The Impact of “At-the-Border” and “Behind-the-Border” Trade Policies on Research & Development: What Does a Duopolistic Model of Trade with Uncertainty Tell Us?

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Abstract. This paper analyzes the impact of various trade policies on domestic Research & Development (R&D) expenditures using an international duopolistic model with uncertainty regarding the result of the R&D process. We examine the impact of “at-the border” policies (import tariffs, import quotas, Voluntary Export Restraints (VERs), and minimum price of imports) as well as “behind-the border” policies (output subsidies and R&D subsidies). We demonstrate new theoretical conclusions, in particular the increasing then decreasing impact of a quota on R&D, or the impact of production subsidy and of minimum price agreements. We conclude that R&D subsidies are beneficial because they support not only local R&D expenditures but also local production and profits without reducing consumers’ surplus. These results hold under both types of competition (Cournot and Bertrand). This conclusion has important policy implications because the World Trade Organization does not forbid R&D subsidies, thus making them a viable policy option.

JEL classification: F13, O30.

Keywords: Research & Development; Trade policy; Tariff on imports; Quota; VER; Minimum Price; Output subsidy; R&D subsidy.

Abstract. Cet article étudie l’impact de la mise en place d’une politique commerciale sur l’investissement en Recherche & Développement (R&D) local dans une structure en duopole international avec incertitude sur le succès de la R&D. Nous étudions l’impact d’instruments «à la frontière » (tarif sur les importations, quota sur les importations, Restriction Volontaire des Exportations, prix-plancher des importations) et d’instruments «derrière la frontière » (subvention de la production, subvention de la R&D). Nous mettons en évidence de nouveaux effets théoriques, notamment l’impact croissant puis décroissant d’un quota sur la R&D, selon son degré de restrictivité, ou encore l’impact d’une subvention de la production ou d’un accord de prix-plancher des importations. Nous concluons sur l’intérêt d’une subvention de la R&D de la firme domestique : cet instrument soutient la production et les profits locaux sans pénaliser les consommateurs ; ces

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conclusions sont robustes à un changement de mode de concurrence (Cournot ou Bertrand) ; enfin l'Organisation Mondiale du Commerce n'interdit pas ce type de politique.

Classification JEL : F13, O30.

Mots-clefs : Recherche & Développement ; Politique commerciale ; Tarif des importations ; Quota ; RVE ; Prix-plancher ; Subvention de la production ; Subvention de la R&D.

1. Introduction

For many high-income countries, the issue of economic competitiveness in the face of growing globalization has been at the center of public debate for more than a decade. Competitiveness is an essential element of a country's market shares and exports, as well as its production and employment levels. But determining the right policies to improve the competitiveness of an economy or a sector is complex, especially in the context of globalization. In particular, there is much debate over how to ensure that the private industrial sector can compete with imports coming from countries with low production costs.

Competitiveness measures the ability of a firm, a sector, or a country to sell goods and/or services in a given market in relation to other firms, sectors, or countries. A distinction is often made between price and non-price competitiveness; the former concept refers to compared levels of costs, prices, and exchange rates, while the latter focuses on other features such as a product's quality, reliability, and technological content. The technological dimension is a key issue because Research & Development (R&D) expenditures can lead to either reduced production costs or increased product quality. In that sense, R&D may be one way in which high-income countries' private industrial sectors may react to increased competition from countries with lower production costs.

Consequently, it becomes crucial to determine whether a high-income country's government is in a position to support its domestic firms' R&D expenditures, in particular through trade policy. The objective of this article is to evaluate the impact of various trade policy instruments on domestic firms' R&D. We also evaluate the impact of these instruments on other variables like domestic production and profits, consumers' surplus, and public revenues. We use a broad definition of trade policy, including "at-the-border" policies and "behind-the-border" policies (see below).

The impact of trade policy on R&D has been studied in the economic literature. The reference model is an article by Spencer and Brander (1983) in which they analyze the impact of an R&D subsidy in an international Cournot duopoly: they descrive a long-term strategic interaction between firms which compete in the short term in an international market-share rivalry. R&D investment decreases the marginal cost of each profit-maximizing firm. Spencer and Brander show that an R&D subsidy increases both local R&D expenditures and the government's objective function, consisting of the domestic firms' profit net of the cost of the subsidy, while decreasing foreign R&D expenditures and profits.

In a Cournot duopolistic model with segmented markets and scale economies, Krugman (1984) analyzes the impact of various trade policies on domestic profits. He shows that a protectionist barrier increases local R&D investment while reducing foreign R&D. Again, in this theoretical structure, any increase in local R&D has a direct and certain (negative) impact on a firm's marginal cost.

Reitzes (1991) designs a model similar to that of Spencer and Brander (1983), but studies the impact of two trade policy instruments: an import tariff and a quota. He shows that the former instrument increases local investment in R&D, while the latter decreases it. Leahy and Neary (1996) also study a Cournot international duopoly model with R&D investment in the first period and output decision in the second. In their model, a government may tax or subsidize R&D or output, the focus being on the timing of the moves and the ability of agents to engage in intertemporal committment. Again, in this model, the higher the investment in R&D, the lower the marginal cost of production. Leahy and Neary (1997) also design an oligopolistic model with n firms and R&D spillovers. In this model, investment in R&D lowers marginal costs, but thanks to the spillover, local R&D also decreases competitors' marginal costs. It is shown that firms' strategic behavior tends to reduce output, R&D investment, and welfare, thus justifying higher subsidies for R&D investment. Qiu and Tao (1998) analyze the relationship between trade policy and R&D under international cooperation. Firms may engage in either "coordination," in order to reduce the traditionally identified R&D overinvestment in strategic duopolistic games (mentioned by Spencer and Brander (1983) and tackled in more detail by Leahy and Neary (1997)), or "collaboration," by sharing the extra profits coming from R&D investment. Each government implements an R&D subsidy, which increases local R&D but does not systematically decrease foreign R&D. The impact of the subsidy on foreign R&D is negative under international "coordination," while its effects are undetermined under international "collaboration."

Along the line of Reitzes (1991), Bouët (2001) studies the impact of an import tariff and a Voluntary Export Restraint (VER) on R&D, using an international Cournot duopoly model where the effect of R&D on marginal cost is uncertain. A Northern firm faces competition in its home market from a Southern firm with low marginal cost. The former may invest in R&D, which can *potentially* reduce its marginal cost but can also fail, in which case the marginal cost remains unchanged. R&D expenditures increase the probability that the marginal cost will be low, without guarantee of success. Like Reitzes (1991), he concludes that an import tariff may increase local investment in R&D, while a VER may decrease local R&D investment. In this model, the Southern firm is ready to restrain its exports since that will lead the Northern firm to limit its R&D expenditures; thus, the probability of successful R&D efforts in the Northern country is reduced. Finally, Haaland & Kind (2008) include the issue of intra-industry trade in the relationship between trade policy and R&D. With intra-industry trade, an R&D subsidy augments the domestic firm's R&D investment and decreases the foreign firm's one.

The objective of this article is to study the potential impact of various trade policy instruments on local R&D investments: import tariffs, production subsidies, R&D subsidies, import quotas, VERs, and minimum prices. Clearly, our definition of the concept of trade policy is broad. While trade policy is traditionally understood as a set of policy instruments implemented "at the border," such as import tariffs, quotas, or VERs, we study the impact of other barriers implemented "behind the border," such as production subsidies, R&D subsidies, or minimum prices. These "behind-the-border" policies are typically implemented with the objective of benefiting domestic firms over foreign firms. R&D subsidies in particular are becoming more and more common; in 2013, the French government created a "*banque publique d'investissement*" in charge of funding innovating firms. Also in 2013, "Romi," a Brazilian firm, received a governmental loan of Reals 27 Mios with a below-market interest rate in order to invest in innovation and new "process design" (The Economist, Thursday, October 10th, 2013). This is what Evenett (2013) describes as the "protectionism's quiet return".

We also study the impact of a minimum price agreement on R&D, as well as on domestic profits, production, and consumers' surplus. This type of agreement has recently been implemented in the European Union: in 2013 the European Commission set a minimum price on imports of photovoltaic panels from China. Just prior to this agreement, the European Commission threatened Chinese exporters with a 47.6% antidumping duty.

According to Evenett (2013), these types of "behind-the-border" policies are becoming more frequently used, and this is particularly true of R&D subsidies. Such subsidies largely escape the notice of the World Trade Organization (WTO), which is more effective in prohibiting quotas and VERs and puts severe constraints on the use of import tariffs.

We conclude that R&D subsidies are an appealing policy instrument because their impact on R&D investments is systematically positive. They also have a positive impact on domestic activity, local profits, and domestic consumption. These results are robust to a change in the mode of competition (Cournot or Bertrand), which is all the more important because the literature on strategic trade policy has been criticized on the ground of a lack of robustness. Moreover, R&D subsidies may be more easily implemented than other policies. The use of instruments like quotas and production subsidies is forbidden by the WTO and the use of tariffs is not totally free, but instruments like R&D subsidies or minimum price are not prohibited by the WTO as long as they do not have a negative impact on international trade. While we show that these policies can in fact have a negative impact on international trade, they are "behind-the-border" policies that are much less visible; WTO members are not obligated to notify the institution of the implementation of such policies, unlike changes in tariffs or the implementation of quotas or export taxes/subsidies ("at-the-border policies"), which do have to be brought to the attention of the WTO.

The model that we use is based on Bouët (2001); the framework is simple, introducing uncertainty in the impact of R&D in a very simple way. This uncertainty makes the model more realistic, which is an advantage over Spencer and Brander (1983) or Reitzes (1991). Moreover, this theoretical structure may be extended to a Bertrand competition. We analyze the impact of five trade policy instruments (three "at-the-border" – a tariff, a quota, and a VER – and two "behind-the-border" – a production subsidy and a R&D subsidy) under Cournot competition and the impact of four instruments (two "at-the-border" – a tariff and a minimum price – and two "behind-the-border" – a production subsidy and an R&D subsidy) under Bertrand competition. Some of these effects have never been studied before in this theoretical framework, specifically the quota, the minimum price, and the production and R&D subsidies.

