the patent on behalf of the inventor or owner of the patent. It may also be the address of the inventor or owner. This address is not very useful for research purposes because for example, all foreign applicants have to apply for a patent through a Canadian agent. Therefore, this would not be the correct address of the inventor.

Figure 4 – The percentage of patents with addresses to total patents (1977-2003)



However, CIPO also keeps the address of the inventor or the owner of the patent. This piece of information is useful for research purposes. The problem is that only a small proportion of patents have the address of the inventor. This is especially an issue for the patents granted prior to 1997. Figure 4 presents the percentage of patents for which the country of origin of their owner or inventor is known to total patents from 1977 to 2003. The figure suggests that, on average, only 40 to 45 percent of patents have addresses (country of origin) before 1997. This percentage increases to around 94 percent after 1997.

Figure 5- The distribution of patent applications in Canada with respect to their country of origin

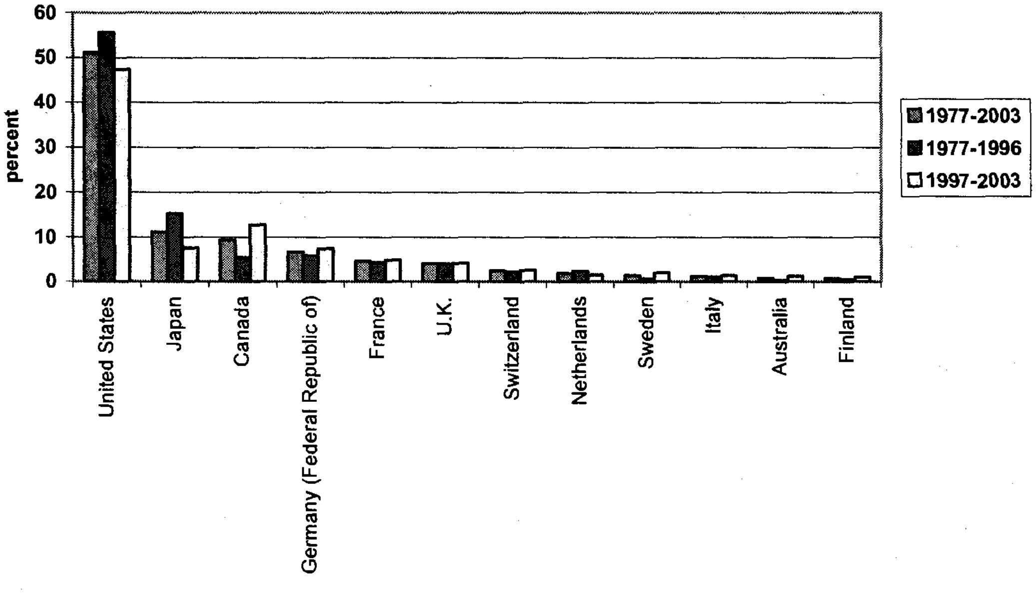


Figure 5 presents the distribution of patent applications in Canada with respect to their country of origin. The 12 countries presented in figure 5 represent 95 percent of patent applications in Canada. The figure distinguishes between 1977-1996 and 1997-2003, in which the addresses are more reliable. Around 50 percent of total patent applications in Canada are from the United States, 10.2 percent from Japan, 6.8 percent from Germany, 4.5 percent from France, and 4 percent from the United Kingdom. Canadian applications represent only 9.4 percent of total applications during this period. This is around 5 percent of total applicants from 1977 to 1995 and around 12.5 percent of applicants after 1997. However, we should be cautious on the number of Canadian applicants in Canada as studies show that many Canadian inventors prefer to apply for a patent first in the United States and then in Canada.

An important issue in terms of economic analysis is the number of patents in each industry. Patents are assigned a product code, which helps lawyers and patent examiners in grant and litigation decisions. The most widely used patent classification system is the International Patent Classification system (IPC). All major countries, except for the United States, use this system. Historically, Canada was using the Canadian Patent Classification system (CPC), but it gradually moved to IPC in the 1970s and 1980s, as the applications of some years have both CPC and IPC. CIPO then stopped assigning CPC to applications. All patent applications after 1977 have an IPC. IPC categorizes inventions by product or process. However, IPC is useful only for legal purposes. Researchers cannot use it because it corresponds with no other classification systems. Economists and policy makers are interested to know the number of patents in each industry to be able to combine this information with other economic variables such as R&D expenditures, value added, investment, etc.

A few efforts have been made to find a concordance between patent classifications and industry classifications. This paper maps the patents at CIPO to the International Standard Industrial Classification (ISIC) revision 3 based on the IPC-ISIC concordance of Johnson (2002). The first attempt to find an industry classification for patents was done at CIPO. Between 1972 and 1995, CIPO simultaneously assigned IPC codes as well as an industry of manufacture (IOM) and sector of use (SOU) code to each of over 300,000 granted patents. This industry code was based on Standard Industrial Classification (SIC). Later, a group of researchers at Yale University developed the Yale Technology Concordance (YTC) between IPC and SIC based on this data. Their methodology was to use the information on all 300,000 patents to determine the probability that a patent with a specific IPC has a particular IOM-SOU combination.

Table 6- The number of patent applications per industry (1990-2003)[1]

ISIC	Patent Applications
36/37: Furniture, manufacturing n.e.c.; recycling * (i14)	190244
33: Medical, precision, opt. Instruments; watches * (i12)	94309
31: Electrical machinery and apparatus n.e.c. * (i10)	76833
30: Office, accounting and computing machinery * (i9)	23727
32: Radio, TV and communication equipment * (i11)	15259
15/16: Food, beverages and tobacco * (i1)	14639
17/19: Textiles, wearing apparel, leather, footwear * (i2)	5037
35: Other transport equipment * (i13)	4916
27: Basic metals * (i6)	4328
10/14: Mining and quarrying	4023
26: Non-metallic mineral products * (i5)	3235
29: Machinery and equipment n.e.c. * (i8)	3030
25: Rubber and plastics products * (i4)	1122
24: Chemical products * (i3)	813
28: Fabricated metal products * (i7)	786
40/45: Electricity, gas and water supply; construction	628
01/05: Agriculture, hunting, forestry, and fishing	508
50/99: total services	373

Johnson (Evenson and Johnson, 1997, Johnson and Evenson, 1997, 1999; Johnson and Santaniello, 2000; and Johnson, 2002) used the YTC to develop the OECD Technology Concordance (OTC) between IPC and ISIC. Table 6 presents the number

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[1] Industries with * are those that we will use in the empirical part of this paper. The numbers in parentheses represent the industry dummy variables that will be presented in the empirical results.

of patents applications in selected industries between 1990 and 2003 when the OECD Technology concordance is applied to patent applications in Canada.

