

## Trade Policy and Innovation Policy with Asymmetric R&D Spillovers

By RASHID NIKZAD and GAMAL ATALLAH\*

*This paper studies the effect of tariffs on R&D expenditures when there are R&D spillovers between firms. We consider a three-stage game, where the government determines the amount of the tariff and R&D subsidy 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. 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.*

**Keywords:** R&D, Spillovers, Tariffs, Game Theory

**JEL Classification:** O3

### I. 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. Section II reviews the literature on this topic. Section III presents the model. Section IV, solves the model and the results are presented. Section V studies the case where the foreign government supports the foreign firm by means of an R&D subsidy. Section VI assumes both governments give R&D subsidies to their firms. Section VII

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studies the special case where spillovers are very low or very high. Section VIII presents the conclusion and discussion.

## II. 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 this 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. The authors show that in the absence of export subsidies, national governments have an incentive to subsidize R&D. D'Aspremont and Jacquemin (1988, 1990), Qiu and Tao (1998), Kamien and Zang (2000) also use a two- or three-stage game to find optimal R&D structure for firms.

DeCourcy (2005) uses a three-stage game with symmetric R&D spillovers, where the government can choose a particular R&D cooperative arrangement to maximize national welfare. Atallah (2005a) analyses R&D cooperation with asymmetric spillovers. He shows that with symmetric spillovers cooperation is always beneficial to firms, but 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 Research Joint Venture (RJV) cartelization, where firms coordinate R&D expenditures and share their research results.

Meanwhile, some researchers extend the model to analyze the impact of trade and tariffs on R&D by including these variables in the model. Examples of this kind of analysis include Reitzes (1991), Hwang, Kou and Mai (1997), Zigic (1998), Neary and Leahy (2002), Kabiraj and Marjit (2003), Muller and Schnitzer (2003), and Liao (2008). 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).

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. Other reasons for firms to cooperate on R&D include the following (Nakamura, Nelson, and Vertinsky, 2003):

- 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.



Kamien et al. (1992) cite three types of R&D cooperation. The first type is an 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.

### III. Model

This paper uses a three-stage game-theoretic framework with perfect and complete information. Two firms, a domestic firm and a foreign firm, 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  $\beta$  dollars, where  $\beta \in [0,1]$ . We consider three types of interaction in R&D: non-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 as follows:

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

where  $c$  is the marginal production cost, and  $x_d$  and  $x_f$  are the R&D outputs of the domestic and foreign firms, respectively. 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 as follows:

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

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  $\beta$  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  $\beta_d$ , while the technology of the foreign firm leaks at the rate  $\beta_f$ . 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  $\beta_i$ , for  $i = f$  and  $d$ . For small values of  $\beta_i$ , an increase in  $x_i$  will decrease firm  $j$ 's output, but for large values of  $\beta_i$ , 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.

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

For simplicity, we assume a linear relationship between price and output. The slope of the inverse demand function is assumed to be -1, for simplicity:

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

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



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

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

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 the following:

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

where  $CS$  represents consumer surplus and  $ty_f$  is the revenue from tariffs. This last term is justified under the assumption that both producers compete in the domestic market, and the home country imposes tariffs on foreign products.  $CS$  is given by the following:

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

Note that  $A - p = y_d + y_f$  from equation 4. Now, we consider the three-stage game. In the first stage, the government chooses the tariff rate to maximize social welfare:

$$\max_t W(y_d(t), y_f(t), x_d(t), x_f(t), t). \quad (9)$$

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:

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

and the problem of the foreign firm is as follows:

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

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:

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

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 as follows:

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

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

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. First, R&D increases each firm's profit directly by lowering the firm's marginal cost. Second, 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 (Qiu and Tao, 1998).

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:

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

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<sup>1</sup>:

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

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 levels of domestic and foreign R&D investments for any given tariff. If firms are coordinating their R&D expenditures (i.e., R&D cartelization) 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 (i.e. RJV cartelization), 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  $x_f^*$ :

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

#### IV. 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 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.

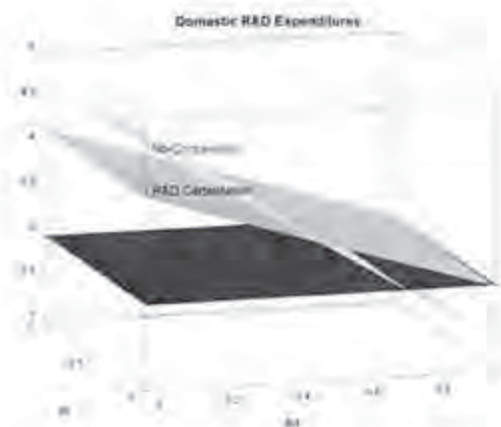
We assign some values to the parameters of the model as follows. We assume  $A=1000$ ,  $\alpha_d = \alpha_f = 50$ , and  $\gamma=60$ . By simulating the values of the variables of the model, we obtain the results based on the values of R&D spillovers  $\beta_d$  and  $\beta_f$ . Note that none of the 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. Appendix 2 shows that the results obtained in this section do not depend on the assumed numeric values of  $A$ ,  $\alpha_d$ ,  $\alpha_f$ , and  $\gamma$ .

<sup>1</sup> Since the equations are too long and complicated, we do not show them in the paper, but they are available upon request.

### A. R&D

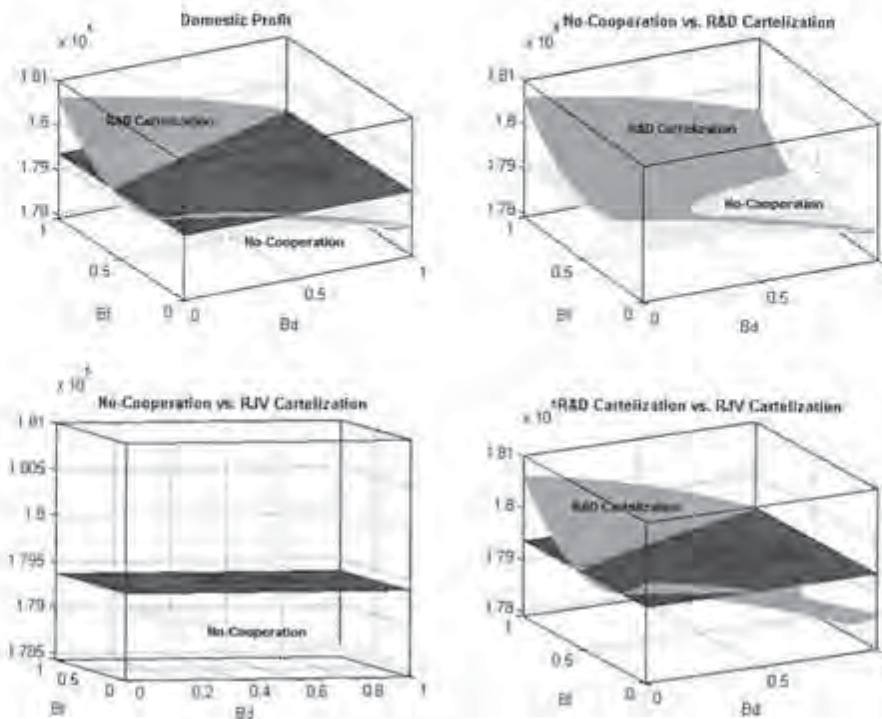
Figure 1 presents domestic R&D. The ranking of domestic R&D across the different scenarios depends on  $\beta_d$ , and is largely independent of  $\beta_f$ . For low  $\beta_d$ , domestic R&D is higher under no cooperation. This is due to the well-known reduction in duplication that results from R&D cooperation with low spillovers. For high  $\beta_d$ , 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  $\beta_d$ , 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  $\beta_f$ .