Section 2 presents the model under Cournot competition and section 3 analyzes the impact of the five trade policy instruments under this competition. After explaining how the model is modified under a Bertrand competition, section 4 analyzes the impact of the four trade policy instruments under this alternate competition. Section 5 synthetizes and discusses the results. Section 6 concludes.

2. The Model under Cournot Competition

Consider a partial equilibrium model of a home market Cournot duopoly in which a domestic firm and a foreign firm sell a homogeneous good in the home market. The foreign firm's marginal cost of production is low, while the domestic firm's marginal cost of production is low conditional to the success of an investment in Research & Development (R&D).

In the body of this article, we use a general form of this model. In the annex, we use linear forms for demand function and an isoelastic function for the R&D success in order to illustrate our different conclusions.

Assumption 1a. Denoting x (respectively, y) the domestic (respectively, foreign) firm's output and p the market price, we have: $p = p(x + y) = p(X)$. We suppose: $p' = \mathrm{d}p/\mathrm{d}X < 0$.

We denote c (c^*) the domestic (foreign) firm's marginal cost of output and F (F^*) the domestic (foreign) firm's fixed cost of output. We have: $c^* = c_l$. The domestic firm invests in R&D. If this R&D investment succeeds, its marginal cost is: $c = c_l$. If it does not succeed, its marginal cost is: $c = c_h$, with $c_l < c_h$. The domestic firm invests in a level r of R&D, with a constant average cost of R&D denoted by v.

$$Prob\{c = c_l/r\} = \alpha(r)$$

$$Prob\{c = c_h/r\} = 1 - \alpha(r) \quad (1)$$

The larger the R&D investment, the higher the likelihood that $c = c_l$. However, returns of the R&D investment are decreasing.

Assumption 2: $\alpha'(r) = \mathrm{d}\alpha(r)/\mathrm{d}r > 0$, $\alpha''(r) = \mathrm{d}^2\alpha(r)/\mathrm{d}r^2 \leq 0$.

The expressions of profit are:

$$\Pi(x, y) = xp(x + y) - cx - F - vr \quad (2)$$

$$\Pi^*(x, y) = yp(x + y) - c_l y - F^* \quad (3)$$

In the short run, firms select the level of output that maximizes their profit. The first order conditions lead to the following reaction functions:

$$x = (c - p)/p' \quad (4)$$

$$y = (c^* - p)/p' \quad (5)$$

Assumption 3a: The second order conditions are verified: $\Pi_{xx} = xp'' + 2p' < 0$, $\Pi^*_{yy} = yp'' + 2p' < 0$. Output's cross effects on marginal profits are negative: $\Pi_{xy} = xp'' + p' < 0$, $\Pi^*_{yx} = yp'' + p' < 0$. Own effects are greater than cross effects: $|\Pi_{xx}| > |\Pi_{xy}|$, $|\Pi^*_{yy}| > |\Pi^*_{yx}|$.[3]

Assumption 3a implies that reaction functions are decreasing in the $(x; y)$ space and that the Nash equilibrium's stability condition is verified: in the $(x; y)$ space, the slope of the domestic firm's reaction function is greater in absolute value than that of the foreign firm.

$$\Delta = \Pi_{xx}\Pi^*_{yy} - \Pi_{xy}\Pi^*_{yx} > 0 \quad (6)$$

We denote π_i the domestic firm's profit, fixed and R&D costs excluded, and x_i, the optimal domestic firm's supply when $c = c_i, \forall i = l, h$.

$$\pi_i = x_i p(x_i + y_i) - c_i x_i \text{ and } x_i = (c_i - p)/p', \forall i = l, h \quad (7)$$

Let us demonstrate first that: $x_l > x_h$ and $\pi_l > \pi_h$. Differentiating the first order conditions $\pi_x = 0$ and $\pi^*_y = 0$, we find:

$$\frac{\mathrm{d}x}{\mathrm{d}c} = \frac{\Pi^*_{yy}}{\Delta} < 0 \quad (8)$$

$$\frac{\mathrm{d}y}{\mathrm{d}c} = -\frac{\Pi^*_{yx}}{\Delta} > 0 \quad (9)$$

[3] We call $F_a = \frac{\partial F}{\partial a}$ and $F_{ab} = \frac{\partial^2 Y}{\partial a \partial b}$.

$$\frac{\mathrm{d}X}{\mathrm{d}c} = \frac{\Pi^*_{yy} - \Pi^*_{yx}}{\Delta} < 0 \quad (10)$$

Equation (10) implies that $x_l > x_h$. When the domestic firm's marginal cost is low (i.e. when the domestic R&D is successful), x is higher, y is lower, and the total supply is larger. This implies that under this scenario, in the home market, consumers' surplus is larger since consumers' surplus decreases with p and increases with X. Concerning profits, we denote $V(c_i)$, the domestic firm's maximum profit when $c = c_i, \forall i = l, h$. To obtain $V(c_i)$, we solve

$$Max_{x \geq 0}\, \pi(x, y, c_i) \;\; s.t. \;\pi^*_y(x, y, c_i) = 0 \quad (11)$$

Let $x(c_i)$ be the solution of (8) and $y(c_i)$, such that: $\pi^*_y(x(c_i)\,, y(c_i), c_i) = 0$. The maximum domestic profit is: $V(c_i) = \pi[x(c_i), y(c_i), c_i]$. We call λ a Lagrange multiplier. The Envelope Theorem implies:

$$\frac{\partial V(c_i)}{\partial c_i} = \frac{\partial \pi[x(c_i), y(c_i), c_i]}{\partial c_i} - \lambda \frac{\partial \pi^*_y}{\partial c_i} = \frac{\partial \pi[x(c_i), y(c_i), c_i]}{\partial c_i} = -x(c_i) < 0 \quad (12)$$

since $\frac{\partial \pi^*_y}{\partial c_i} = 0$. Therefore, the domestic firm's maximum profit is lower when its marginal cost is high.

Let us call E[.] the expectation operator with respect to $c = c_i, \forall i = l, h$. In the long run, the domestic firm selects the R&D investment that maximizes its expected profit:

$$Max_{r>0}\, E[\Pi(r)] = \alpha(r)\pi_l + [1 - \alpha(r)]\pi_h - F - vr \quad (13)$$

The first order condition of (13) leads to:

$$\alpha'(r) = \frac{v}{\pi_l - \pi_h} \quad (14)$$

Equation (14) means that the domestic firm equalizes the marginal gain of R&D ($\alpha'(r).(\pi_l - \pi_h)$) to the marginal cost of R&D (v). The second order condition is verified thanks to Assumption 2.

$$\frac{\mathrm{d}^2 E[\Pi(r)]}{\mathrm{d}r^2} = \alpha''(r)(\pi_l - \pi_h) < 0 \quad (15)$$

A simple interpretation of (14) stems from rewriting this equation as: $r = \Phi(v; \pi_l - \pi_h)$ with $\Phi_1 = \frac{\partial \Phi}{\partial v} < 0$ and $\Phi_2 = \frac{\partial \Phi}{\partial(\pi_l - \pi_h)} > 0$. These signs come directly from downwards concavity of $\alpha(r)$. So the domestic firm's R&D only depends on the unit cost of R&D v and the marginal benefit of R&D $\pi_l - \pi_h$, that is to say, the difference in profits under $c = c_l$ and under $c = c_h$. Moreover, as was expected, this optimal level of R&D decreases with the unit cost of the R&D and increases with the marginal benefit from R&D.

This simple theoretical structure allows us to study the impact of various trade policies ("at-the-border" or "behind-the-border") implemented by the domestic government. In section 3, we study the impact of five trade policies: three policies implemented "at-the-border" (an import duty, a quota on imports, and a Voluntary Export Restraint, or VER) and two "behind-the-border" policies (a production subsidy and an R&D subsidy). We evaluate the effects of these policies on each firm's output, on total supply, on profits, on market price, on consumers' surplus, and on public revenues with a focus on R&D.

3. The Impact of Five Policy Options in Cournot Competition

In this section, we consider five policy instruments. In these scenarios, the foreign government does not retaliate; indeed, the domestic firm does not export to the foreign country and consequently cannot be hurt by an import tariff or a quota on imports in the foreign country. Moreover, there is no R&D in the foreign country, such that we cannot consider a foreign R&D subsidy. The only way for the foreign government to retaliate would be to subsidize its firm's output. However, we exclude this case: we can consider that the foreign government's revenues are too low to implement a subsidy. This assumption fits in well with the basic idea of the model, which focuses on international trade between a poor country (from the South) with a production cost advantage and a rich country where R&D is the only way to react to low marginal production costs.

3.1. A Tariff on Imports under Cournot

Consider that the domestic country's government implements a specific tariff on imports, denoted t. The foreign firm's profit is modified into:

$$\Pi^*(x, y, t) = yp(x + y) - c^*y - ty - F^* \quad (16)$$

The domestic firm's profit expression is still (2). In the short run, only the foreign firm's first order condition is modified into:

$$y = (c^* + t - p)/p' \quad (17)$$

Let us differentiate the first order conditions to determine the impact of the tariff on outputs:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = -\frac{\Pi_{xy}}{\Delta} > 0 \quad (18)$$

$$\frac{\mathrm{d}y}{\mathrm{d}t} = \frac{\Pi_{xx}}{\Delta} < 0 \quad (19)$$

$$\frac{\mathrm{d}X}{\mathrm{d}t} = \frac{\Pi_{xx} - \Pi_{xy}}{\Delta} < 0 \quad (20)$$

The tariff increases (respectively, reduces) the domestic (respectively, foreign) firm's output. The effect on the total output is negative. This leads to:

$$\frac{\mathrm{d}p}{\mathrm{d}t} = p' \frac{\mathrm{d}X}{\mathrm{d}t} > 0 \quad (21)$$

The tariff increases the market price and reduces the global supply; it also reduces consumers' surplus. Finally, we find the effect of an import tariff on each firm's profit:

$$\frac{\mathrm{d}\Pi}{\mathrm{d}t} = \Pi_x . \frac{\mathrm{d}x}{\mathrm{d}t} + \Pi_y . \frac{\mathrm{d}y}{\mathrm{d}t} + \Pi_t = \Pi_y \frac{\mathrm{d}y}{\mathrm{d}t} = xp' \frac{\mathrm{d}y}{\mathrm{d}t} > 0 \quad (22)$$

$$\frac{\mathrm{d}\Pi^*}{\mathrm{d}t} = \Pi_x^* . \frac{\mathrm{d}x}{\mathrm{d}t} + \Pi_y^* . \frac{\mathrm{d}y}{\mathrm{d}t} + \Pi_t^* = y\left(p' \frac{\mathrm{d}x}{\mathrm{d}t} - 1\right) < 0 \quad (23)$$

The tariff increases the domestic firm's profit and reduces the foreign firm's profit. Moreover, the domestic government benefits from additional public revenues.