4- Modeling the number of patents in Canada

This section describes the model that will be used to estimate technology diffusion to Canada by using the number of foreign patent applications. This model is based on Eto and Lee (1993), Eaton and Kortum (1996), Kortum and Lerner (1997), and Rafiquzzaman and Whewell (1998). This study extends previous studies in two directions. First, the study will be done at the industry level instead of the country level. Second, some new explanatory variables will be examined to see if they affect technology diffusion into Canadian industries. The difference in patent propensity of industries is also examined empirically. The model will be examined with a new patent data set that has been extracted and modified from Canadian Intellectual Property Office (CIPO) databases.

According to the literature, the following parameters could affect international patent activities in a destination country: (i) the speed at which the destination country absorbs new innovation, (ii) the innovativeness of the source country, (iii) imports, (iv) foreign direct investment (FDI), (v) geographic proximity, and (vi) market size.

The main reason for patenting in a country is the potential rent the inventor may receive from that country. This depends on how well an innovation will be adopted in that country. An inventor makes profit in a foreign country as long as the invention is adopted in the country, and at the same time, has not been imitated or moved out from the market by a more advanced technology. We use industrial R&D intensities in the destination country as a proxy for technology adoptability. This variable may have two opposite impacts on foreign patents. On one hand, higher R&D intensity helps the industry adopt foreign technology; therefore, the foreign country has incentives to patent in an industry with a higher R&D intensity because there is more chance for the patent to be adopted. Secondly, there is a higher chance the foreign competitor loses its market share to a domestic innovator if he or she does not patent. On the other hand, if the R&D intensity is very high, the industry might be more innovative than its competitors, and foreigners cannot easily patent a new invention. This means that we may get mixed results with respect to the R&D intensity.

Another important factor in receiving foreign patents is the innovativeness of source countries and the number of patents they produce. If the patent activity in the source country increases, we expect receiving more patents in the destination country. Coe and Helpman (1995) suggest that trade is a vehicle for technology transfer. The other important vehicle of technology transfer is FDI. We expect that foreign exporters and investors protect their product market or increase their shares by patenting their products in the destination country. Therefore, we expect a positive relationship between imports and FDI with foreign patents. These two variables are included in the model to test these hypotheses. According to the gravity model (Eaton and Kortum, 1996; Rafiquzzaman and Whewell, 1998; Smith, 1999; Rafiquzzaman, 2002), diffusion of technology has a negative relationship with the square of the distance between the inventor and the user of the technology. Distance reflects possible geographical barriers to the free flow of ideas. For this purpose, the distance between Ottawa and the capitals of other countries is included in the model. We expect a negative sign for the distance. Market size measures the demand for the innovation and final production. We measure the market size by industrial output.

Under these assumptions, technology diffusion into Canadian industries can be modeled as follows:

$$Patent_{ijt} = ForPatent_{ijt-1}^{\alpha_{FP}} \cdot Trade_{ijt}^{\alpha_T} .FDI_{jt}^{\alpha_{FI}} \cdot Dist_j^{\alpha_D} \cdot GDP_{it}^{\alpha_G} .RD_{it}^{\alpha_{RD}}, \quad (1)$$

where $Patent_{ijt}$ is the number of patent applications of country *j* in Canada in industry *i* at time *t* and is a measure of foreign technology diffusion. $ForPatent_{ijt-1}$ is the number of foreign patents produced by industry *i* of country *j* at time *t-1* and measures the patent activities of the source countries. This variable has a lag because it takes time for foreign inventors to apply for patents in Canada. $Trade_{ijt}$ is the imports of Canada in industry *i* from country *j* at time *t*. FDI_{jt} is the foreign direct investment from country *j* in Canada at time *t*. $Dist_j$ is the square of distance between Ottawa and the capital of country *j*. GDP_{it} is the output of industry *i* of Canada at time *t* and is a measure of market size. RD_{it} is the R&D intensity of industry *i* at time *t* and shows the ability of the country to absorb foreign technology.

We define measures of foreign technology absorption, imports and market size as follows. As explained in section 3, there is an industry of manufacture (IOM) and a sector of use (SOU) for each patent. Johnson (2002) extended this mapping to ISIC-IPC concordance. I have used this concordance to construct an annual input-output table for patents based on ISIC revision 3. This patent input-output table shows the percentage of patents of each industry that will be used in another industry. A sample of this patent input-output matrix is presented in appendix 1. We can redefine the technology adoptability of industries, imports and market size by using this patent matrix as follows:

$$RD_{it} = \sum_k w_{ikt} RD_{ikt}, \qquad (1.1)$$

$$Trade_{ijt} = \sum_k w_{ikt} Trade_{ikjt}, \qquad (1.2)$$

$$GDP_{it} = \sum_k w_{ikt} GDP_{ikt}, \qquad (1.3)$$

where w_{ikt} is the share of patents of industry *i* that are used in industry *k* at time *t*.

The number of patents produced by industry *i* of country *j* is not available, but we have the number of patent applications received by country *j* in industry *i*. If we assume the fraction γ_{ij} of the patents received by country *j* are produced by industry *i* of country *j*, and the fraction η_{ij} of these patents will also apply in Canada, we will have:

$$ForPatent_{ijt} = \eta_{ij} \gamma_{ij} FPatent_{ijt}, \qquad 0 \le \eta_{ij} < 1, \ 0 \le \gamma_{ij} < 1 \qquad (2)$$

where $FPatent_{ijt}$ is the number of patent applications received by foreign country *j* in industry *i* at time *t*, and we assume γ_{ij} and η_{ij} are exogenous country-industry specific parameters. Also, since patent propensity differs greatly from one industry to another, we add industry dummy variable μ_i to reflect these differences. Taking these into account, equation (1) will transform as follows:

$$Patent_{ijt} = \mu_i \cdot (\eta_{ij} \gamma_{ij} FPatent_{ijt-1}^{\alpha_{FP}}) \cdot Trade_{ijt}^{\alpha_T} \cdot FDI_{jt}^{\alpha_{FI}} \cdot Dist_j^{\alpha_D} \cdot GDP_{it}^{\alpha_G} \cdot RD_{it}^{\alpha_{RD}}. \ (3)$$

By taking the logarithm from both sides of (3):

$$\begin{aligned}\log Patent_{ijt} = \log(\mu_i \eta_{ij} \gamma_{ij}) + \alpha_{FP} \log FPatent_{ijt-1} + \alpha_T \log Trade_{ijt} + \alpha_{FP} \log FDI_{jt} \\ + \alpha_D \log Dist_j + \alpha_G \log GDP_{it} + \alpha_{RD} \log RD_{it}.\end{aligned} \qquad (4)$$