**Figure 1: Domestic R&D**



A notable feature is that domestic R&D declines with  $\beta_d$  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  $\beta_d$  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 in Figure 2, the optimal tariff first increases then decreases with  $\beta_d$ . 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  $\beta_d$ , this improves the competitive position of the foreign firm, increasing its market share, and reducing the R&D of the domestic firm.



**Figure 2: Domestic Firm's Profits**

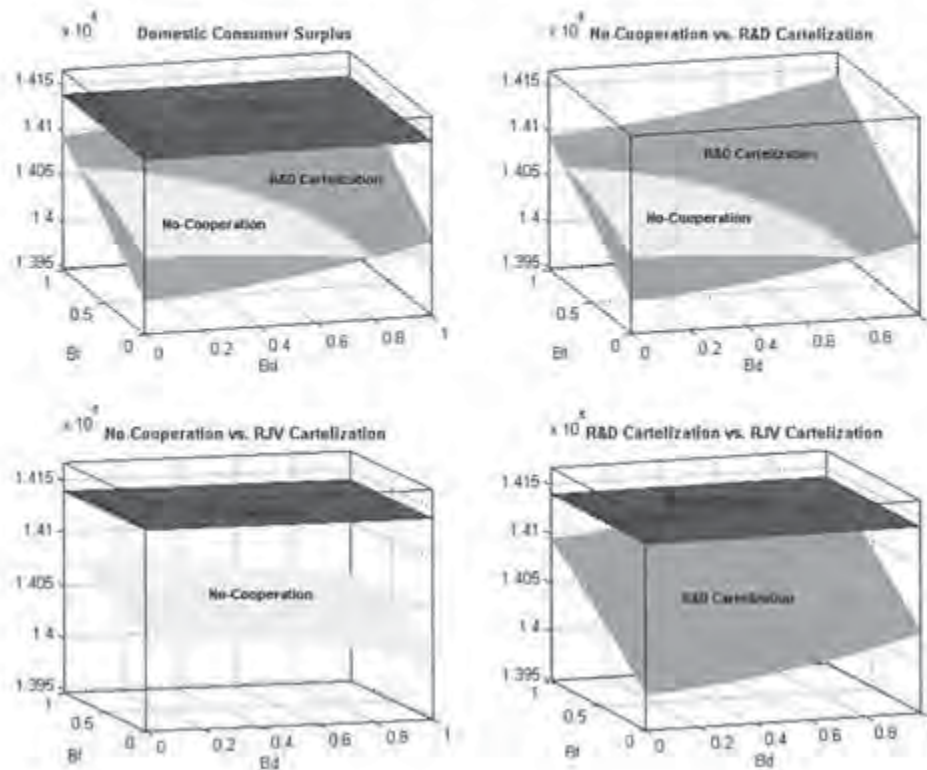
### B. Profits

Figure 2 presents the domestic firm's profit. Please note that in this and some of the following figures, the first quadrant compares all three scenarios simultaneously; whereas, the other three quadrants compare the scenarios pairwise for more clarity. The domestic firm always earns a higher profit under RJV cartelization than under no-cooperation. Also, its profits are higher under RJV cartelization compared with 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 no cooperation unless the domestic spillover is high and the foreign spillover is not very high.

### C. Consumer Surplus

Figure 3 shows (domestic) consumer surplus. Consumer surplus is always higher under RJV cartelization than R&D cartelization and no cooperation. The reason is that the sum of the outputs of the firms yields a higher amount under RJV cartelization. Consumer surplus is higher under R&D cartelization if either foreign or domestic spillovers are high, and it is higher under no cooperation if both foreign and domestic spillovers are low.

Figure 3: Domestic Consumer Surplus

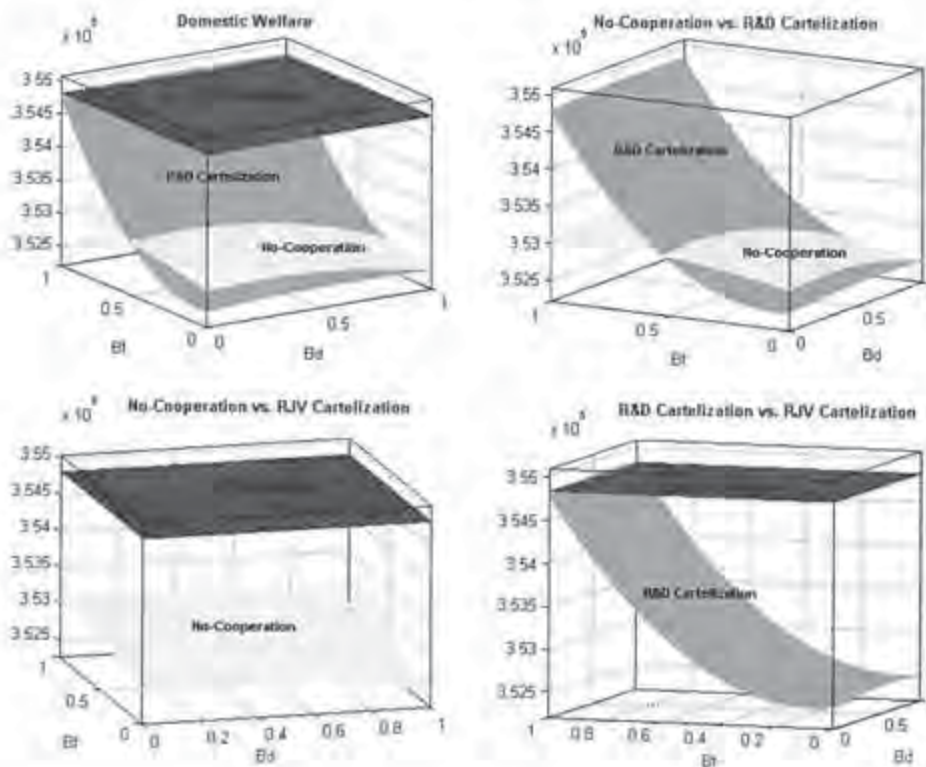


#### D. Welfare

Figure 4 presents changes in welfare based on the changes in domestic and foreign spillovers. Welfare is always higher under RJV cartelization than no 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 no cooperation. When the foreign spillover is low, welfare is higher under no cooperation than under R&D cartelization. These results are independent of  $\beta_d$ . Note that under R&D cartelization welfare is essentially flat with respect to domestic spillovers, but increases steeply with  $\beta_f$ . The reason is that the benefits of the domestic firm increase with  $\beta_f$ .



Figure 4: Domestic Welfare



### E. 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; 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 5 shows, under no cooperation, the optimal tariff increases with  $\beta_d$ . An increase in  $\beta_d$  induces the domestic firm to reduce its R&D under no cooperation, which hurts both domestic profits and consumers. To mitigate this effect, the tariff is increasing in  $\beta_d$ , 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.