In the long run, the firm selects the R&D investment that maximizes its expected profit. These are the same conditions as in section 2, except that the equilibrium profits (π_l and π_h) are modified by the import tariff.

Proposition 1. In Cournot competition an import tariff increases the domestic firm's R&D investment as compared to free trade if the inverse demand function is linear. Under a convex or a concave demand function, the effect is either positive or negative, but R&D is generally increased with the import tariff as compared to free trade.

Proof. First note that the impact of an import tariff on the production game between both firms is equivalent to the impact of the foreign firm's marginal cost c^*. Let us call $x^*(c^*) = Arg\ Max\ \pi(x(c^*), c^*)$ and $V(c^*) = \pi(x^*(c^*), c^*)$.[4] We get:

$$\frac{dV}{dc^*} = \frac{\partial \pi(x^*(c^*), c^*)}{\partial x^*} \frac{dx^*(c^*)}{dc^*} + \frac{\partial \pi(x^*(c^*), c^*)}{\partial c^*} = \frac{\partial \pi(x^*(c^*), c^*)}{\partial x^*} \frac{dx^*(c^*)}{dc^*} \text{ since: } \frac{\partial \pi(x^*(c^*), c^*)}{\partial c^*} = 0$$

Note that $\pi = x(p - c)$. Thanks to (4), we get: $\pi(x^*(c^*), c^*) = -x^*(c^*)^2 p'$.

A simple derivation gives: $\frac{\partial \pi(x^*(c^*), c^*)}{\partial x^*} = -2x^*(c^*)p' - x^*(c^*)^2 p'' = -x^*(c^*)\pi_{xx} > 0$

Note also that (18) gives $\frac{dx^*(c^*)}{dc^*} = -\frac{\Pi_{xy}}{\Delta}$. So we have: $\frac{dV}{dc^*} = x^*(c^*) \frac{\Pi_{xx}\Pi_{xy}}{\Delta} > 0$.

Suppose $p'' = 0$. We obtain: $\frac{dV}{dc^*} = \frac{2x^*(c^*)}{3}$. So in the case of a linear demand function, the impact of an import tariff is proportional to the optimal domestic firm's supply x^*. This supply is all the bigger since the domestic firm's marginal cost is smaller. So in this case, the difference in profit $DP = (\pi_l - \pi_h)$ increases with the tariff. So the optimal level of R&D.

[4] In order to simplify our notations, we omit the index i, referring to the level of marginal cost reached by the domestic firm: $i = l, h$.

If the demand function is not linear, $\frac{\Pi_{xx}\Pi_{xy}}{\Delta}$ depends on x and y. The first order effect remains the impact of the import tariff on x^*, and generally the difference in profit $DP = (\pi_l - \pi_h)$ increases with the tariff.[5]

We can summarize the effect of a tariff on imports in this way: it raises the domestic firm's profit and gives birth to tariff revenues, but it reduces the foreign firm's profit and the consumers' surplus. In general, the tariff increases R&D investment because a firm with low marginal costs benefits more from a tariff than a firm with high marginal costs. The tariff increases the marginal gain of R&D $(\pi_l - \pi_h)$, while the cost of R&D v remains constant.

3.2. A Production Subsidy under Cournot

The domestic country's government can implement a production subsidy, denoted s.[6] The domestic firm's profit equals:

$$\Pi(x, y, s) = x.p(x+y) - c.x + s.x - F - v.r \tag{25}$$

In the short run, the domestic firm's first order condition is:

$$x = (c - p - s)/p' \tag{26}$$

The foreign firm's profit expression and first order condition remain (3) and (5). The second order and stability conditions are not modified. We differentiate the first order conditions to find the impact of the production subsidy.

$$\frac{\mathrm{d}x}{\mathrm{d}s} = -\frac{\Pi^*_{yy}}{\Delta} > 0 \tag{27}$$

$$\frac{\mathrm{d}y}{\mathrm{d}s} = \frac{\Pi^*_{yx}}{\Delta} < 0 \tag{28}$$

$$\frac{\mathrm{d}X}{\mathrm{d}s} = \frac{\Pi^*_{yx} - \Pi^*_{yy}}{\Delta} > 0 \tag{29}$$

$$\frac{\mathrm{d}p}{\mathrm{d}s} = p'.\frac{\mathrm{d}X}{\mathrm{d}s} = p'.\frac{\Pi^*_{yx} - \Pi^*_{yy}}{\Delta} < 0 \tag{30}$$

The subsidy increases (reduces) the domestic (foreign) firm's output. The effect on the total supply is positive, which means that the subsidy decreases the market price and therefore increases the consumers' surplus. Finally, we find the derivatives of each profit with respect to s:

$$\frac{\mathrm{d}\Pi}{\mathrm{d}s} = \Pi_x.\frac{\mathrm{d}x}{\mathrm{d}s} + \Pi_y.\frac{\mathrm{d}y}{\mathrm{d}s} + \Pi_s = \Pi_y.\frac{\mathrm{d}y}{\mathrm{d}t} + \Pi_s = x.\left(p'.\frac{\mathrm{d}y}{\mathrm{d}s} + 1\right) > 0 \tag{31}$$

[5] Working with a mathematical solver on different functional forms, it is difficult to find a case where the difference in profit $DP = (\pi_l - \pi_h)$ decreases with the tariff.
[6] For the sake of simplicity, we also choose a specific, and not an ad valorem, subsidy.

$$\frac{d\Pi^*}{ds} = \Pi_S^*.\frac{dx}{ds} + \Pi_y^*.\frac{dy}{ds} + \Pi_s^* = \Pi_x^*.\frac{dx}{ds} = y.p'.\frac{dx}{ds} < 0 \quad (32)$$

The subsidy increases (reduces) the domestic (foreign) firm's profit; it increases (reduces) the domestic (foreign) country's producer surplus. In the domestic country, the public revenues decrease because of the subsidy.

In the long run, the domestic firm chooses the R&D investment that maximizes its expected profit. First and second order conditions remain (14) and (15).

Proposition 2: In Cournot competition a subsidy implemented by the domestic government increases the domestic firm's R&D investment compared to free trade.

Proof: Let $\hat{x}$ be the output which corresponds to the maximum profit: $\hat{x}(s, c_i) = Arg\ Max_{x\geq 0}\ \pi(x, s, c)\ s.t. \pi_y^* = 0$. We have: $V = V[\hat{x}(s, c_i), s, c_i]$. The Envelope Theorem leads:

$$\frac{\partial V[\hat{x}(s,c_i),s,c_i]}{\partial s} = \frac{\partial \pi(x,s,c_i)}{\partial s} - \lambda.\frac{\partial \pi_y^*}{\partial s} = \frac{\partial \pi(x,s,c_i)}{\partial s} = \hat{x}(s, c_i) \quad (33)$$

Indeed, $\partial \pi_y^*/\partial s = 0$. Since the optimal supply $\hat{x}(s, c_i)$ is greater when the domestic firm's marginal cost is low ($c = c_l$), the positive effect of the production subsidy on the domestic firm's maximum profit is greater when $c = c_l$, which implies that R&D increases with s: $dr/ds > 0$.

Thus, a production subsidy increases the domestic firm's profit and domestic consumers' surplus, but reduces the foreign firm's profit. It also reduces the domestic government's public revenues. Finally, the production subsidy increases R&D because it has a positive effect on the domestic firm's maximum profit when its marginal cost is low $c = c_l$; thus, the subsidy increases the marginal gain of R&D $(\pi_l - \pi_h)$, while the cost v remains constant.

3.3. An R&D Subsidy under Cournot

The domestic government can also decide to subsidize R&D instead of production. We denote the R&D subsidy as σ. The domestic firm's profit is:

$$\Pi(x, y, \sigma) = x.p(x + y) - c.x - F - (v - \sigma).r \quad (34)$$

The foreign firm's profit expression remains (2). In the short run, the first and second order conditions remain the same as those under free trade. Moreover, we have: $\Pi_{x\sigma} = 0$, which leads $dx/d\sigma = 0$. Therefore, in the short run, the R&D subsidy doesn't modify outputs, price, or profits.

In the long run, the domestic firm's expected profit is:

$$E[\Pi(r)] = \alpha(r).\pi_l + [1 - \alpha(r)].\pi_h - F - (v - \sigma).r \quad (35)$$

The first order condition leads to:

$$\alpha'(r) = \frac{v-\sigma}{\pi_l-\pi_h} \quad (36)$$

The second order condition doesn't change.

Proposition 3: In Cournot competition a R&D subsidy implemented by the domestic government increases the domestic firm's R&D investment compared to free trade.

Proof: According to (36), $\alpha'(r)$ decreases in σ. Therefore, Assumption 2 implies that the subsidy σ increases R&D: $\mathrm{d}r/\mathrm{d}\sigma > 0$.

With a positive R&D subsidy, the likelihood of having low marginal costs increases. In that case, it is more likely that the domestic firm's profit is greater and that the market price is lower with an R&D subsidy. Therefore, the subsidy increases the domestic country's expected producers' and consumers' surplus. However, it decreases the domestic government's public revenues. We now introduce the impact of quantitative restrictions.

3.4. A Quota on Imports under Cournot

Suppose that the domestic government implements a quota on imports. We assume that the quota does not create public revenues because imports licenses are free; we do so because an introduction of quota revenues under imperfect competition is really a complex issue. For Matschke (2003), *"modeling the quota revenue is somewhat arbitrary"* [p. 212] in a duopolistic context under Cournot competition. Many academic articles proceed along the same assumption.[7]

We denote the quota level (i.e. the foreign firm's maximum exports) as q. Profit expressions are now:

$$\Pi(x,q) = x.p(x+q) - c.x - F - v.r \quad (37)$$

$$\Pi^*(x,q) = q.p(x+q) - c_l.q - F^* \quad (38)$$

In the short run, only the domestic firm can maximize its profit. We suppose that the quota is binding such that the first order condition (5) does not hold. The foreign firm's exports equals q. The domestic firm's first order condition remains (4).