By assuming:

$$\log(\mu_i \eta_{ij} \gamma_{ij}) = \log(\mu_i \Theta_{ij}) = d_i + \theta_{ij}, \quad (5)$$

where d_i are the industry fixed effects, and θ_{ij} $\sim iid(0, \sigma_\theta^2)$ are country-industry random effects, we obtain the following two-way random effects model:

$$\begin{aligned}\log Patent_{ijt} = \alpha_{FP} \log FPatent_{ijt-1} + \alpha_T \log Trade_{ijt} + \alpha_{FI} \log FDI_{jt} \\ + \alpha_D \log Dist_j + \alpha_G \log GDP_{it} + \alpha_{RD} \log RD_{it} + d_i + \theta_{ij} + \lambda_t + \varepsilon_{ijt},\end{aligned} \qquad (6)$$

where λ_t is the time dummy and ε_{ijt} is the error term.

5- Data

The data on patents have been extracted from a new patent database that has been developed by the author at the Canadian Intellectual Property Office (CIPO). In the new patent database, the country of origin of foreign applicants as well as the address of Canadian innovators can be identified. Moreover, a mapping between each patent and its industry classification has been developed. This mapping allows us to categorize patents into industry classifications (ISIC revision 3). Because of data limitations on patent addresses, the model will be examined only for the period of 1997-2003. Eleven foreign countries have been selected for this study. These countries represent over 95 percent of foreign patent applications in Canada. The patent applications of foreign countries have been extracted from PATSTAT, the EPO Worldwide Patent Statistical Database (April

2007). Since the patent-industry concordance has been made for IPC-ISIC, the data for industrial R&D intensity, industrial output, and imports to Canada have been obtained from SourceOECD database in ISIC revision 3. Figure 15 presents the 11 countries that have been selected, and table 17 presents the 14 industries that we use in this study.

6- Results

This section presents the econometric results of the model. Also, it examines the robustness of the results by using various methods.

6-1- Main findings

Since the cross-section dimension is much larger (14 industries * 11 countries = 154) than the time dimension (7 years), the best approach is to use a usual cross-sectional time-series pooled estimation adjusted for heteroskedasticity and autocorrelation (Levin, Lin and Chu, 2002; Baltagi, 2005). Table 7 presents the estimation results of model (6). The results suggest that the patent activity of foreign countries is the most important factor for the number of patent applications in Canada. Moreover, trade and FDI are significant factors in transferring foreign technology into Canadian industries. The coefficient of distance is negative and significant, which confirms the gravity model for patents. The highly big and significant negative coefficient on distance indicates that technological diffusion from foreign countries falls as the distance increases. This variable also captures country specific impacts. All of these variables are quite significant under different specifications. The significance of imports as a vehicle for technology transfer contradicts with the results of Eaton and Kortum (1996) and Rafiquzzaman and

Whewell (1998), but supports the finding of Eto and Lee (1993) and Lerner (2002). The negative impact of distance on diffusion of technology is consistent with Rafiquzzaman and Whewell (1998).

Table 7 – Estimation results

logPatent	(1)	(2)	(3)	(4)	(5)	(6)	(7)
logFPatent	0.324*** (0.010)	0.326*** (0.010)	0.266*** (0.011)	0.411*** (0.007)	0.359*** (0.010)	0.386*** (0.008)	0.324*** (0.010)
logTrade	0.119*** (0.009)	0.117*** (0.008)	0.206*** (0.010)		0.130*** (0.011)		0.119*** (0.009)
logFDI	0.128*** (0.012)	0.132*** (0.011)	0.250*** (0.011)			0.152*** (0.012)	0.128*** (0.012)
logDist	-0.282*** (0.012)	-0.283*** (0.012)		-0.472*** (0.008)	-0.364*** (0.011)	-0.366*** (0.011)	-0.282*** (0.012)
logGDP	-0.180** (0.071)		-0.294*** (0.077)	-0.164** (0.072)	-0.244*** (0.073)	-0.113 (0.073)	-0.167** (0.074)
logRD		0.021 (0.022)	-0.003 (0.027)	-0.014 (0.024)	-0.011 (0.024)	0.004 (0.024)	0.012 (0.024)

*** significant at 1 percent level; ** significant at 5 percent level; * significant at 10 percent level. The numbers in the parenthesis are standard errors. All regressions are cross-sectional time-series FGLS with heteroskedastic error terms and panel-specific AR(1). All regressions include industry and time dummies. The panel consists of 14 industries and 11 countries for 7 years.

Contrary to expectations, the impact of market size measured by industrial output on receiving foreign patent applications is negative and significant. One explanation for this result is that most of the patent activities in Canada occur in the science-based sector, which is the smallest sector within Canadian manufacturing (Rafiquzzaman and Whewell, 1998). Table 11 confirms this finding. The finding suggests that though there is a positive and significant correlation between the GDP and foreign patents in the cross-country studies of Eto and Lee (1993), Eaton and Kortum (1996) and Rafiquzzaman and Whewell (1998), this relationship turns out to be negative at the industry level. In fact, taking a simple correlation between industrial patent applications and industrial output shows that there is a negative correlation of -0.195 between the two variables. Another argument mentioned by Lerner (2002) and Rafiquzzaman and Whewell (1998) for the impact of the GDP of a small country is that there may be some threshold size of economy below which it is not profitable for foreign inventors to exploit their latest technologies. Moreover, small economies may tend to be relatively specialized and not recipients of a wide variety of products and inventions. The facts that most of patent activities are in smaller science-based sectors and Canada is relatively a small economy can explain the negative relationship between industrial output and the number of foreign patents.

Finally, R&D intensity is not a significant factor in absorbing foreign patents into Canadian industries. Its coefficient is small and insignificant. This result contradicts the cross-country studies of Eto and Lee (1993), Eaton and Kortum (1996) and Rafiquzzaman and Whewell (1998). The reason is because of the mixed impact that the R&D intensity can have: As McFetridge (1999) explains: "the capacity to innovate is also the capacity either to adopt or to imitate. The greater is the domestic innovative capability, the greater is the portion of the international pool of technology pool that can profitably be applied domestically (p.2)". These two capacities conflict when foreign patents matter and have opposite impacts on foreign patent applicants, which will lead to mixed results on the role of R&D intensity. It is worth mentioning that even though the impact of R&D intensity on patents is insignificant, there is a positive and significant interaction between R&D intensity and foreign patents: the coefficient of *logRD* * *logFPatent* is equal to 0.013 and significant at 0.01 percent. This means industries with higher R&D intensities are better recipients of foreign patents. The results of this study confirm Gallini, Putnam, and Tepperman's (2001) results as they suggest that an increase in foreign patenting in Canada may be due to an increase in innovative activity of the foreign countries that spills over into Canada regardless of the incentives provided in Canada. Appendix 2 presents the sensitivity of the model to specific industries and countries.