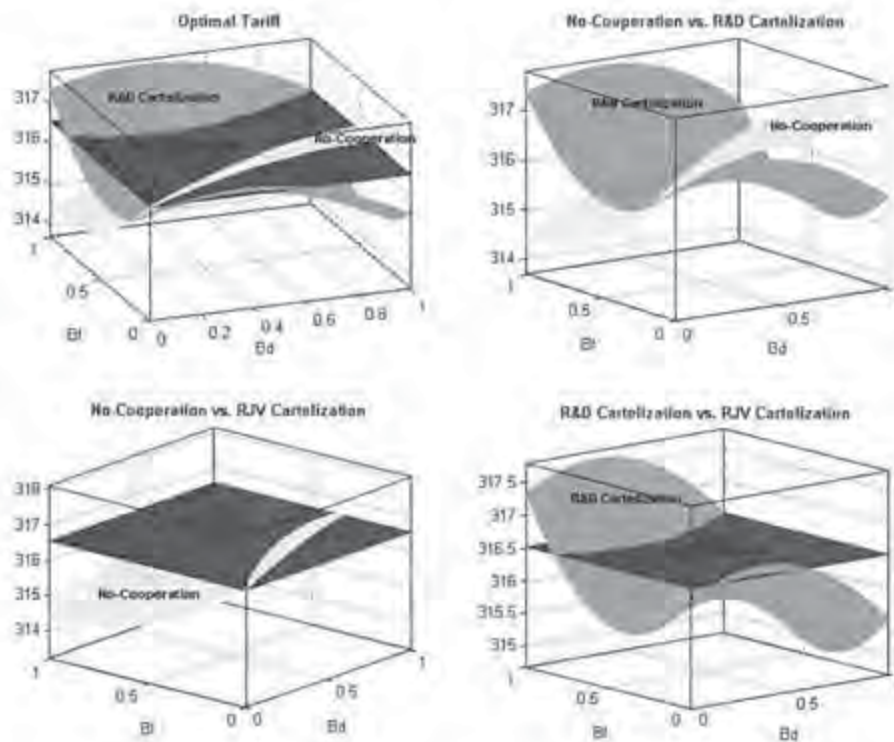
At the same time, under no cooperation, the optimal tariff declines with  $\beta_f$ . As  $\beta_f$  increases, the foreign firm reduces its R&D, which benefits the domestic producer, but hurts



consumers. To mitigate the loss to consumers, and to mitigate the reduction in R&D by the foreign producer, the government reduces the tariff as  $\beta_f$  increases.

Under R&D cartelization, the tariff first increases then decreases with  $\beta_d$ . It first increases with  $\beta_d$  to protect the domestic firm: as  $\beta_d$  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  $\beta_d$  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 then increases with  $\beta_f$ . It first decreases with  $\beta_f$  because as  $\beta_f$  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  $\beta_f$  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.

Figure 5. Optimal Tariffs



In other words, under R&D cartelization, the optimal tariff increases with  $\beta_d$  when it is low and with  $\beta_f$  when it is high; and it decreases with  $\beta_d$  when it is high and with  $\beta_f$  when it is low. A low  $\beta_d$  or a high  $\beta_f$  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  $\beta_d$  or a low  $\beta_f$  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 no cooperation when  $\beta_f$  is sufficiently low and  $\beta_d$  is sufficiently high; in this case the domestic firm is in a strong position, and the high tariff under no cooperation benefits both the domestic firm and consumers. When  $\beta_f$  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  $\beta_f$  is intermediate (or  $\beta_f$  is low and  $\beta_d$  is very low), the tariff is highest under RJV cartelization. In this range, the tariff declines sharply with  $\beta_f$  under no cooperation, and is still going up under R&D cartelization.

### V. 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 III 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:

$$\pi_f = (p - c_f - t)y_f - \gamma x_f^2 + s_f x_f, \quad (19)$$

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:

$$W_f = \pi_f - s_f x_f. \quad (20)$$

The rest of the model is as in section III. 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  $A$ ,  $\alpha_d$ ,  $\alpha_f$ , and  $\gamma$  as before. 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:

#### A. R&D

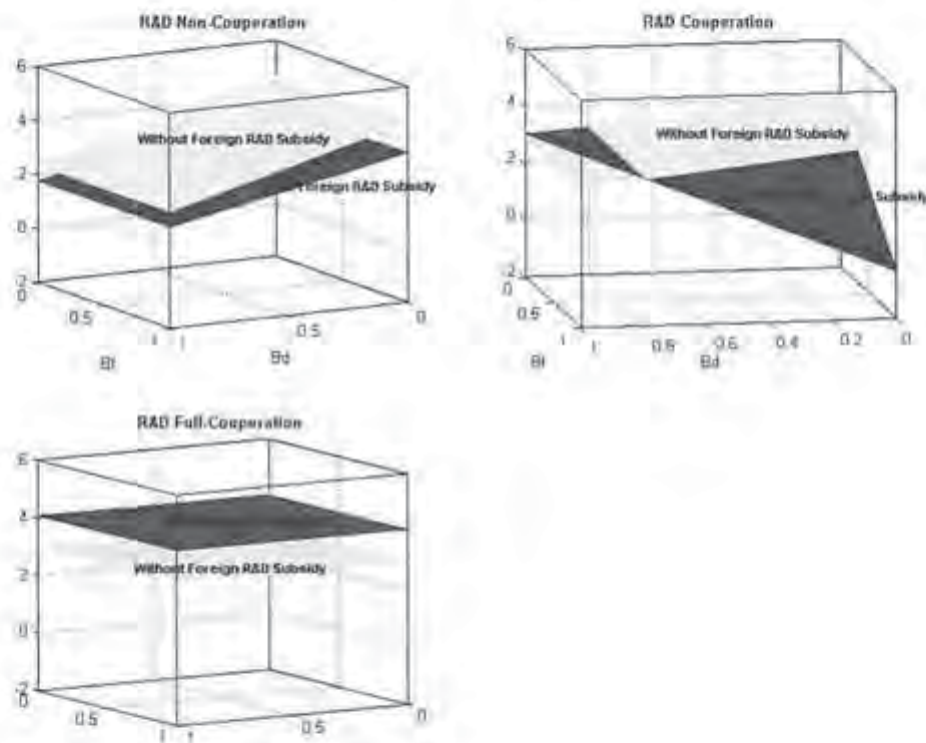
Figure 6 compares domestic R&D with and without the foreign subsidy. Domestic R&D under no cooperation is higher when there is no foreign R&D subsidy, and it is lower under RJV cartelization.



### B. Profits

Figure 7 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 no cooperative, even though the domestic firm benefits from the invested R&D of the foreign firm, it reduces its own R&D (see Figure 5), 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 6: Domestic R&D; Foreign R&D Subsidy vs. No Foreign R&D Subsidy