We consider two cases for the quota level. The first case corresponds to an interval between the foreign firm's exports when the domestic firm's marginal cost of output is low ($c = c_l$) and the foreign firm's exports when the domestic firm's marginal cost is high ($c = c_h$): $y_l \leq q < y_h$, where $y_i = (c^* - p)/p'$ under $c = c_i$, $\forall i = l,h$ is the foreign firm's exports under free trade.

[7] See for example Bouët and Cassagnard, 2013.

The second case corresponds to a very binding quota which is inferior or equal to the foreign firm's exports when the domestic firm's marginal cost is low ($c = c_l$): $q < y_l$. Note that if $q \geq y_h$, the quota is never binding and has no impact.

First case: $y_l \leq q < y_h$. If the domestic firm has low marginal costs, the quota is greater than the foreign firm's optimal response. The domestic firm's profit doesn't change. However, if the domestic firm has high marginal costs, the quota is binding and the foreign firm must export less than the Nash equilibrium's level. The domestic firm's profit is increased since: $\pi_y = x.p' < 0$. Denoting π_i^q, the domestic firm's profit without the fixed and R&D costs when its marginal cost is c_i and when the domestic government implements the quota q. We have: $\pi_l^q = \pi_l$ and $\pi_h^q > \pi_h$. As far as the foreign firm is concerned, its profit doesn't change (decreases) if the domestic firm's marginal cost is low (high).

Second case: $q < y_l$. The quota is binding whether the R&D investment succeeds or fails; it increases the domestic firm's profit in all states of nature: $\pi_l^q > \pi_l$ and $\pi_h^q > \pi_h$. The foreign firm's profit always decreases.

In the long run, the domestic firm chooses R&D investment that maximizes its expected profit. This leads to:

$$\alpha'(r^q) = \frac{v}{\pi_l^q - \pi_h^q} \tag{39}$$

Proposition 4: In Cournot competition a relatively unrestrictive quota ($y_l \leq q < y_h$) always reduces the domestic firm's R&D investment with respect to free trade. With a linear or concave demand function, a relatively restrictive quota ($q < y_l$) increases R&D compared to free trade. With a convex demand function, a relatively restrictive quota ($q < y_l$) can either increase or decrease R&D as compared to free trade.

Proof: We consider again two cases.

Consider the first case ($y_l \leq q < y_h$): The quota increases the domestic firm's profit only when its marginal cost is high, such that the profits differential decreases: $\pi_l^q - \pi_h^q < \pi_l - \pi_h$. Therefore, a relatively unrestrictive quota decreases the domestic firm's R&D. The lower the quota (as long as it is still greater than y_l), the lower R&D.

Consider the second case: The domestic firm's profit increases under the quota regardless of its marginal cost. Let us suppose a linear example. Units are chosen such that the inverse demand function is: $p(X) = a - X$, with $a > 0$. If a prohibitive quota ($q = 0$) is implemented, the domestic firm is under monopoly. Its optimal supply equals $(a - c_i)/2$, which leads to a profit without the fixed and R&D costs included: $\pi_i^{q=0} = (a - c_i)^2/4$. Under a zero quota, the difference in profits is $DP^{q=0} = (c_h - c_l).(2a - c_h - c_l)/4$. It is greater than the difference in profits under free trade: $DP^{q=0} > DP \Leftrightarrow (1/2).(c_h - c_l).[a - (c_h + c_l)/2] > (4/9).(c_h - c_l).(a - c_h)$.

This result holds for a nonlinear demand function if the demand function is concave or not too convex. Let us denote V as the domestic firm's maximum profit for a certain quota q.

Note: $\hat{x}(q, c_i) = Arg\ Max_{x \geq 0}\ \pi(x, q, c_i)$. The foreign firm's first order constraint disappears because the quota is binding.

$V(q, c_i) = \pi(\hat{x}(q, c_i), q, c_i)$.

The Envelope Theorem implies: $\partial V[q, c_i]/\partial q = \partial \pi(x, q, c_i)/\partial q = \hat{x}(q, c_i).p' < 0$. The domestic firm's maximum profit increases when the quota becomes more restrictive. With a linear (p' constant) or a concave ($p'' < 0$), the absolute value of ($\hat{x}(q, c_i).p'$) is greater when the domestic firm's marginal cost is low; if the quota becomes more and more restrictive starting from $q = y_l$, the difference in profit DP^q increases. This is a necessary condition but is not sufficient to have more difference in profit under a quota than under free trade.

If the demand function is convex ($p'' > 0$), ($\hat{x}(q, c_i).p'$) may be smaller or greater when the domestic firm's marginal cost is low depending on the convexity of the demand function (let us note that in most of cases, it is greater since the effect through $\hat{x}(q, c_i)$ is a first order effect). With a convex demand function, we find some examples where a binding quota increases R&D[8] and other examples where the effect is negative[9].

The effect of a quota on R&D investment is ambiguous. A not very restrictive quota ($y_l \leq q < y_h$) decreases R&D; however, with a relatively restrictive quota, in general, R&D is augmented compared to free trade.

3.5. A VER under Cournot

Quantitative restrictions can also take the form of Voluntary Exports Restrictions (VER). Because this policy is "Voluntary," it must be implemented by the foreign firm (or the foreign country, if we consider that both have the same interest) and generally increases the foreign firm's expected profit.

[8] Consider the following demand function: $p(X) = a - X^b$, with $0 < b < 1$ (a convex demand function). We set: $c_l = 3$, $c_h = 6$, $a = 100$, $b = 0.75$. Under free trade, we get: $x_l = y_l = 145.75$, $x_h = 134.53$, $y_h = 150.97$. The difference in profits is: $DP = 553.6$. With a quota $q = y_l = 145.75$, the difference in profits is $DP^q = 424.06$, which is less than that of free trade. But with a quota $q = 50$, the profits differential equals $DP^q = 555.37$, which means that R&D is increased compared to free trade. With a prohibitive quota $q = 0$, the profits differential equals $DP^q = 620.99$. We didn't find any value of b which modifies this result.

[9] Consider the following demand function: $p(X) = a/X^b$, with $0 < b < 1$. With $b \geq 0.7$ and the same values than in the previous footnote, the difference in profits is always lower with a quota than under free trade: a binding quota always reduces the domestic firm's R&D investment under this example.

According to Bouët (2001), in the same theoretical structure, a VER has a strategic interest. The foreign firm implements a VER, denoted q (which corresponds to the maximum exports that the foreign firm can realize), such as: $y_l \leq q < y_h$. Therefore, a VER decreases the domestic firm's R&D investment because it only increases its profit if the domestic marginal cost is high; it decreases the marginal gain of an R&D investment (see previous subsection). Bouët (2001) shows that a VER can increase the foreign firm's expected profit because the likelihood of a domestic firm's R&D success is lower. So a VER must be such that $y_l \leq q < y_h$. If not, the foreign profit is lower regardless of the state of the R&D investment.

Proposition 5: In Cournot competition a VER always reduces the domestic firm's R&D investment with respect to free trade.

4. A Bertrand competition

We introduce now a price competition. To avoid a "Bertrand Paradox," we assume that goods are slightly differentiated.

Assumption 1b: Both firms supply slightly differentiated goods. Competition is of Bertrand-type. Each firm's output depends on both firms' prices. Denoting p (respectively, p^*) as the domestic (respectively, foreign) firm's price: $x = x(p, p^*)$, $y = y(p, p^*)$, $X = X(p, p^*)$. The domestic (respectively, foreign) firm's output decreases (respectively, increases) in the domestic price and increases (respectively, decreases) in the foreign price: $x_p = \partial x/\partial p < 0$, $x_{p^*} = \partial x/\partial p^* > 0$, $y_p = \partial y/\partial p > 0$, $y_{p^*} = \partial y/\partial p^* < 0$. Own effects are greater than cross effects: $|x_p| > |x_{p^*}|$, $|y_p| < |y_{p^*}|$.

The profit expressions are:

$$\Pi(p, p^*) = x(p, p^*).p - c.x(p, p^*) - F - v.r \tag{40}$$

$$\Pi^*(p, p^*) = y(p, p^*).p^* - c_l.y(p, p^*) - F^* \tag{41}$$

In the short run, each firm chooses the price that maximizes its profit. The first order conditions lead to the following reaction functions:

$$p = c - x/x_p \tag{42}$$

$$p^* = c^* - y/y_{p^*} \tag{43}$$

Assumption 3b: Second order conditions are verified: $\Pi_{pp} = x_{pp}.(p - c) + 2x_p < 0$, $\Pi^*_{p^*p^*} = y_{p^*p^*}.(p^* - c^*) + 2y_{p^*} < 0$. The domestic (foreign) marginal profits increases in the foreign (domestic) firm's price: $\Pi_{pp^*} = x_{pp^*}.(p-c) + x_{p^*} > 0$, $\Pi^*_{p^*p} = y_{p^*p}.(p^* - c_l) + y_p < 0$. Own effects are greater than cross effects: $|\Pi_{pp}| > |\Pi_{pp^*}|$, $|\Pi^*_{p^*p^*}| > |\Pi^*_{p^*p}|$.

This implies the stability condition of the Nash equilibrium:

$$\Gamma = \Pi_{pp}.\Pi^*_{p^*p^*} - \Pi_{pp^*}.\Pi^*_{p^*p} > 0 \quad (44)$$

The success or failure of the R&D investment implies two different levels of price and profit:

$$\pi_i = p_i.x(p_i, p_i^*) - c_i.x(p_i, p_i^*) \text{ with } p_i = c_i - x/x_p, \forall i = l, h \quad (45)$$

Let V be the domestic firm's maximum profit. V solves the program: $Max_{p\geq 0}\, \Pi(p, p^*, c_i)\ \ s.t.\ \Pi^*_{p^*} = 0$. The Envelope Theorem leads to:

$$\frac{\mathrm{d}V(c_i)}{\mathrm{d}c_i} = \frac{\partial \Pi[p(c_i), p^*(c_i), c_i]}{\partial c_i} - \lambda.\frac{\partial \Pi^*_{p^*}}{\partial c_i} = \frac{\partial \Pi[p(c_i), p^*(c_i), c_i]}{\partial c_i} = -\hat{x}[p(c_i), p^*(c_i)] < 0 \quad (46)$$

Indeed, $\partial \Pi^*_{p^*}/\partial c_i = 0$. (46) shows that the domestic firm's maximum profit is greater when its marginal cost of output is low since as shown later the equilibrium output decreases with c_i.