6-2- Robustness of the results

Tables 8, 9, and 10 show how robust the results are. Around 50% of patent applications in Canada are from the United States. Therefore, one test for the model is to exclude the United States from the data and rerun the models. Table 8 suggests that excluding the United Stated does not change the results significantly.

Next, we examine how the estimations change if we use other proxies for the variables of the model. We try a different set of variables for this purpose. First, we use lagged foreign R&D expenditures instead of lagged foreign patents. Literature shows that there is a strong correlation between R&D expenditures and patent activity (e.g. Hall, Griliches and Hausman, 1986; Griliches, 1990). Therefore, we use foreign R&D expenditures as a measure of innovative activities of the source countries instead of their number of patents. In this case, the innovative activity of foreign countries measured by R&D expenditures is still the most important factor for the number of patents in Canada, though its coefficient is smaller now. Second, we try the industry level human capital[1] instead of R&D intensity as a measure of the ability of the country to absorb foreign

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[1] Number of researchers.

technology. Estimation results show that this variable is still small and insignificant. This means neither R&D intensity nor the number of researchers can explain the number of foreign patent applications in Canadian industries.

Table 8 – Estimation results when the United States is excluded

logPatent	(1)	(2)	(3)	(4)	(5)	(6)	(7)
logFPatent	0.336*** (0.012)	0.335*** (0.012)	0.250*** (0.011)	0.435*** (0.008)	0.374*** (0.010)	0.402*** (0.009)	0.336*** (0.012)
logTrade	0.121*** (0.009)	0.121*** (0.009)	0.153*** (0.009)		0.129*** (0.012)		0.121*** (0.009)
logFDI	0.122*** (0.012)	0.124*** (0.012)	0.190*** (0.011)			0.142*** (0.013)	0.122*** (0.012)
logDist	-0.313*** (0.036)	-0.311*** (0.037)		-0.551*** (0.022)	-0.446*** (0.031)	-0.415*** (0.030)	-0.315*** (0.036)
logGDP	-0.217** (0.086)		-0.278*** (0.089)	-0.203** (0.084)	-0.287*** (0.091)	-0.137 (0.087)	-0.217** (0.090)
logRD		0.014 (0.025)	-0.002 (0.028)	-0.022 (0.028)	-0.018 (0.029)	-0.019 (0.026)	-0.002 (0.027)

*** significant at 1 percent level; ** significant at 5 percent level; * significant at 10 percent level. The numbers in the parenthesis are standard errors. All regressions are cross-sectional time-series FGLS with heteroskedastic error terms and panel-specific AR(1). All regressions include industry and time dummies. The panel consists of 14 industries and 11 countries for 7 years.

Next, we try four new proxies for the market size instead of industrial output to see if any of these variables change the negative impact of industrial output on foreign patents. The new proxies are industry value added, industry gross operating surplus, industry expenditures on intermediate goods, and industry investment. The estimation results show that the impact of all of these variables is negative.

Regarding market size, one may argue that the market size of Canadian industries alone is not a good indicator because innovators look at the relative market size of a country to other countries when they decide on their markets. For example, it is much more profitable for an innovator to patent its product in the United States than in Canada because it is a much bigger market.

Table 9 – Using other proxies for the variables of the model

logPatent	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
logFPatent	0.198***	0.324***	0.325***	0.325***	0.326***	0.326***	0.326***	0.325***
	(0.016)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
logTrade	0.183***	0.119***	0.119***	0.119***	0.116***	0.116***	0.117***	0.119***
	(0.015)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)
logFDI	0.146***	0.128***	0.130***	0.131***	0.133***	0.132***	0.132***	0.129***
	(0.014)	(0.012)	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)	(0.012)
logDist	-0.203***	-0.282***	-0.281***	-0.282***	-0.283***	-0.283***	-0.282***	-0.282***
	(0.017)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
logGDP	-0.211**	-0.177**	-0.158***	-0.119***	0.000*	-0.048	-0.040	-0.085
	(0.095)	(0.071)	(0.055)	(0.041)	(0.000)	(0.057)	(0.071)	(0.055)
logRD	0.033	-0.004	0.024	0.021	-0.001	0.020	0.023	0.012
	(0.030)	(0.026)	(0.023)	(0.023)	(0.024)	(0.022)	(0.022)	(0.012)

*** significant at 1 percent level; ** significant at 5 percent level; * significant at 10 percent level. The numbers in the parenthesis are standard errors. All regressions are cross-sectional time-series FGLS with heteroskedastic error terms and panel-specific AR(1). All regressions include industry and time dummies. (1) Lagged foreign R&D expenditures instead of lagged foreign patents; (2) Industry human capital (number of researchers) instead of R&D intensity; (3) Industry value added instead of output; (4) Industry gross operating surplus instead of output; (5) Expenditures on intermediate goods instead of output; (6) Industry investment instead of output; (7) Value added shares of manufacturing industries relative to OECD18 instead of output; (8) Unweighted variables with patent input-output matrix (R&D intensity, imports, and GDP). The panel consists of 14 industries and 11 countries for 7 years.

This argument was mentioned earlier in this paper to explain why the impact of industrial output on patent applications is negative. To test this argument, we substitute the industrial output with the value added shares of manufacturing industries of Canada relative to the 18 larger OECD countries. These shares show the relative importance of Canadian industries to other OECD countries as a market for the inventors. The coefficient of this variable is still negative, but very small and insignificant. Finally, we use the R&D intensity, imports, and industrial output when they are not weighted by the patent input-output matrix according to the equations 1.1-1.3. In this case, the coefficients of foreign patent activities, imports, FDI, and distance do not change significantly, thought the coefficient of industrial output becomes small and insignificant. Table 9 presents the results of estimations with new proxies.