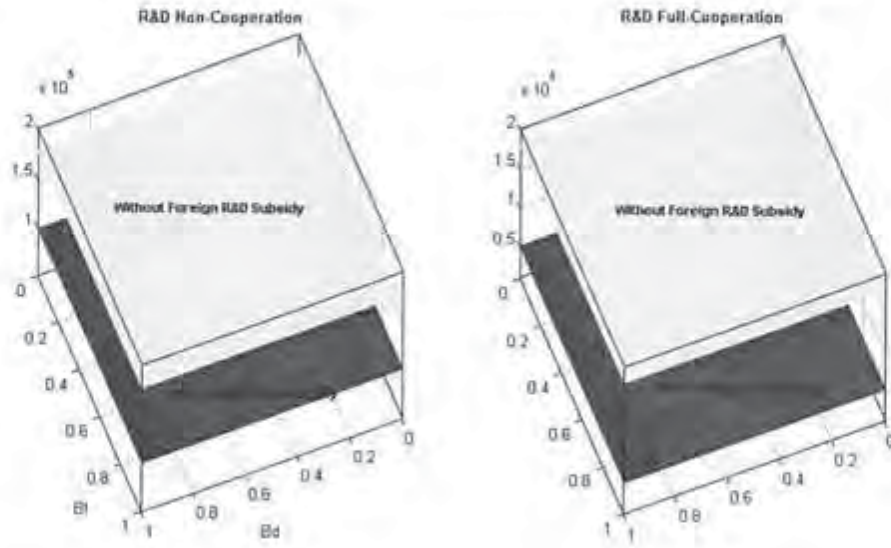


### C. Consumer Surplus

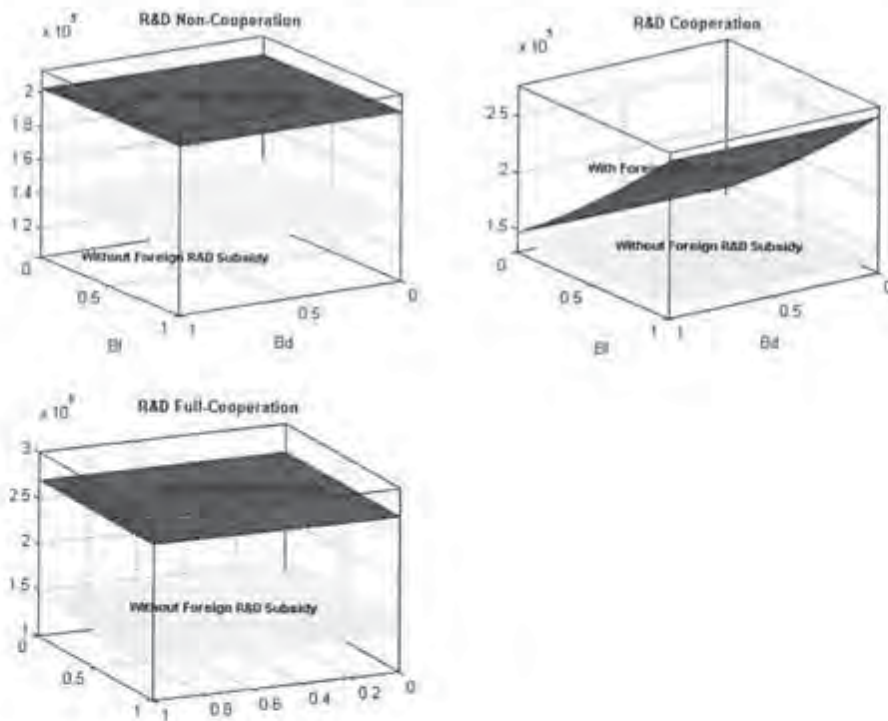
Figure 8 shows that domestic consumer surplus is always higher when there is a foreign R&D subsidy. The reason is that the production of the foreign firm increases due to the foreign R&D subsidy and more output is available in the market, and part of this output is produced at a lower cost, which reduces 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 7: Domestic Profit; Foreign R&D Subsidy vs. No Foreign R&D Subsidy**



**Figure 8: Domestic Consumer Surplus; Foreign R&D Subsidy vs. No Foreign R&D Subsidy**

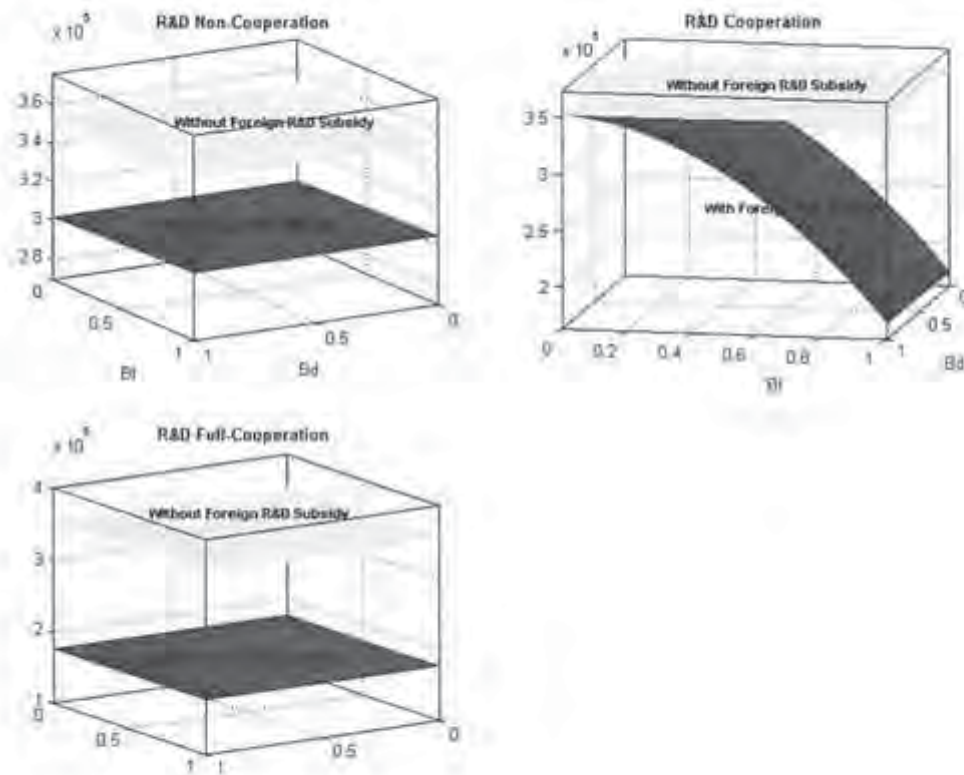




### D. Welfare

Figure 9 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 7 and 8. Figure 9 suggests that the profit loss outweighs the consumer surplus gain in this case.

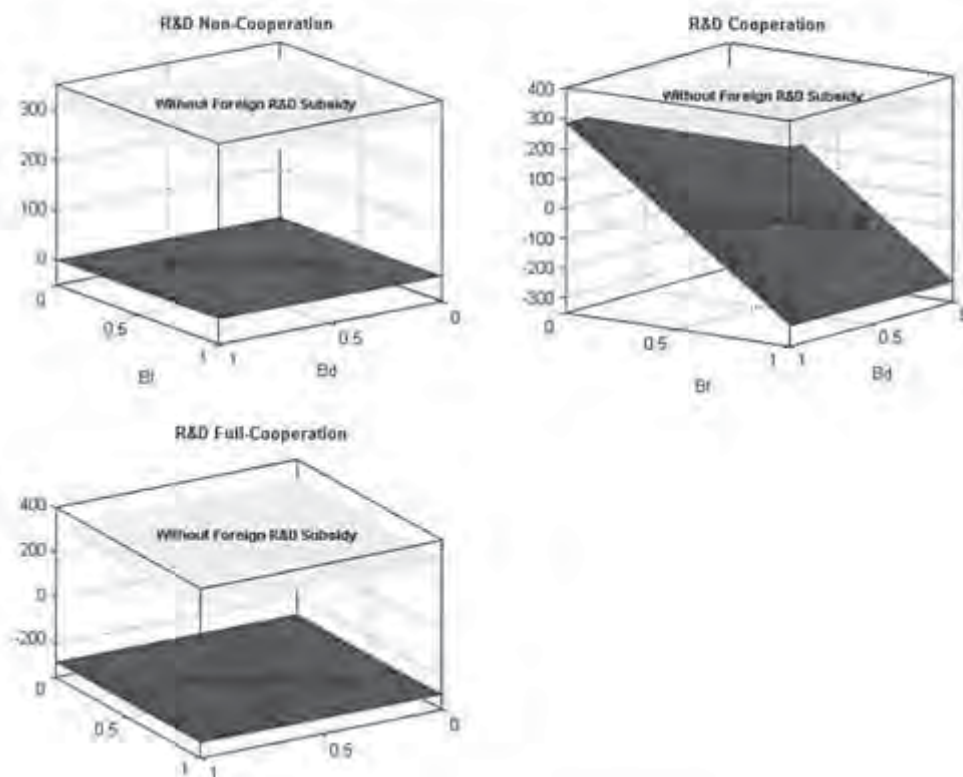
**Figure 9: Domestic Welfare; Foreign R&D Subsidy vs. No Foreign R&D Subsidy**