Differentiating the first order conditions, we obtain:

$$\frac{\mathrm{d}p}{\mathrm{d}c} = \frac{x_p.\pi^*_{p^*p^*}}{\Gamma} > 0 \quad (47)$$

$$\frac{\mathrm{d}p^*}{\mathrm{d}c} = -\frac{x_p.\pi^*_{p^*p}}{\Gamma} > 0 \quad (48)$$

$$\frac{\mathrm{d}x}{\mathrm{d}c} = x_p\frac{\mathrm{d}p}{\mathrm{d}c} + x_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}c} = \frac{x_p\left(x_p\pi^*_{p^*p^*} - x_{p^*}\pi^*_{p^*p}\right)}{\Gamma} < 0 \quad (49)$$

$$\frac{\mathrm{d}y}{\mathrm{d}c} = y_p\frac{\mathrm{d}p}{\mathrm{d}c} + y_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}c} = \frac{x_p.\left(y_p.\pi^*_{p^*p^*} - y_{p^*}.\pi^*_{p^*p}\right)}{B} \quad (50)$$

$$\frac{\mathrm{d}X}{\mathrm{d}c} = \left(x_p + y_p\right)\frac{\mathrm{d}p}{\mathrm{d}c} + \left(x_{p^*} + y_{p^*}\right)\frac{\mathrm{d}p^*}{\mathrm{d}c} \quad (51)$$

An increase in the domestic profit's marginal cost of output increases each firm's price. The effect on the domestic firm's output is negative. We cannot conclude about the sign of $\frac{\mathrm{d}y}{\mathrm{d}c}$ and $\frac{\mathrm{d}X}{\mathrm{d}c}$. However, considering an effects symmetry ($x_p = y_{p^*}$ and $x_{p^*} = y_p$), then $\mathrm{d}X/\mathrm{d}c < 0$; in that case, a fall in the marginal cost increases the consumers' surplus.

In the long run, the domestic firm's expected profit remains (12) and the first order condition leads to (13) again. The second order condition is verified again.

The impact of an R&D subsidy is the same as that seen under Cournot competition. We introduce only a tariff on imports, a production subsidy, and a minimum price because introducing quantitative restrictions in a Bertrand competition is a very complex issue (see Krishna, 1989); moreover, it implies a mixed strategy equilibrium. In place of quantitative restrictions, we introduce minimum price commitments.

4.1. A Tariff on Imports under Bertrand

The domestic firm's profit expression remains (40). For the foreign firm, we have:

$$\Pi^*(p,p^*,t) = y(p,p^*).p - c^*.y(p,p^*) - t.y(p,p^*) - F^* \tag{52}$$

The foreign firm's first order condition changes:

$$p^* = c^* + t - y/y_{p^*} \tag{53}$$

Differentiating the first order conditions, we have:

$$\frac{\mathrm{d}p}{\mathrm{d}t} = -\frac{y_{p^*}\Pi_{pp^*}}{\Gamma} > 0 \tag{54}$$

$$\frac{\mathrm{d}p^*}{\mathrm{d}t} = \frac{y_{p^*}\Pi_{pp}}{\Gamma} > 0 \tag{55}$$

We find the effect on outputs and profits:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = x_p \frac{\mathrm{d}p}{\mathrm{d}t} + x_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}t} \tag{56}$$

$$\frac{\mathrm{d}y}{\mathrm{d}t} = y_p \frac{\mathrm{d}p}{\mathrm{d}t} + y_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}t} < 0 \tag{57}$$

$$\frac{\mathrm{d}X}{\mathrm{d}t} = \left(x_p + y_p\right)\frac{\mathrm{d}p}{\mathrm{d}t} + \left(x_{p^*} + y_{p^*}\right)\frac{\mathrm{d}p^*}{\mathrm{d}t} \tag{58}$$

$$\frac{\mathrm{d}\Pi}{\mathrm{d}t} = \Pi_p \frac{\mathrm{d}p}{\mathrm{d}t} + \Pi_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}t} + \Pi_t = (p-c)x_{p*}\frac{\mathrm{d}p^*}{\mathrm{d}t} > 0 \tag{59}$$

$$\frac{\mathrm{d}\Pi^*}{\mathrm{d}t} = \Pi^*_p \frac{\mathrm{d}p}{\mathrm{d}t} + \Pi^*_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}t} + \Pi^*_t = \Pi^*_p \frac{\mathrm{d}p}{\mathrm{d}t} + \Pi^*_t = -y\left(1 - \frac{y_p\pi_{pp*}}{\Gamma}\right) \tag{60}$$

The effect on the domestic firm's output and the total supply is uncertain. However, the tariff reduces the foreign firm's output. If we assume symmetry in these effects ($x_p = y_{p^*}$ and $x_{p^*} = y_p$), then $\mathrm{d}X/\mathrm{d}t < 0$; in that case, the tariff decreases the consumers' surplus. The tariff increases the domestic firm's profit and decreases the foreign firm's profit if: $1 > y_p\pi_{pp*}/\Gamma$.

In the long run, the domestic firm chooses the R&D investment that maximizes its expected profit. The first order conditions remains (13).

Proposition 6: Under Bertrand competition a tariff on imports increases R&D investment under a linear or a concave demand functions. Under convex demand functions, the effect is uncertain.

Proof: First note that the impact of an import tariff on the price game between both firms is equivalent to the impact of the foreign firm's marginal cost c^*. Let us call $\hat{p}(c^*) = Arg\ Max_p\ \pi(p, p^*, c^*)$; $\widehat{p^*}(c^*) = Arg\ Max_{p^*}\ \pi^*(p, p^*, c^*)$; $V(c^*) = \pi(\hat{p}(c^*), c^*)$; and $x^*(c^*) = x\left(\hat{p}(c^*), \widehat{p^*}(c^*)\right)$. We get:

$$\frac{dV}{dc^*} = \frac{\partial\pi(p(c^*),c^*)}{\partial p}\frac{dp(c^*)}{dc^*} + \frac{\partial\pi(p(c^*),c^*)}{\partial c^*} = \frac{\partial\pi(p(c^*),c^*)}{\partial p}\frac{dp(c^*)}{dc^*} \text{ since: } \frac{\partial\pi(p(c^*),c^*)}{\partial c^*} = 0$$

Note that: $\pi = x(p - c)$. Thanks to (42), we get: $V(c^*) = -(p(c^*) - c)^2 x_p$. As in (54), we get: $\frac{\mathrm{d}p(c^*)}{\mathrm{d}c^*} = -\frac{y_{p^*}\Pi_{pp^*}}{\Gamma} > 0$. Therefore:

$$\frac{dV}{dc^*} = \left[-2(p(c^*) - c)x_p - (p(c^*) - c)^2 x_{pp}\right]\left(-\frac{y_{p^*}\Pi_{pp^*}}{\Gamma}\right)$$

Let us consider three cases:

(i) With linear demand functions, $x_{pp} = 0$. So: $\frac{dV}{dc^*} = \left[2(p(c^*) - c)x_p\right]\left(\frac{y_{p^*}\Pi_{pp^*}}{\Gamma}\right)$. We know that x_p, Π_{pp^*}, y_{p^*} and Γ are constant, and that $(p - c_i)$ decreases in c_i since $\mathrm{d}p/\mathrm{d}c < 1$. Therefore, we have $\frac{dV}{dc^*}$ larger when $c = c_l$.

(ii) With concave demand functions, $x_{pp} < 0$ and $x_{p^*p^*} < 0$, which implies that x_{p^*} decreases in p^*. We have proved that both prices increase in the marginal cost. Therefore, since $x_{p^*p^*} < 0$ and $x_{p^*p} < 0$, x_{p^*} is greater when the domestic firm's marginal cost is low. Moreover, according to (47), we can prove that $\mathrm{d}p/\mathrm{d}c < 1$ with concave demand functions, which implies that $(p - c_i)$ is also greater when the domestic firm's marginal cost is low. The positive effect of the tariff on the domestic firm's maximum profit is greater when its marginal cost is low.

(iii) With convex demand functions, $x_{pp} > 0$ and $x_{p^*p^*} > 0$, which implies that x_{p^*} increases in p^* (but always decreases in p). Convexity leads to that x_{p^*} being more sensitive to p^* than p. The effect of the marginal cost on x_{p^*} is uncertain, and we cannot prove that $(p - c_i)$ is greater with a low marginal cost because we cannot prove that $\mathrm{d}p/\mathrm{d}c < 1$. Therefore, we cannot check that the positive effect of the tariff on the domestic firm's maximum profit is greater when its marginal cost is low or that the tariff increases R&D. However, only a high convexity degree could imply that the tariff decreases R&D investment.

In general, the tariff increases the domestic firm’s R&D investment. The effect is certainly positive with linear or concave demand functions. However, the effect is either positive or negative with convex demand functions.