Table 10 – Other estimation methods

logPatent	(1)	(2)	(3)	(4)	(5)
logFPatent	0.367*** (0.023)	0.324*** (0.010)	0.306*** (0.010)	0.336*** (0.012)	0.311*** (0.022)
logTrade	0.116*** (0.011)	0.119*** (0.009)	0.096*** (0.011)	0.121*** (0.009)	0.112*** (0.024)
logFDI	0.112*** (0.041)	0.128*** (0.012)	0.125*** (0.013)	0.122*** (0.012)	0.109*** (0.027)
logDist	-0.273*** (0.035)	-0.282*** (0.012)	-0.296*** (0.014)	-0.313*** (0.036)	-0.307*** (0.034)
logGDP	-0.149 (0.112)	-0.167** (0.074)	-0.245*** (0.083)	-0.217** (0.086)	-0.233 (0.142)
logRD	0.004 (0.38)	0.012 (0.024)	0.008 (0.029)	0.000 (0.036)	-0.016 (0.050)

***: significant at 1 percent level; **: significant at 5 percent level; *: significant at 10 percent level. The numbers in the parenthesis are standard errors. All regressions include industry and time dummies. (1) Cross-sectional time-series Prais-Winsten regression with panels corrected autocorrelation; (2) Cross-sectional time-series GLS with heteroskedastic error structure and panel specific autocorrelation; (3) Cross-sectional time-series GLS with heteroskedastic error structure and common autocorrelation; (4) Cross-sectional time-series GLS with heteroskedastic error structure and no autocorrelation; (5) Random-effects cross-sectional time-series GLS regression. The panel consists of 14 industries and 11 countries for 7 years.

Table 10 presents other estimation methods and the cases where we do not correct heteroskedasticity and autocorrelation problems. The results suggest that the coefficients of foreign patent activities, imports, FDI, and distance remain stable in all cases, but the coefficient of industrial output becomes insignificant if we do not correct for heteroskedasticity.

6-3- Ranking industries

Another hypothesis we want to examine empirically is whether different industries have different propensities to patent. For this purpose, industry dummies have been included in the model. This way, industries can be ranked according to their patent intensities. All of the dummy variables are statistically significant. Table 11 suggests that their propensities to patent match more or less with the ranking of table 6. Based on table 11, Furniture, manufacturing n.e.c., and recycling (ISIC 36/37), Electrical machinery and apparatus n.e.c (ISIC 31), Medical, precision, opt. Instruments, and watches (ISIC 33), and Office, accounting and computing machinery (ISIC 30) have the highest rate of patenting among industries. On the other hand, Machinery and equipment n.e.c (ISIC 29), Rubber and plastics products (ISIC 25), Fabricated metal products (ISIC 28), and Chemical products (ISIC 24) do not rely on patents heavily.

Table 11 – Ranking of industries based on their propensities to patent

Industry	Rank according to table 18	Coefficient in table 7*	Rank according to table 6
i14: Furniture, manufacturing n.e.c.; recycling	1	4.537	1
i10: Electrical machinery and apparatus n.e.c	2	3.729	3
i12: Medical, precision, opt. Instruments; watches	3	3.443	2
i9: Office, accounting and computing machinery	4	2.729	4
i1: Food, beverages and tobacco	5	2.567	6
i11: Radio, TV and communication equipment	6	2.254	5
i2: Textiles, wearing apparel, leather, footwear	7	1.828	7
i6: Basic metals	8	1.818	9
i13: Other transport equipment	9	1.797	8
i5: Non-metallic mineral products	10	1.099	10
i8: Machinery and equipment n.e.c	11	1.251	11
i4: Rubber and plastics products	12	0.657	12
i7: Fabricated metal products	13	0.493	14
i3: Chemical products	14	0.00	13

* All coefficients are significant at 1%. We removed industry 3 (i3) to avoid collinearity among industry dummies and the constant term.

7- Conclusion

This paper consists of two parts. In the first part, we reviewed the patent applications in Canada for the period of 1977-2003. The main source of data for this analysis is TECHSOURCE, the patent database of the Canadian Intellectual Property Office. We paid more attention on retrieving and polishing the data of 1977-2003 because the datasets are more complete for this period. International comparison was made wherever possible. The second part of the paper presented a model to estimate the number of patent applications in Canada. We assumed the number of foreign patent applications is a measure of technology transfer to a country. Therefore, this model also estimates the diffusion rate of foreign technology to Canadian industries.

The model suggests that the patent activity of foreign countries is the most important determinant of the number of patent applications in Canada. Imports and FDI are important vehicles for technology transfer, and distance has a negative and significant impact on receiving foreign patents. Contrary to expectations, industrial market size has a negative correlation with the number of patents received from foreign countries. R&D intensity does not have a significant impact in this regard; however, the interaction term between R&D intensity and foreign patents suggest that industries with higher R&D intensities may be better recipients of foreign patents. Moreover, the paper showed empirically that different industries have different propensities to patent. The fact that imports and FDI have a strong relationship with the number of foreign patents is another support for more open trade and investment policies.

This paper is one of the few studies that model patent activities at the industrial level. For this purpose, an IPC-ISIC concordance has been used to map patents to industry classifications. One path to extend this study for Canadian industries is to develop an IPC-NAICS concordance. This way, the impacts of more variables on patenting activities in Canada can be examined. This model can also be used to forecast the number of foreign patents applications received by patent jurisdictions such as the Canadian Intellectual Property Office.

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Appendix 1- Patent input-output matrix for 14 manufacturing industries - the average sample over 1997-2003:

		Sector of Use (SOU)													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Industry of Manufacturing (IOM)	**1**	0.403	0.019	0.004	0.002	0.009	0.010	0.006	0.003	0.023	0.025	0.065	0.045	0.006	0.133
	2	0.013	0.579	0.055	0.004	0.007	0.018	0.000	0.000	0.005	0.010	0.017	0.144	0.006	0.036
	3	0.000	0.002	0.611	0.000	0.000	0.000	0.000	0.000	0.009	0.021	0.000	0.000	0.000	0.065
	4	0.000	0.003	0.000	0.286	0.012	0.003	0.000	0.000	0.003	0.003	0.001	0.004	0.003	0.002
	5	0.000	0.003	0.000	0.004	0.604	0.001	0.006	0.001	0.006	0.007	0.061	0.017	0.000	0.041
	6	0.006	0.016	0.004	0.004	0.002	0.508	0.036	0.000	0.008	0.004	0.001	0.021	0.006	0.053
	7	0.023	0.012	0.003	0.000	0.008	0.065	0.686	0.000	0.002	0.031	0.000	0.074	0.000	0.058
	8	0.005	0.002	0.000	0.000	0.002	0.000	0.001	0.383	0.139	0.077	0.050	0.076	0.003	0.039
	9	0.014	0.011	0.000	0.017	0.016	0.001	0.003	0.017	0.301	0.123	0.045	0.027	0.007	0.034
	10	0.048	0.019	0.004	0.010	0.002	0.058	0.022	0.051	0.048	0.271	0.029	0.029	0.020	0.109
	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006	0.960	0.001	0.001	0.002
	12	0.001	0.000	0.000	0.000	0.001	0.001	0.003	0.003	0.007	0.026	0.025	0.805	0.001	0.022
	13	0.003	0.005	0.000	0.004	0.001	0.002	0.000	0.039	0.033	0.037	0.028	0.088	0.428	0.052
	14	0.029	0.011	0.002	0.003	0.000	0.008	0.004	0.004	0.015	0.016	0.012	0.022	0.003	0.530