### E. 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 10 presents the optimal tariff.



**Figure 10: Optimal Tariff; Foreign R&D Subsidy vs. No Foreign R&D Subsidy**

## VI. 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, an 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 III and VI to show these changes. The profit of the domestic firm will be as follows:

$$\pi_d = (p - c_d)y_d - \gamma x_d^2 + s_d x_d, \quad (21)$$

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:

$$W_d = CS + \pi_d + ty_f - s_d x_d. \quad (22)$$

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,  $s_d$ , to the domestic firm. Simultaneously, the government of the foreign country sets the level of R&D subsidy,  $s_f$ , to 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 non-cooperatively as in Section III. 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  $A$ ,  $\alpha_d$ ,  $\alpha_f$ , and  $\gamma$  as before.

Figure 11 presents the optimal R&D subsidy to the domestic firm. The R&D subsidy is very low when there is full information sharing. The reason is that when there is full information sharing, the 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 11: Optimal Domestic R&D Subsidy**

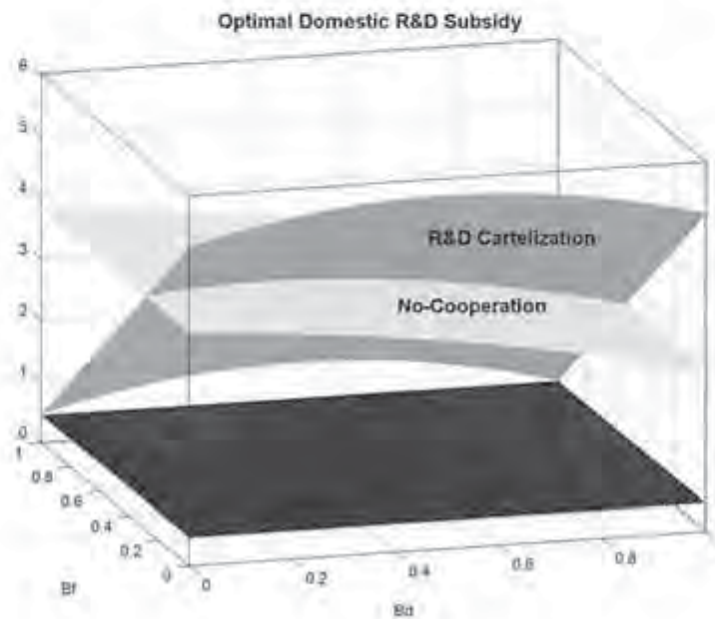


Figure 12 compares domestic R&D under the three scenarios of only domestic tariff (without foreign R&D subsidy), domestic tariff and foreign R&D subsidy (with foreign R&D subsidy), and domestic tariff, domestic R&D subsidy, and foreign R&D subsidy (two R&D subsidies).



Figure 12: Domestic R&D

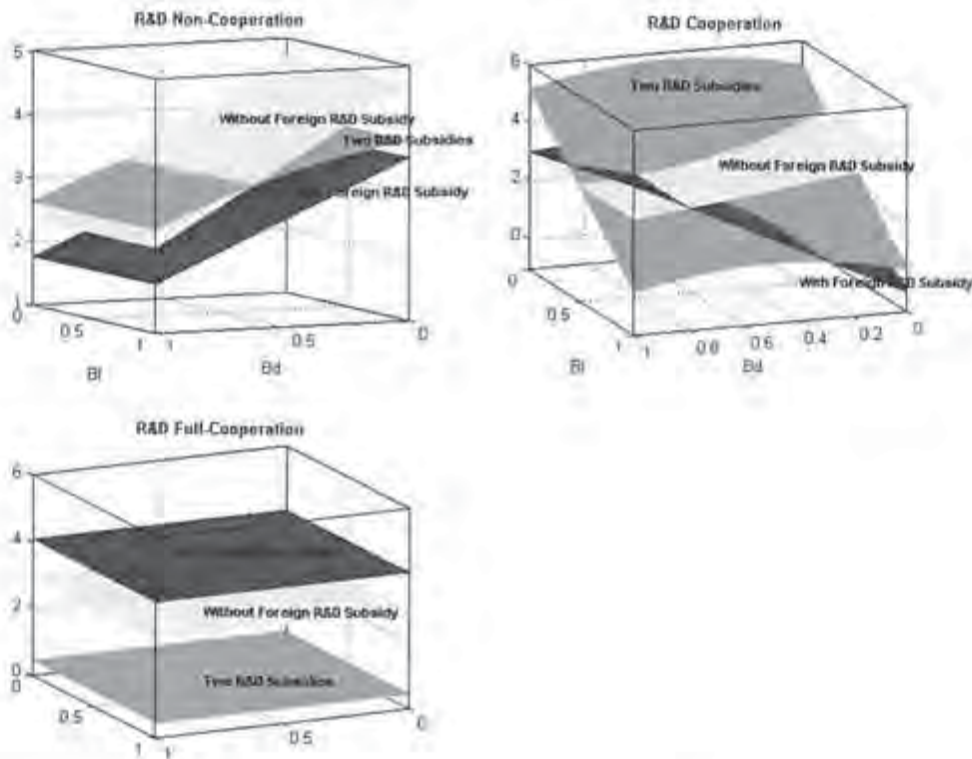


Figure 13 presents domestic profits under the three scenarios. This figure suggests that the domestic firm may achieve a higher profit if the home country uses an R&D subsidy. As expected, domestic profit is lowest when the foreign firm receives an R&D subsidy. Under RJV cartelization, the domestic firm attains the highest profit when the domestic firm receives the subsidy. Under no cooperation, the profit of the domestic firm with two R&D subsidies is highest when  $\beta_d$  is high.

Figure 14 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 13 and 14 suggest that the government of the domestic country may help the domestic firm increase its profit by granting an R&D subsidy, but this subsidy will be at the expense of domestic consumers.