4.2. A Production Subsidy

We next introduce a production subsidy implemented by the domestic government. The domestic firm’s profit expression is:

$$\Pi(p,p^*,s) = x(p,p^*).p - c.x(p,p^*) + s.x(p,p^*) - F - v.r \qquad (62)$$

The foreign firm’s profit expression remains (41). The domestic firm’s first order condition is:

$$p = c - s - x/x_p \qquad (63)$$

The second order conditions are verified. We differentiate the first order conditions to find the effect of the subsidy:

$$\frac{\mathrm{d}p}{\mathrm{d}s} = -\frac{\Pi^*_{p^*p^*}.x_p}{\Gamma} < 0 \qquad (64)$$

$$\frac{\mathrm{d}p^*}{\mathrm{d}s} = \frac{\Pi^*_{p^*p}.x_p}{\Gamma} < 0 \qquad (65)$$

We find the effect on outputs and profits:

$$\frac{\mathrm{d}x}{\mathrm{d}s} = x_p.\frac{\mathrm{d}p}{\mathrm{d}s} + x_{p^*}.\frac{\mathrm{d}p^*}{\mathrm{d}s} = \frac{-x_p\left(x_p{\pi^*}_{p^*p^*} - x_{p^*}{\pi^*}_{p^*p}\right)}{\Gamma} > 0 \qquad (66)$$

$$\frac{\mathrm{d}y}{\mathrm{d}s} = y_p.\frac{\mathrm{d}p}{\mathrm{d}s} + y_{p^*}.\frac{\mathrm{d}p^*}{\mathrm{d}s} = \frac{-x_p\left(y_p{\pi^*}_{p^*p^*} - y_{p^*}{\pi^*}_{p^*p}\right)}{\Gamma} \qquad (67)$$

$$\frac{\mathrm{d}X}{\mathrm{d}s} = \left(x_p + y_p\right).\frac{\mathrm{d}p}{\mathrm{d}s} + \left(x_{p^*} + y_{p^*}\right).\frac{\mathrm{d}p^*}{\mathrm{d}s} \qquad (68)$$

$$\frac{\mathrm{d}\Pi^*}{\mathrm{d}s} = \Pi^*_p\frac{\mathrm{d}p}{\mathrm{d}s} + \Pi^*_{p^*}\frac{\mathrm{d}p^*}{\mathrm{d}s} + \Pi^*_s = \Pi^*_p\frac{\mathrm{d}p}{\mathrm{d}s} = (p - c_b)y_p\frac{\mathrm{d}p}{\mathrm{d}s} < 0 \qquad (69)$$

The subsidy increases the domestic firm’s output, and the effect on the foreign output total supply is either positive or negative. If we assume an effects symmetry, then $\mathrm{d}X/\mathrm{d}s > 0$; in that case, the subsidy increases the consumers’ surplus (because it decreases prices). The subsidy decreases the foreign firm’s profit.

In the long run, the domestic firm chooses the R&D investment that maximizes its expected profit with the same first order condition.

Proposition 7: Under Bertrand competition the production subsidy always increases the domestic firm’s R&D investment.

Proof: V is the domestic firm's maximum profit. The Envelope Theorem implies:

$$\frac{\partial V[p(c_i,s),c_i,s]}{\partial s} = \frac{\partial \pi(p,c_i,s)}{\partial s} - \lambda.\frac{\partial \pi^*_{p^*}}{\partial s} = \frac{\partial \pi(p,c_i,s)}{\partial s} = \hat{x}[p(c_i,s),p^*(c_i,s)] > 0 \quad (70)$$

The production subsidy increases the domestic firm's maximum profit. According to (49), $\hat{x}$ is greater when its marginal cost is low. Therefore, the positive effect of the subsidy on the domestic firm's maximum profit is greater also when its marginal is low.

4.3. A Minimum Price under Bertrand Competition

We next introduce a minimum price, denoted by $\underline{p}^*$, implemented by the domestic government. The foreign firm cannot sell its goods at a price below $\underline{p}^*$. Profits are:

$$\Pi\left(p,\underline{p}^*\right) = p.x\left(p,\underline{p}^*\right) - c.x\left(p,\underline{p}^*\right) - v.r - F \quad (71)$$

$$\Pi^*\left(p,\underline{p}^*\right) = \underline{p}^*.y\left(p,\underline{p}^*\right) - c^*.y\left(p,\underline{p}^*\right) - F^* \quad (72)$$

In the short run, only the domestic firm chooses the output that maximizes its profit. We consider two intervals for the minimum price. We denote p_i^* as the foreign firm's equilibrium price under free trade when the domestic firm's marginal cost is $c_i, \forall i = l,h$. According to (48), we have: $p_l^* < p_h^*$. If the domestic government implements a minimum price such as $\underline{p}^* \leq p_b^*$, it has no effect on the equilibrium between both firms, so we only consider $\underline{p}^* > p_l^*$. Therefore, we have two cases: $\underline{p}^* \leq p_h^*$ or $\underline{p}^* > p_h^*$.

First case: $\boldsymbol{p_l^* < \underline{p}^* \leq p_h^*}$. If the domestic firm's marginal cost is high, its profit remains the same as under free trade because the foreign firm is not able to sell below p_h^*. However, if this marginal cost is low, the minimum price increases its profit because domestic profit is increasing with the foreign price: $\pi_{p^*} = x_{p^*}.(p-c) > 0$. Denoting $\pi_i^{\underline{p}^*}$ as the domestic firm's profit with the minimum price $\underline{p}^*$ and when its marginal cost is c_i, we have: $\pi_l^{\underline{p}^*} > \pi_l$ and $\pi_h^{\underline{p}^*} = \pi_h$.

Second case: $\boldsymbol{\underline{p}^* > p_h^*}$. The minimum price increases the domestic firm's profit regardless of its marginal cost of output: $\pi_l^{\underline{p}^*} > \pi_l$ and $\pi_h^{\underline{p}^*} > \pi_h$.

In the long run, the domestic firm chooses the R&D investment that maximizes its expected profit. The first order condition implies:

$$\alpha'(r^{\underline{p}}) = \frac{v}{\pi_l^{\underline{p}^*} - \pi_h^{\underline{p}^*}} \quad (73)$$

Proposition 8: Under Bertrand competition when $\boldsymbol{p_l^*} < \underline{\boldsymbol{p}}^* \leq \boldsymbol{p_h^*}$, the minimum price increases R&D investment as compared to free trade. When $\underline{\boldsymbol{p}}^* > \boldsymbol{p_h^*}$, in general, it increases R&D investment as compared to free trade. The effect is certainly positive with linear or concave demand functions, but remains uncertain with convex demand functions.

Proof: We consider the first case. Previously, we showed that $\pi_l^{\underline{p}^*} > \pi_l$ and $\pi_h^{\underline{p}^*} = \pi_h$. The profit differential is greater with the minimum price than under free trade: $DP^{\underline{p}^*} = \pi_l^{\underline{p}^*} - \pi_h^{\underline{p}^*} > DP = \pi_l - \pi_h$. R&D investment increases the profit differential again. Therefore, with this interval, the minimum price always increases the domestic firm's R&D investment.

Now consider the second case. The minimum price increases the domestic firm's profit regardless of its marginal cost: $\pi_l^{\underline{p}} > \pi_l$ and $\pi_h^{\underline{p}} > \pi_h$. $V\left(p, \underline{p}^*, c_i\right)$ is the domestic firm's maximum profit, which solves the program: $Max_{p\geq 0}\, \pi\left(p, \underline{p}^*, c_i\right)$. There are no constraints due to the minimum price. The Envelope Theorem implies:

$$\frac{\partial V\left(p,\underline{p}^*,c_i\right)}{\partial \underline{p}^*} = \frac{\partial \pi\left[p,\underline{p}^*,c_i\right]}{\partial \underline{p}^*} = x_{\underline{p}^*}.(p - c_i) > 0 \tag{74}$$

Under a linear or a concave demand function, the term $x_{\underline{p}^*}.(p - c_i)$ is greater with a low marginal cost $(c_i = c_l)$. This result is certain with linear or concave demand functions. Under a convex demand function, we cannot conclude.

5. Discussion

We now summarize and discuss Propositions 1 to 8. Table 1 provides a summary of the results presented in this article.

Table 1. Economic Impact of each instrument.

Instrument	Impact on the domestic firm's R&D investment		Impact on the domestic firm's profit		Impact on the foreign firm's profit		Impact on the domestic country's consumer surplus		Impact on the domestic country's public revenues	
	Cournot	Bertrand	Cournot	Bertrand	Cournot	Bertrand	Cournot	Bertrand	Cournot	Bertrand
Tariff on imports	+?	+?	+	+	–	+/–	–	–?	+	+
Subsidy of output	+	+	+	+	–	–	+	+?	–	–
R&D subsidy	+	+	+	+	–	–	+	+	–	–
Quota on imports	+/–	na	+	na	–	na	–	na	0	na
VER	–	na	+	na	–	na	–	na	0	na
Minimum price	na	+?	na	+	na	–	na	–	na	0

Source: authors.
Notes: "+" (respectively "–") means that the impact is positive (respectively negative). "+?" ("-?") means that the result is uncertain with a high presumption to find a positive (respectively negative) effect. "+/–" means that the result is positive or negative according to the trade policy. "na" means: not available.

A production subsidy and an R&D subsidy systematically increase R&D investment. In general, a tariff increases R&D investment. These results hold both under Cournot and Bertrand competitions. Under a Cournot competition, a quota has either a positive or negative effect depending on its restrictiveness. AVER always decreases R&D investment. Under a Bertrand competition, in general, a minimum price increases R&D investment.

Table 1 also reminds us of the effect of each instrument on the domestic country's consumers' and producers' surplus and public revenues, as well as on the foreign country's producers' surplus. Each instrument increases the domestic firm's profit under both Cournot and Bertrand competitions. However, each instrument decreases the foreign firm's profit except for:

(i) a tariff under Bertrand competition because it increases the price, creating a collusive impact;

(ii) a VER under Cournot competition because it decreases the domestic firm's R&D investment in response to the foreign firm's exports restriction.

Border instruments such as tariffs, quotas, or VERs decrease consumers' surplus while, in general, a production subsidy increases consumers' surplus; however, under a Bertrand competition, this effect is not systematic. On the contrary, an R&D subsidy systematically increases consumers' surplus under this competition. Only the tariff increases public revenues, while the subsidies decreases it and the quota (or VER) has no effect.

Therefore, we conclude that the R&D subsidy is an interesting instrument:

(i) It is an offensive instrument which can help the domestic firm against competition from countries which benefit from lower production costs.

(ii) It increases the domestic producer's profit and consumers' surplus.

(iii) These results are robust; they holds regardless of the form of the demand function and regardless of the mode of competition (Cournot or Bertrand).