Industries:

Industry	**ISIC**	**Industry Name**
1	15/16	Food, beverages and tobacco
2	17/19	Textiles, wearing apparel, leather, footwear
3	24	Chemical products
4	25	Rubber and plastics products
5	26	Non-metallic mineral products
6	27	Basic metals
7	28	Fabricated metal products
8	29	Machinery and equipment n.e.c.
9	30	Office, accounting and computing machinery
10	31	Electrical machinery and apparatus n.e.c.
11	32	Radio, TV and communication equipment
12	33	Medical, precision, optical instruments; watches
13	35	Transport equipment
14	36/37	Furniture, manufacturing n.e.c.; recycling
15	39452	Agriculture, Hunting, Forestry and Fishing
16	39735	Mining and quarrying
17	4045	Electricity, gas and water supply; construction
18	50/99	Total services

Appendix 2– Sensitivity analysis with respect to industries and countries

The following graphs present the coefficients of the variables of the model when we remove one industry or one country from the data set. As the graphs suggest, the results are quite stable over industries and countries in most cases.

i) By industry:

Figure 12- The coefficient of foreign patent applications and its 95 confidence interval when each industry is omitted from the data

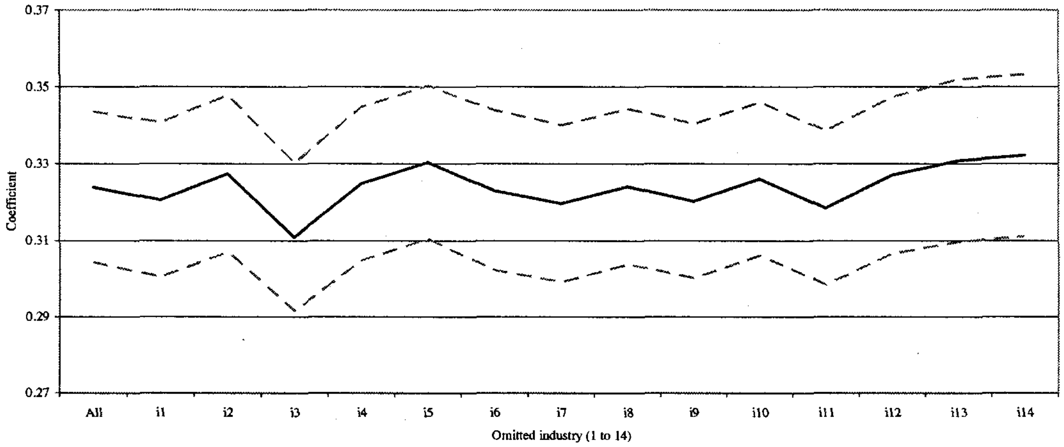


Figure 13- The coefficient of imports and its 95 confidence interval when each industry is omitted from the data

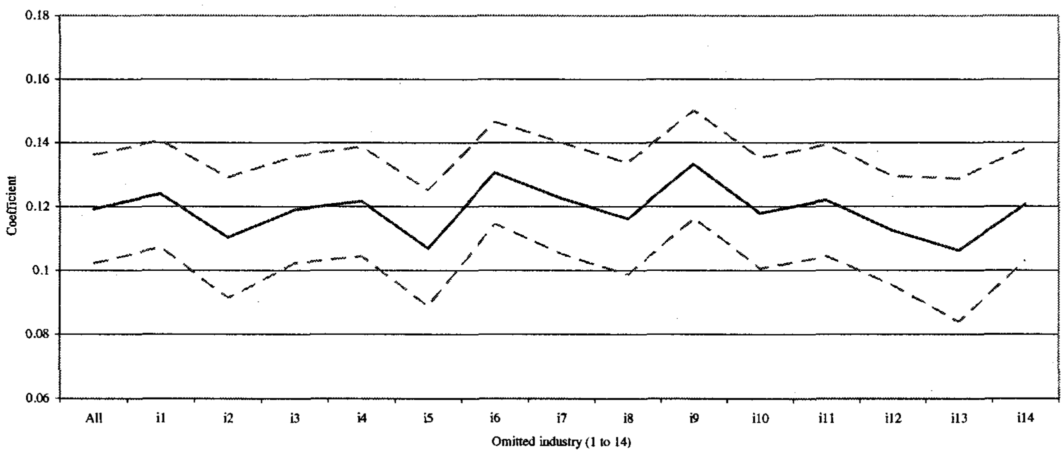


Figure 14- The coefficient of FDI and its 95 confidence interval when each industry is omitted from the data

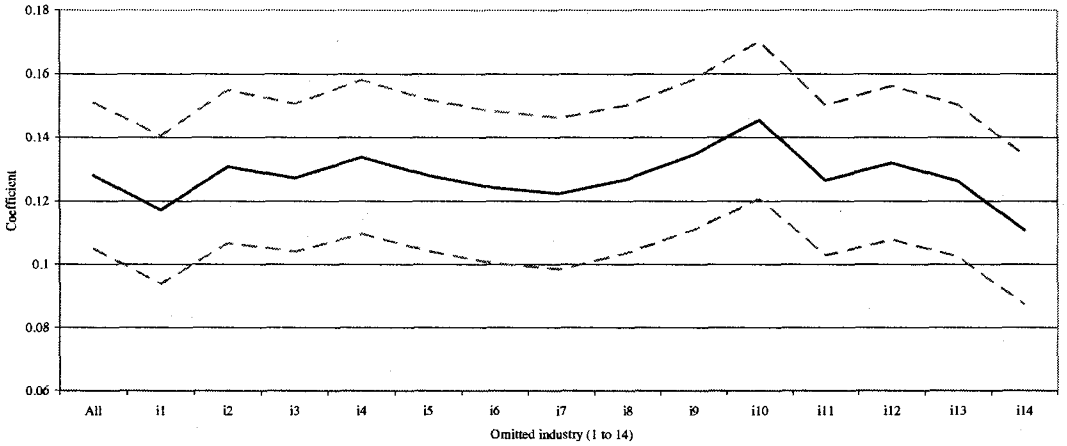


Figure 15- The coefficient of distance (square) and its 95 confidence interval when each industry is omitted from the data