Figure 13: Domestic Profit

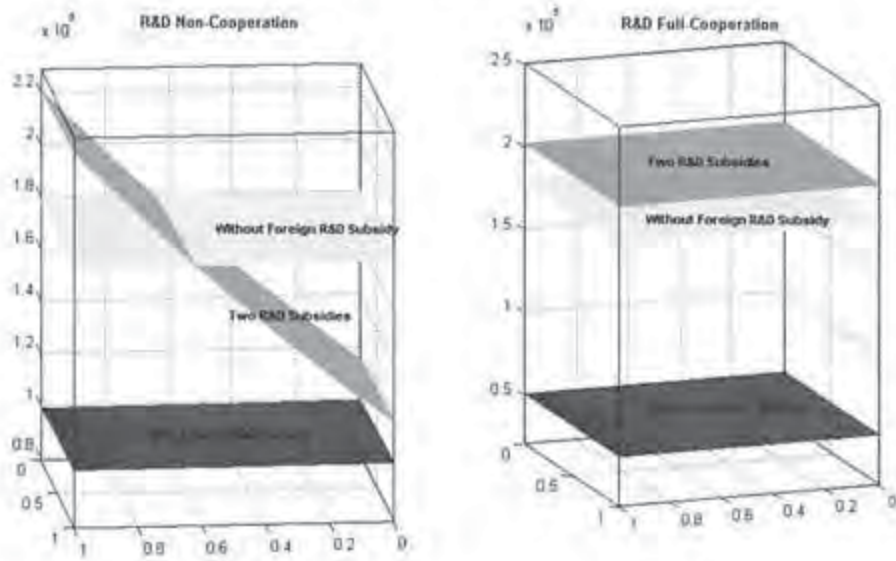


Figure 14: Domestic Consumer Surplus

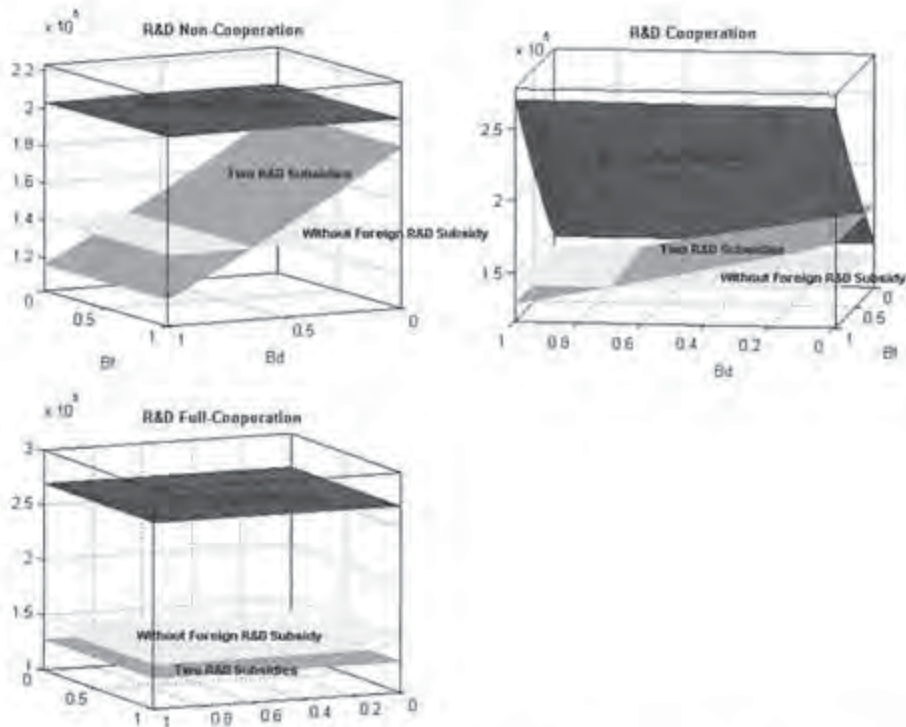


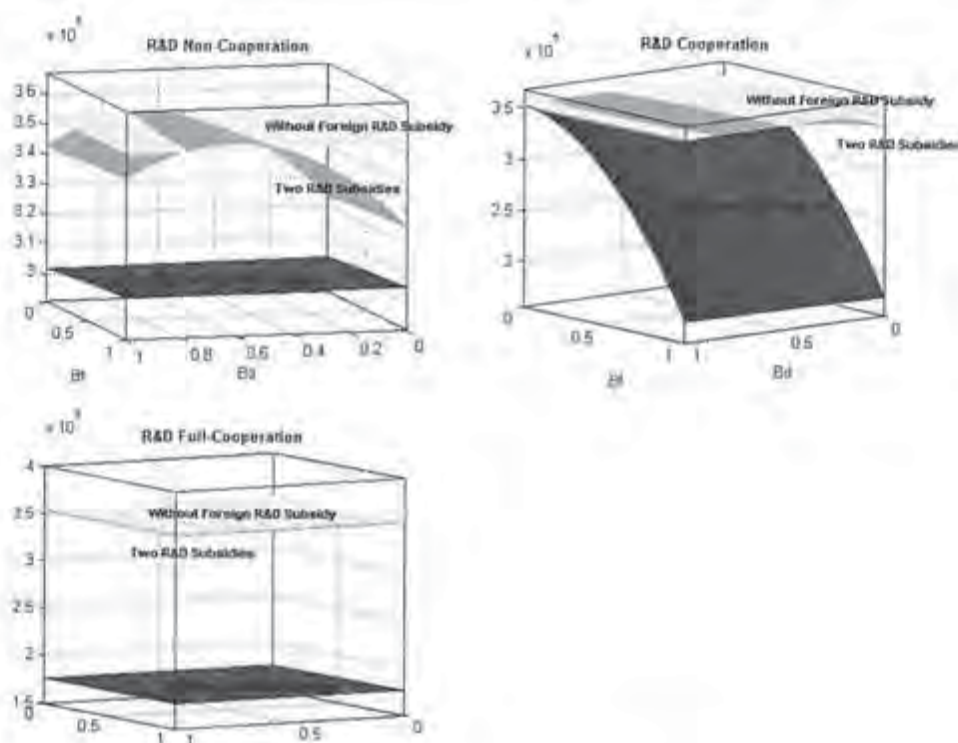
Figure 15 presents domestic welfare under the three scenarios. Welfare is always lowest when there is only a foreign R&D subsidy. This means the gain in consumer surplus due to the



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 15: Domestic Welfare**



By solving analytically the impact of an exogenous tariff on the variables of interest in all models, the authors prove that these results do not depend critically on the parameters of the model (proofs in Appendix 2).

## VII. Special Cases: $\beta_d$ and $\beta_f$ 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 no cooperation under each scenario for the domestic firm and the government regarding the values of the profit, consumer surplus and welfare. The goal of this section is to find out what will be the optimal scenario that the government of the home country 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 governments implement its policies by using the tariff and/or R&D subsidy. The firms react by cooperating or not cooperating in R&D. The four cases are as follows. For each variable of interest, the tables show



whether R&D cartelization or R&D no cooperation is the dominant strategy for each firm under the three scenarios we discussed in the paper. The highest value of variable under different scenarios is presented in **bold**.

**Case 1-** Both spillovers are very high ( $\beta_d = \beta_f = 1$ )- This resembles the case where both countries are technologically advanced (see Table 1).

**Table 1: Both Spillovers are Very High**

Case 1 $\beta_d = 1, \beta_f = 1$	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Domestic profit	R&D cartelization	No cooperation	<b>No cooperation</b>
Foreign profit	No cooperation	<b>R&amp;D cartelization</b>	R&D cartelization
Consumer surplus	R&D cartelization	<b>R&amp;D cartelization</b>	R&D cartelization
Welfare	<b>R&amp;D cartelization</b>	No cooperation	R&D cartelization
Tariff	R&D cartelization	No cooperation	<b>No cooperation</b>

The results suggest that no-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 no-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.

Consumer surplus is the highest when only the foreign firm receives an R&D subsidy and firms cooperate on R&D. 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 would be second best.

In terms of tariffs, 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 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 more technologically advanced than the foreign country.

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 no-cooperation strategy and "Foreign R&D subsidy" scenario (see Table 2).



**Table 2: Domestic Spillovers are Very High; Foreign Spillovers are Very Low**

Case 2 $\beta_d=1, \beta_f=0$	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Domestic profit	No cooperation	R&D cartelization	<u>No cooperation</u>
Foreign profit	R&D cartelization	<u>No cooperation</u>	R&D cartelization
Consumer surplus	R&D cartelization	<u>No cooperation</u>	R&D cartelization
Welfare	<u>R&amp;D cartelization</u>	R&D cartelization	R&D cartelization
Tariff	No cooperation	R&D cartelization	<u>No cooperation</u>

Consumer surplus is highest when there is only a foreign R&D subsidy. 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. The explanation for the tariff is the same as in Case 1.