(iv) According to the WTO, import tariffs are bound, meaning they cannot be increased above a certain level. Production subsidies, quotas, VERs, and minimum prices are forbidden. There are more tolerance for R&D subsidies as long as they do not have a distortionary effect on global trade. In the model presented in this article, an R&D subsidy has an impact on the expected level of imports; however, once the domestic firm's marginal cost has been determined, the level of imports is not affected by this instrument.

(v) R&D may bring positive externalities for the rest of the domestic economy (for example, innovations in other sectors). An R&D subsidy increases these externalities.

Nevertheless, firms tend to overinvest in R&D as shown by Spencer & Brander (1983). An R&D subsidy can increase the overinvestment problem. This is a concern of this type of "behind-the-border" policy.

6. Concluding remarks

The objective of this paper was to evaluate the potential impact of various trade policy instruments, both "at-the-border" or "behind-the-border" on local R&D expenditures. We have shown that these instruments have contrasting effects on R&D; for example, a production subsidy has a positive impact on R&D while a VER has a negative impact. Quotas on imports may decrease R&D if they are not too restrictive and may expand it if they are very restrictive.

We conclude that an R&D subsidy is an attractive instrument for policymakers since it has an unambiguously positive impact on R&D and since it is less controlled by the WTO as compared to other instruments. These other instruments are comparatively either uncertain or ambiguous in terms of their effect on R&D or they are forbidden by international law. We believe that this theoretical conclusion fits well with today's trade environment since many interventions in high-income or emerging countries are (or are close to) R&D subsidies.

From a theoretical point of view, this article is based on a duopolistic model (under either Bertrand or Cournot competition) with a specific feature (as compared to the literature); the impact of R&D is uncertain. R&D expenses increase the probability of R&D success, which we think is a realistic assumption. In that sense, this article is largely innovative, particularly the analysis of the impact of a quota on imports (under Cournot competition) and of a minimum price commitment (under Bertrand competition) on R&D.

What is the best instrument amongst all those considered here? We did not strictly conclude on a hierarchy of instruments for two reasons. First, we did not suppose a government's objective function. This type of assumption is always arbitrary since it is difficult to state the importance of consumers' surplus, producers' profit, and public revenues in a political process. Moreover, an important aspect of R&D expenses is externalities, which should be included in a government's objective. Second, dynamic considerations matter since R&D expenditures may have a long-term impact on competitiveness. If we consider a game over several periods, a failure of R&D today may reinforce the attractiveness of R&D tomorrow, while a success of R&D today may weaken a government's interest in such expenses tomorrow.

Another way of enhancing local R&D in order to reinforce domestic competitiveness in the face of competing low-cost producers is to improve the quality of the environment in terms of law, property rights, transmission of knowledge, inventions, and innovation from research centers (public or private) to the private sector of production. In our model, this structural policy would imply a modification of the probability of successful R&D: the α function would become more convex and each US$ spent in R&D would lead to a more probable reduction of the marginal cost of production.

7. References

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8. Annex - Cournot

In this annex we present full Cournot results under a linear demand function and a success probability as an iso-elastic function of R&D.

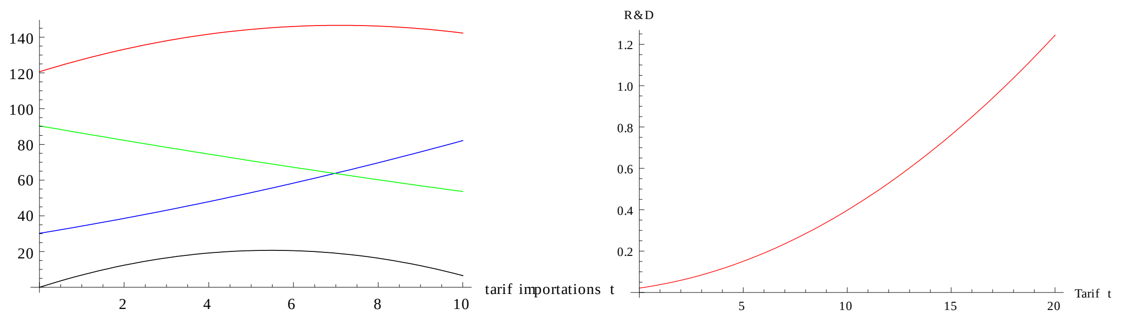
7.1. Cournot – General Framework

Suppose a demand function: $p = a - (x + y)$. We have: $a > c_h > c_b > 0$. Profit function are: $\Pi = p * x - c_i * x - r * v$ for the domestic firm and $\Pi^* = p * y - c_b * y$ for the foreign firm. Nash equilibrium in production is: $\forall i = b, h;\ x = \frac{1}{3}(a - 2c_i + c_b), y = \frac{1}{3}(a + c_i - 2c_b)$, that is to say $x = \frac{1}{3}(a - c_b), y = \frac{1}{3}(a - c_b)$ if R&D is successful while if R&D does not succeed: $x = \frac{1}{3}(a - 2c_h + c_b), y = \frac{1}{3}(a + c_h - 2c_b)$. The R&D success probability is: $\alpha(r) = r^k$ with: $0 < k < 1$. Domestic firm's expected profit is: $\mathrm{E}(\Pi) = r^k * (\frac{1}{9}(a - c_b)^2) + (1 - r^k) * (\frac{1}{9}(a + c_b - 2c_h)^2) - r * v$. Selecting the level of R&D which maximizes expected profit leads to: $r = (\frac{9}{4})^{\frac{1}{k-1}}(\frac{(a-c_h)(c_h-c_b)k}{v})^{\frac{1}{1-k}}$. Second-order condition is verified.

7.2. Cournot – Imports Tariff

Consider that the domestic government implements an import tariff *t*, the foreign firm's profit function becomes: $\Pi^* = p * y - c_b * y - t * y$. Equilibrium supplies are: $x = \frac{1}{3}(a - 2c_i + c_b + t), y = \frac{1}{3}(a + c_i - 2c_b - 2t)$. The R&D level selected by the domestic firm is: $r = (\frac{9}{4})^{\frac{1}{k-1}}(\frac{(c_h-c_b)k(a-c_h+t)}{v})^{\frac{1}{1-k}}$. R&D is increasing with tariff *t*. Graph 1 illustrates evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum when *t* increases. The domestic firm's profit is increasing with the tariff, consumers' surplus is decreasing and public revenues are concave.

Graph 1. Evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum according to the import tariff t - Cournot



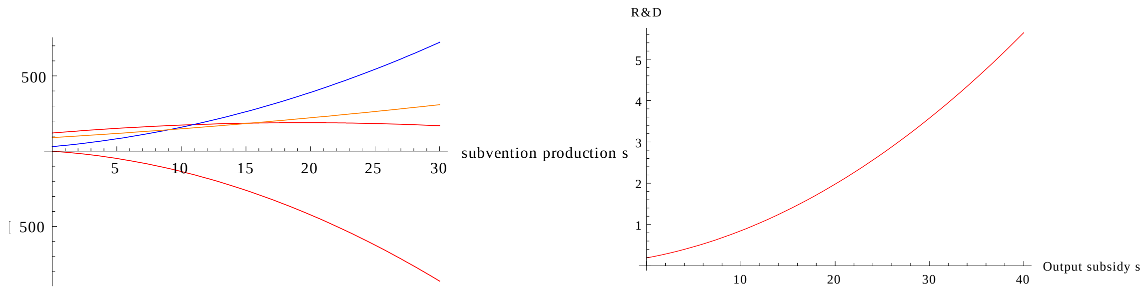
Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum. The right side shows the evolution of optimal R&D when the import tariff varies.

7.3. Cournot – Production Subsidy

Consider that the domestic government implements a production subsidy σ at the benefits of the domestic firm, the domestic firm's profit function becomes: $\Pi = p * x - c_i * x + s * x - r * v$. Equilibrium outputs are: $x = \frac{1}{3}(a - 2c_i + c_b + 2s), y = \frac{1}{3}(a + c_i - 2c_b - s)$. The domestic firm selects an R&D level: $r = (\frac{9}{4})^{\frac{1}{k-1}}(\frac{(c_h - c_b)k(a - c_h + 2s)}{v})^{\frac{1}{1-k}}$. R&D is increasing with the production subsidy and Graph 2 illustrates evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum when s varies. The domestic firm's profit is increasing with the tariff, consumers' surplus is increasing and public revenues are decreasing.

Graph 2. Evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum according to the production subsidy s – Cournot case



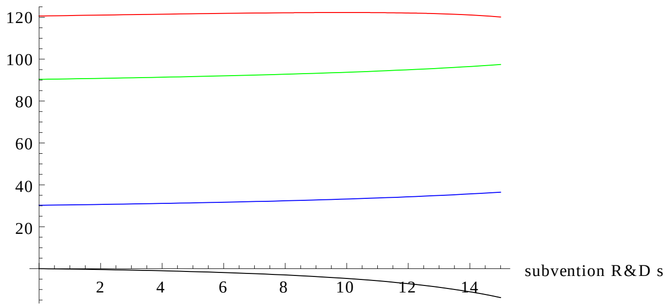
Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left-side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum. The right side shows the evolution of optimal R&D when the import tariff varies.

7.4. Cournot – R&D Subsidy

Consider that the domestic government implements an R&D subsidy σ at the benefits of the domestic firm, the domestic firm's profit function becomes: $\Pi = p * x - c_i * x - r * (v - \sigma)$. Equilibrium outputs are: $=\frac{1}{3}(a-2c_i+c_b), y=\frac{1}{3}(a+c_i-2c_b)$ – this is the free trade output levels-. The domestic firm selects an R&D level: $r=(\frac{9}{4})^{\frac{1}{k-1}}(\frac{(a-ch)(c_h-c_b)k}{v-\sigma})^{\frac{1}{1-k}}$. R&D is increasing with the production subsidy and Graph 2 illustrates evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum when s varies. The domestic firm's profit is increasing with the tariff, consumers' surplus is increasing and public revenues are decreasing.