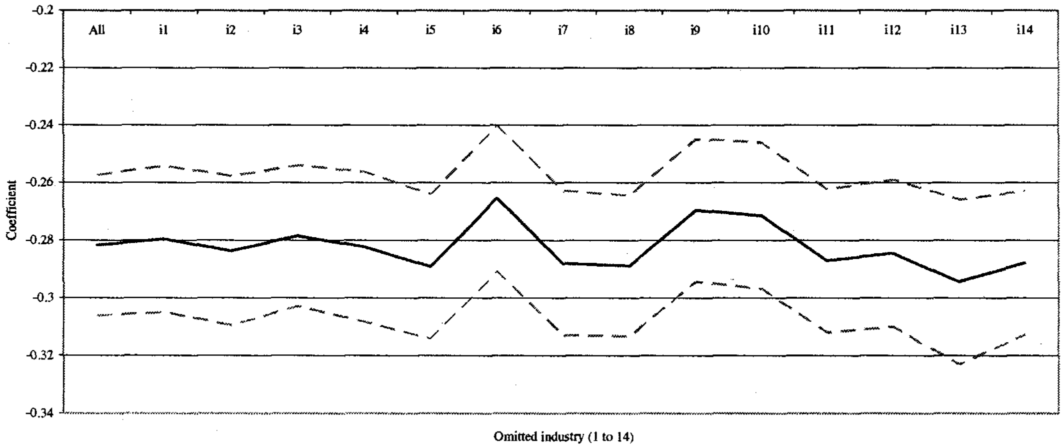
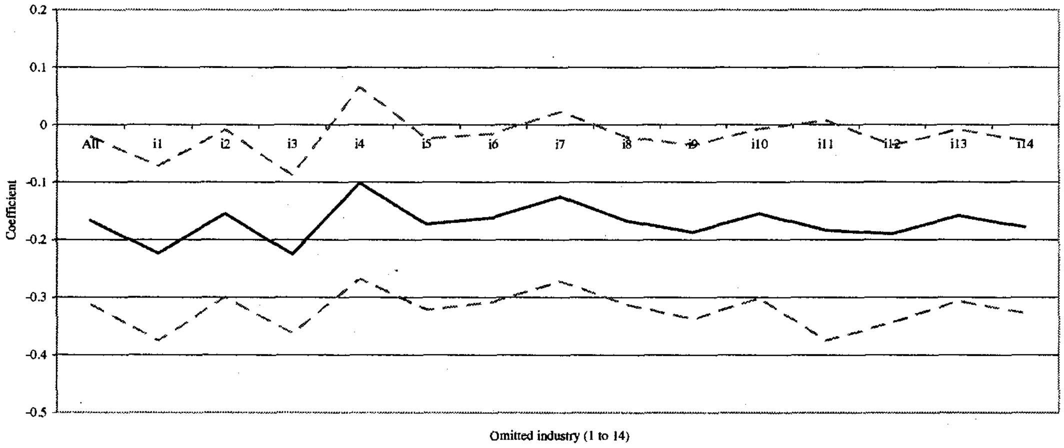


Figure 16- The coefficient of the industrial output and its 95 confidence interval when each industry is omitted from the data



ii) By country:

Figure 17- The coefficient of foreign patent applications and its 95 confidence interval when each country is omitted from the data

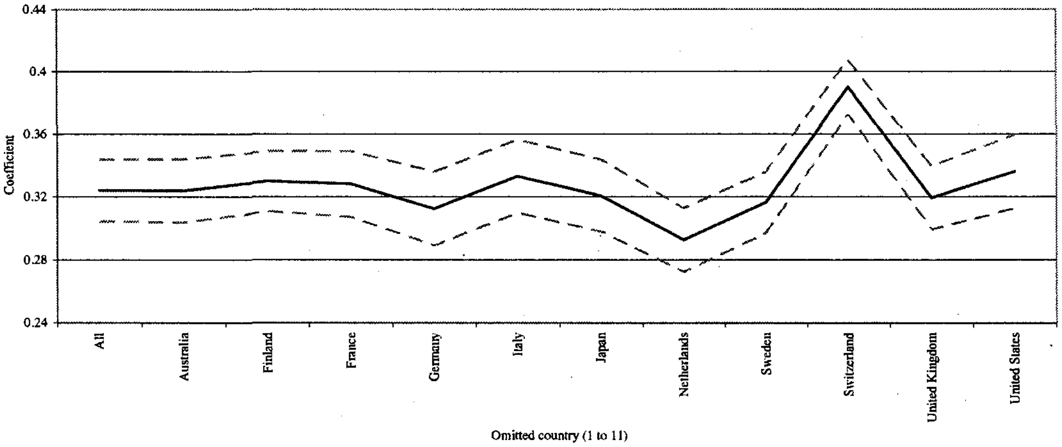


Figure18- The coefficient of imports and its 95 confidence interval when each country is omitted from the data

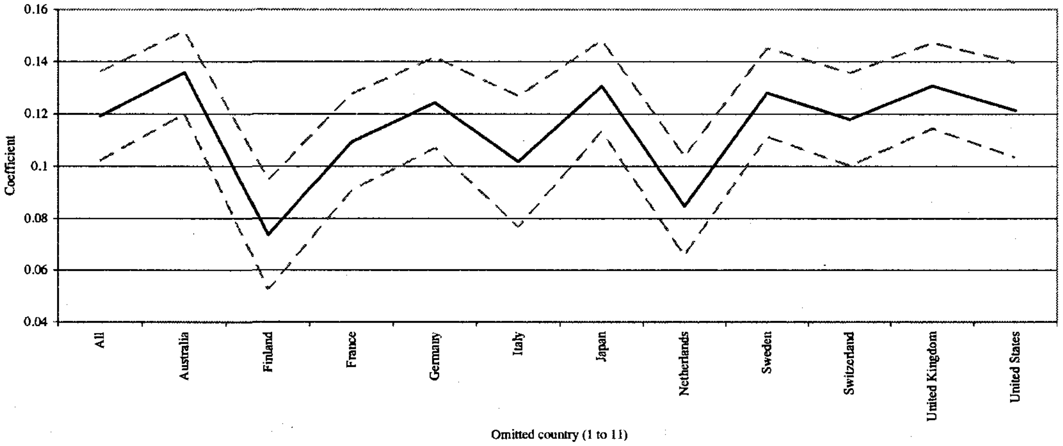


Figure 19- The coefficient of FDI and its 95 confidence interval when each country is omitted from the data