**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 more technologically advanced than the home country.

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 (see Table 3).

**Table 3: Domestic Spillovers are Very Low; Foreign Spillovers are Very High**

Case 3 $\beta_d=0, \beta_f=1$	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Domestic profit	<u>R&amp;D cartelization</u>	No cooperation	R&D cartelization
Foreign profit	No cooperation	<u>R&amp;D cartelization</u>	No cooperation
Consumer surplus	R&D cartelization	<u>R&amp;D cartelization</u>	No cooperation
Welfare	<u>R&amp;D cartelization</u>	No cooperation	R&D cartelization
Tariff	<u>R&amp;D cartelization</u>	No cooperation	R&D cartelization

Consumer surplus is maximized when there is only a foreign R&D subsidy and R&D cartelization. Welfare is maximized when there is only tariff protection and firms choose R&D cartelization. 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.

**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.

In Case 4, domestic maximal profit occurs when there is only tariff protection and the firms cooperate in R&D. As usual, the foreign firm has maximum profits when there is only a foreign



R&D subsidy. Consumer surplus is maximized when there is only a foreign R&D subsidy, while welfare is maximized when there is only tariff protection and there is R&D competition (see Table 4).

**Table 4: Both Spillovers are Very Low**

Case 4 $\beta_d=0, \beta_f=0$	No R&D subsidy (tariff protection only)	Foreign R&D subsidy	Foreign and domestic R&D subsidies
Domestic profit	<u>R&amp;D cartelization</u>	R&D cartelization	R&D cartelization
Foreign profit	No cooperation	<u>No cooperation</u>	No cooperation
Consumer surplus	No cooperation	<u>No cooperation</u>	No cooperation
Welfare	<u>No cooperation</u>	R&D cartelization	R&D cartelization
Tariff	<u>No cooperation</u>	R&D cartelization	R&D cartelization

By comparing the four cases, we realize that welfare is always maximized when there is no R&D subsidy. Although 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 governments 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 no-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 best scenarios in each case for the government to follow, and the reaction strategies of each firm are summarized in Table 5.



**Table 5: First-best Scenarios**

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 <i>cartelization</i>	No R&D subsidy – R&D <i>cartelization</i>	No R&D subsidy – R&D <i>cartelization</i>	No R&D subsidy – <i>no cooperation</i>
Domestic firm's reaction under this scenario	<i>R&amp;D cartelization</i>	<i>no cooperation</i>	<i>R&amp;D cartelization</i>	<i>R&amp;D cartelization</i>
Foreign firm's reaction under this scenario	<i>no cooperation</i>	<i>no cooperation and/or R&amp;D cartelization</i>	<i>no cooperation</i>	<i>no cooperation</i>

The government should target the “No R&D subsidy” scenario with R&D cartelization in three cases and with no cooperation in one case because the highest welfare will be attained under these scenarios. However, given the “No R&D subsidy” scenario, Table 5 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 would 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 are presented for each case in Table 6. Table 6 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 no cooperation will take place. When the foreign spillover is high, the government targets the “foreign and domestic R&D subsidies” scenario; however, it should also 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 encourage the foreign firm to choose the “R&D cartelization” strategy.



**Table 6: Second-best Scenarios**

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 – no cooperation	Foreign and domestic R&D subsidies – R&D cartelization	Foreign R&D subsidies – R&D cartelization
Domestic firm's reaction under this scenario	no cooperation	no cooperation	R&D cartelization	R&D cartelization
Foreign firm's reaction under this scenario	R&D cartelization	no cooperation	no cooperation	no cooperation

The authors further derived the analytical solutions of the models of this section under the “No R&D subsidy” scenario when  $\beta_d$  and  $\beta_f$  are equal to 1 or 0 to see how sensitive the results are to the parameters of the model. The analytical solutions suggest that the results are independent of the values of  $A$  and  $\alpha$ . Only the value of  $\gamma$  may affect the results. Regarding the second-order-conditions and other equations, all results sustain if  $\gamma > 2$  (proofs in Appendix 1).

### VIII. Conclusion and Discussion

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 the 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 no cooperation. However, if both domestic and foreign spillovers are low, no 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 no cooperation. Domestic R&D is higher under R&D cartelization than under RJV cartelization and no cooperation when the domestic spillover is high, and it is higher under no 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 no 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 no 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 developing country, and two developing 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 no 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 no cooperation strategy. This is the best strategy in terms of domestic profit, foreign profit, and welfare.

Analytical results 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. This paper 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 the assumption that R&D spillovers are symmetric, we might get quite different results from DeCourcy (2005).

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#### Appendix 1—Solutions at $\beta_d$ and $\beta_f$ Equal to 1 or 0

In this appendix, we confirm analytically the results of section VII. First, we see which values of  $\gamma$  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 no-cooperation strategies.

The second order conditions are as follows. We will assume  $\gamma > 0.8158$  based on the following second-order-conditions (SOC). The equations are independent of  $A$  and  $\alpha$ . In the following equations,  $W$  stands for welfare,  $t$  for tariff,  $\pi$  for profit,  $CS$  for consumer surplus,  $NOC$  for R&D no-cooperation, and  $RDC$  for R&D cartelization.

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

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

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



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

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

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

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

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

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  $\gamma$  and are independent of  $A$  and  $\alpha$ . 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  $\gamma = 60$ .

i) Domestic profits:

$$\left[ \pi_d^{RDC} - \pi_d^{NOC} \right]_{(\beta_d=1, \beta_f=1)} = \frac{\gamma(A - \alpha)^2 (199290375\gamma^8 - 373878585\gamma^7 + 271311201\gamma^6 - 98918172\gamma^5 + 19176480\gamma^4 - 1861272\gamma^3 + 65724\gamma^2 + 1120\gamma - 64)}{(729\gamma^3 - 252\gamma^2 + 6\gamma + 2)^2(81\gamma^2 - 58\gamma + 8)^2} > 0$$

$$\left[ \pi_d^{NOC} - \pi_d^{RDC} \right]_{(\beta_d=1, \beta_f=0)} = \frac{\gamma^2(A - \alpha)^2 (531441\gamma^9 + 1751787\gamma^8 - 6725106\gamma^7 + 8028711\gamma^6 - 4912749\gamma^5 + 1753464\gamma^4 - 380803\gamma^3 + 49751\gamma^2 - 3608\gamma + 112)}{(243\gamma^3 - 210\gamma^2 + 51\gamma - 4)^2(81\gamma^3 - 88\gamma^2 + 24\gamma - 2)^2} > 0$$

$$\left[ \pi_d^{RDC} - \pi_d^{NOC} \right]_{(\beta_d=0, \beta_f=1)} = \frac{\gamma(A - \alpha)^2 (37732311\gamma^8 - 84695949\gamma^7 + 81174717\gamma^6 - 44294247\gamma^5 + 15217248\gamma^4 - 3376604\gamma^3 + 471084\gamma^2 - 37440\gamma + 1280)}{(81\gamma^3 - 88\gamma^2 + 29\gamma - 4)^2(81\gamma - 16)^2(3\gamma - 1)^2} > 0$$

$$\left[ \pi_d^{RDC} - \pi_d^{NOC} \right]_{(\beta_d=0, \beta_f=0)} = \frac{\gamma^2(A - \alpha)^2 (15057495\gamma^8 - 50672790\gamma^7 + 72480663\gamma^6 - 57553488\gamma^5 + 27787752\gamma^4 - 8367168\gamma^3 + 1536688\gamma^2 - 157568\gamma + 6912)}{(243\gamma^3 - 336\gamma^2 + 132\gamma - 16)^2(81\gamma^2 - 37\gamma + 4)^2(\gamma - 1)} > 0$$

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

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

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

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

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

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

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

iii) Welfare:

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

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

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

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

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

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

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

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

## 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  $\beta_d$  and  $\beta_f$ , and the parameters of the model  $A$ ,  $\alpha$ , and  $\gamma$ . 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  $\alpha$ . Moreover, all results hold for  $\gamma > 2$ . Though we show the analytical results only for case 1, case 2 and 3 solutions can be similarly obtained<sup>2</sup>.