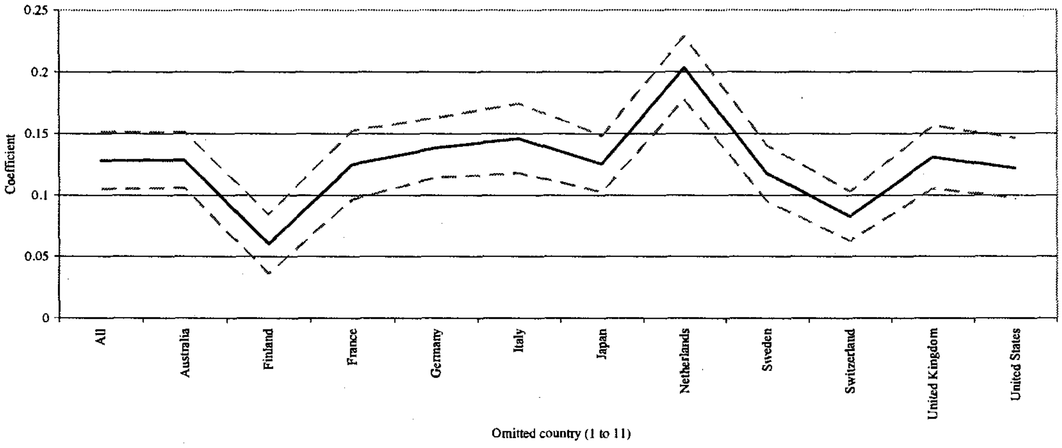


Figure 21- The coefficient of industrial output and its 95 confidence interval when each country is omitted from the data

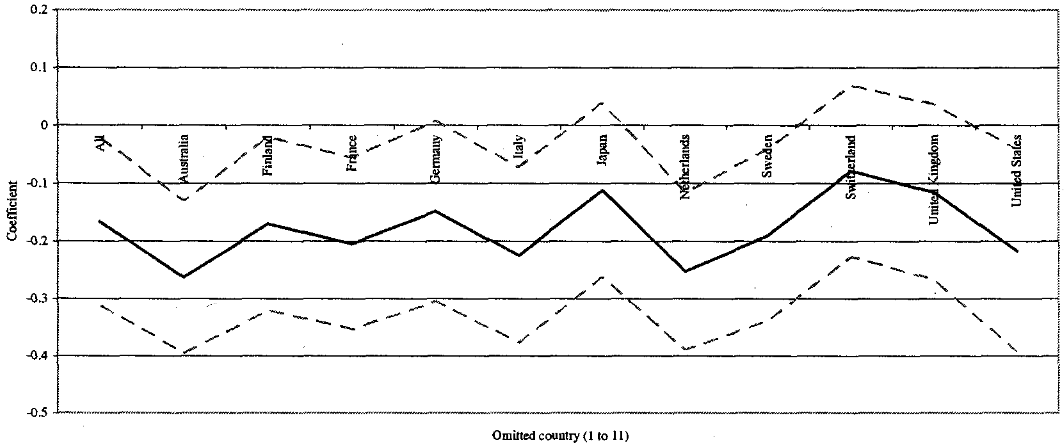
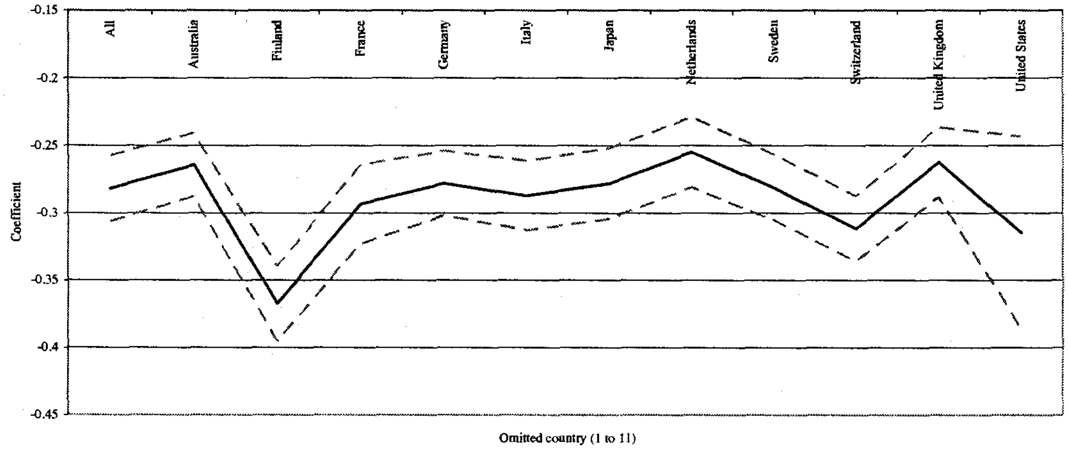


Figure 20- The coefficient of distance (square) and its 95 confidence interval when each country is omitted from the data



CONCLUSION

The three chapters of this dissertation studied technology spillovers between countries from different points of view.

Chapter 1 showed that domestic R&D is higher under R&D cartelization than under RJV cartelization and non-cooperation when the domestic spillover is high, and it is higher under non-cooperation when the domestic spillover is low. If the domestic spillover is high and the foreign spillover is low, the domestic firm's profits are lower under R&D cartelization than under RJV cartelization. Consumer surplus and welfare are always higher under RJV cartelization. Welfare is higher under R&D cartelization than under non-cooperation when the foreign spillover is high. Also, if the foreign government gives an R&D subsidy to the foreign firm, foreign R&D will increase and the domestic firm's profit and domestic welfare will decrease. However, the home country can recover this profit and welfare loss, partially or totally, through the simultaneous use of a tariff and an R&D subsidy.

According to chapter 2, only foreign R&D has a positive and significant impact on productivity. Contrary to the theory and cross-country empirical studies, domestic R&D of Canada does not have a significant impact on TFP under any of the specifications. However, it helps industries absorb foreign R&D. These results suggest that innovation policies should focus more on receiving and absorbing foreign innovations.

Chapter 3 suggests that the patent activity of foreign countries is the most important determinant of the number of patent applications in Canada. Imports and FDI are important vehicles for technology transfer, and distance has a negative and significant impact on receiving foreign patents. Contrary to expectations, industrial market size has a negative correlation with the number of patents received from foreign countries. R&D intensity does not have a significant impact in this regard; however, the interaction term between R&D intensity and foreign patents suggest that industries with higher R&D intensities may be better recipients of foreign patents. Moreover, the paper showed empirically that different industries have different propensities to patent.