### Case 1- Basic Model

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

#### i) No-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 profit; For all  $\gamma$ :

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

i-3) 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-4) Welfare; For all  $\gamma > 2$ :

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

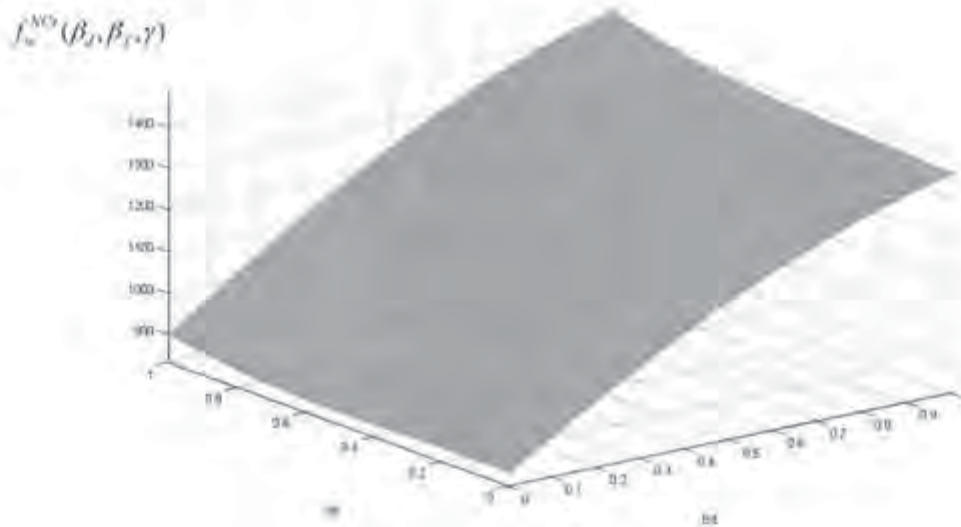
where  $f_w^{NOC}(\beta_d, \beta_f, \gamma)$  is a function of  $\beta_d$ ,  $\beta_f$ , and  $\gamma$ , where NC indicate no-cooperation.

For the equations that are too complicated to be signed analytically, we assign different values to  $\gamma$  and will draw the equation for different  $\beta_d$  and  $\beta_f$  to see if the value of the function

<sup>2</sup> We do not show the solutions for cases 2 and 3 due to space constraints. However, the solutions will be available to interested readers upon request.

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  $f_w^{NCJ}(\beta_d, \beta_f, \gamma)$ . To find the sign of this equation, we draw its graph with respect to  $\beta_d$  and  $\beta_f$  for  $\gamma = 2$ . We start from  $\gamma = 2$  because we need  $\gamma > 2$  for the first and second order conditions of section 7 to hold (appendix 1). As figure 16 suggests, this equation is positive for all values of  $\beta_d$  and  $\beta_f$ . Also, since this equation is of order of  $\gamma^3$  (positive), the sign of the equation will always be positive for large values of  $\gamma$ . This means  $\left[\frac{\partial W}{\partial t}\right]_{t=0}^{NOC} > 0$  for  $\gamma > 2$ .

Figure 16 - The Graph of  $f_w^{NCJ}(\beta_d, \beta_f, \gamma)$  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  $\gamma > 2$ :

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

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

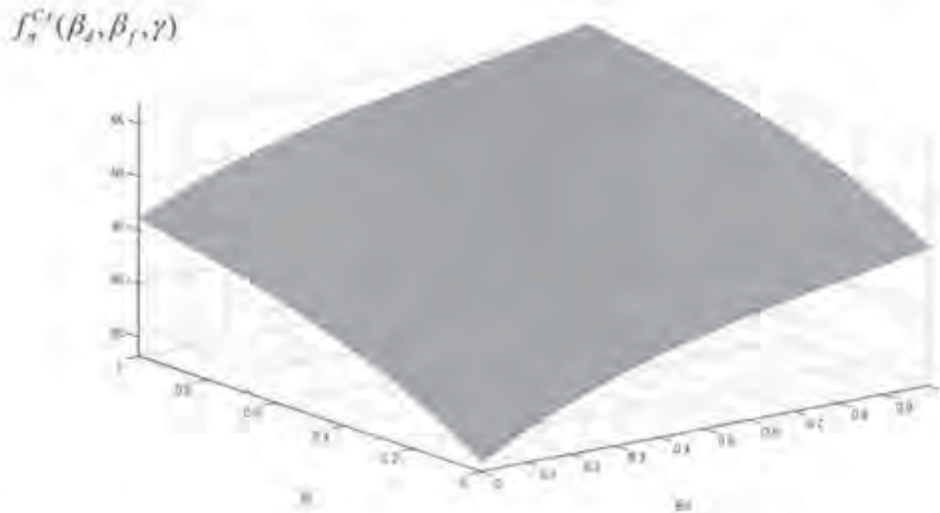


$$\left[ \frac{\partial \pi_d}{\partial t} \right]_{t=0}^C = \frac{2\gamma(A-\alpha)f_{\alpha}^{C2}(\beta_d, \beta_f, \gamma)}{(1+9\gamma^2+8\gamma\beta_d+8\gamma\beta_f+\beta_f^2\beta_d^2-10\gamma-5\gamma\beta_f^2-5\gamma\beta_d^2-2\beta_f\beta_d)^2} > 0,$$

where  $f_{\alpha}^{C2}(\beta_d, \beta_f, \gamma)$  is of order  $\gamma^3$ . The graph of  $f_{\alpha}^{C2}(\beta_d, \beta_f, \gamma)$  at  $\gamma=2$  is presented in figure

17. Therefore,  $\left[ \frac{\partial \pi_d}{\partial t} \right]_{t=0}^C > 0$  for all  $\gamma > 2$ .

Figure 17 - The Graph of  $f_{\alpha}^{C2}(\beta_d, \beta_f, \gamma)$  with  $\gamma = 2$



ii-3) 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-4) Welfare; For all  $\gamma > 2$ :

$$\left[ \frac{\partial W}{\partial t} \right]_{t=0}^C = \frac{\gamma(A-\alpha)f_{\alpha}^{C2}(\beta_d, \beta_f, \gamma)}{(1+9\gamma^2+8\gamma\beta_d+8\gamma\beta_f+\beta_f^2\beta_d^2-10\gamma-5\gamma\beta_f^2-5\gamma\beta_d^2-2\beta_f\beta_d)^2} > 0$$

$f_{\alpha}^{C2}(\beta_d, \beta_f, \gamma)$  is of order of  $\gamma^3$ , Its graph with  $\gamma=2$  is presented in figure 18. Graphs of this

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

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 suggests 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 no-cooperation, R&D cartelization, and RJV cartelization.

Figure 18 - The Graph of  $f_w^{C2}(\beta_d, \beta_f, \gamma)$  With  $\gamma = 2$