Graph 3. Evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum according to the R&D subsidy s – Cournot case



Source : authors' calculation

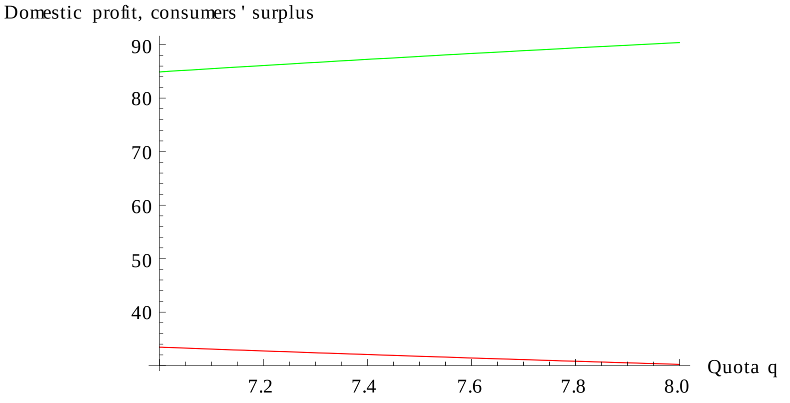
Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left-side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum.

7.5. Cournot – quota q and VER

Consider that the domestic government implements a quota q on imports, the domestic firm's profit function becomes: $\Pi=(a-q-x)x-cx-rv$ since we suppose that the quota is binding. Equilibrium outputs are: $x=\frac{1}{2}(a-c-q), y=q$.

Let us suppose that the quota is not very restrictive: $\frac{1}{3}(a+c_h-2c_b)>q>\frac{1}{3}(a-c_b)$. So the expected profit for the domestic firm is: $E(\Pi)=r^k*(\frac{1}{9}(a-c_b)^2)+(1-r^k)*(\frac{1}{4}(-a+c_h+q)^2)-r*v$. $r=36^{\frac{1}{k-1}}(\frac{k(5a-2c_b-3(c_h+q))(3(c_h+q)-a-2c_b+)}{v})^{\frac{1}{1-k}}$. Domestic R&D is increasing with quota: putting differently, when the quota gets more restrictive, the domestic firm makes less R&D. If we consider that a VER is a type of quota where the foreign firm gets a benefit from restricting its exports, then this is the case of a VER: R&D is decreased as compared to free trade under such agreement. The benefit for the foreign firm comes from less R&D in the North such that the best situation for this firm is more probable. Sur cette partie de courbe le surplus du consommateur est croissant avec le quota, alors que le profit espéré de la firme domestique est décroissant (voir figure 4).

Graph 4. Evolution of the domestic firm's profit and of consumers' surplus according to the level of quota q – the quota is relatively not restrictive

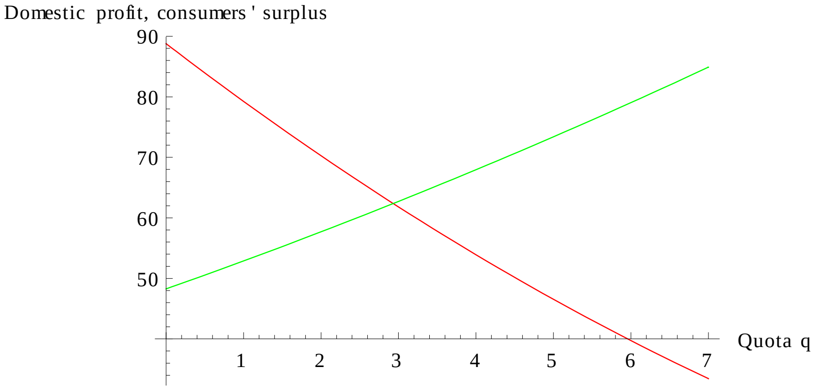


Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left-side the green curve corresponds to the domestic firm's profit, the red one to consumers' surplus.

Let us suppose that the quota is relatively restrictive: $q < \frac{1}{3}(a - c_b)$. So the expected profit for the domestic firm is: $E(\Pi) = \frac{1}{4}(a - cb - q)^2 r^k + \frac{1}{4}(a - ch - q)^2(1 - r^k) - rv$. $r = 4^{\frac{1}{k-1}}(\frac{(c_h - c_b)k(2a - c_b - c_h - 2q)}{v})^{\frac{1}{1-k}}$. Domestic R&D is decreasing with quota: putting differently, when the quota gets more restrictive, the domestic firm makes more R&D.

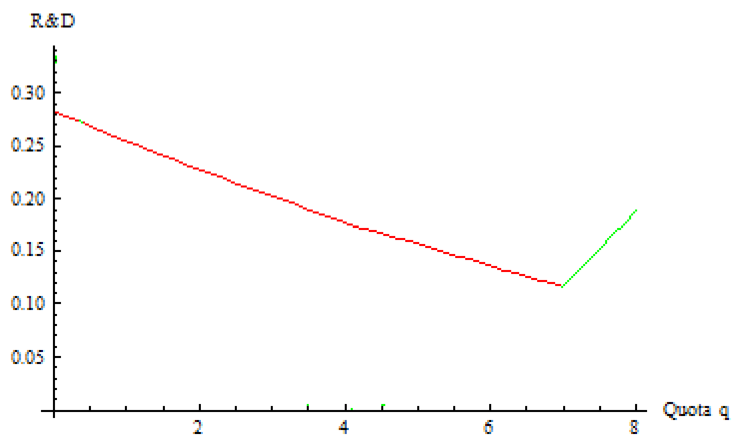
Graph 5. Evolution of the domestic firm's profit and of consumers' surplus according to the level of quota q – the quota is relatively not restrictive



Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left-side the green curve corresponds to the domestic firm's profit, the red one to consumers' surplus.

Graph 6. R&D investment according to quota q



Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5; the green part of the R&D curve corresponds to a quota which is relatively not restrictive while the red one corresponds to a quota which is relatively restrictive.

8. Annex - Bertrand

In this annex we present full Bertrand results under a linear demand function and a success probability as an iso-elastic function of R&D.

8.1. Bertrand - cadre général

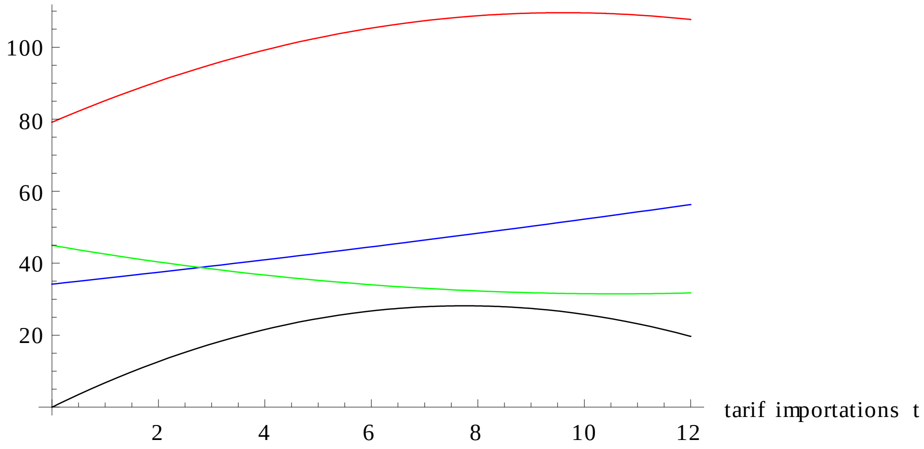
Suppose that both firms propose their products at prices p1 and p2 and that these products are slightly differentiated: $x = a - \mathrm{p1} + b * \mathrm{p2}$ and $y = a - \mathrm{p2} + b * \mathrm{p1}$ with $1 > b > 0$. We have: $a > \mathrm{c}_h > \mathrm{c}_b > 0$. Profits are: $\Pi = \mathrm{p1} * x - c * x - r * v$ for the domestic firm and $\Pi^* = \mathrm{p2} * y - \mathrm{cb} * y$ for the foreign firm. The Nash equilibrium is: $\forall i = b, h;\ p1 = \frac{2a+ab+2c+b\mathrm{cb}}{4-b^2}, p2 = \frac{2a+ab+bc+2\mathrm{cb}}{4-b^2}$. Therefore $p1 = \frac{2a+ab+(2+b)\mathrm{cb}}{4-b^2}, p2 = \frac{2a+ab+(b+2)\mathrm{cb}}{4-b^2}$ if R&D is successful while $p1 = \frac{2a+ab+2ch+b\mathrm{cb}}{4-b^2}, p2 = \frac{2a+ab+bch+2\mathrm{cb}}{4-b^2}$ if it is not. The probability of R&D success is still: $\alpha(r) = r^k$ avec : $0 < k < 1$. The domestic firm's expected profit is: $\mathrm{E}(\Pi) = r^k * \left(\frac{(a+(-1+b)\mathrm{cb})^2}{(-2+b)^2}\right) + (1 - r^k) * \left(\frac{(a(2+b)+b\mathrm{cb}+(-2+b^2)\mathrm{ch})^2}{(-4+b^2)^2}\right) - r * v$. Selecting the level of R&D that maximizes this expected profit leads to: $r = \left(\frac{(-2+b^2)(\mathrm{cb}-\mathrm{ch})((2+b)(2a+b\mathrm{cb})+b^2\mathrm{ch}-2(\mathrm{cb}+\mathrm{ch}))k}{(-4+b^2)^2 v}\right)^{\frac{1}{1-k}}$. The second-order condition is verified.

8.2. Bertrand – Tariff on imports

If the domestic government implements an import tariff the foreign firm's profit becomes: $\Pi^* = \mathrm{p2} * y - \mathrm{cb} * y - t * y$. Both firms' equilibrium prices are : $p1 = \frac{2a+ab+2c+b\mathrm{cb}+bt}{4-b^2}, p2 = \frac{2a+ab+bc+2\mathrm{cb}+2t}{4-b^2}$. The level of R&D selected by the domestic firm is:

$r = \left(\frac{(-2+b^2)(\mathrm{cb}-\mathrm{ch})k(2a(2+b)-2(\mathrm{cb}+\mathrm{ch})+b((2+b)\mathrm{cb}+b\mathrm{ch}+2t))}{(-4+b^2)^2 v}\right)^{\frac{1}{1-k}}$. R&D is increasing with the tariff t. Graph 1 illustrates evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum when *t* increases. The domestic firm's profit is increasing with the tariff, consumers' surplus is decreasing and public revenues are concave.

Graph 7. Evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum according to the import tariff t - Bertrand



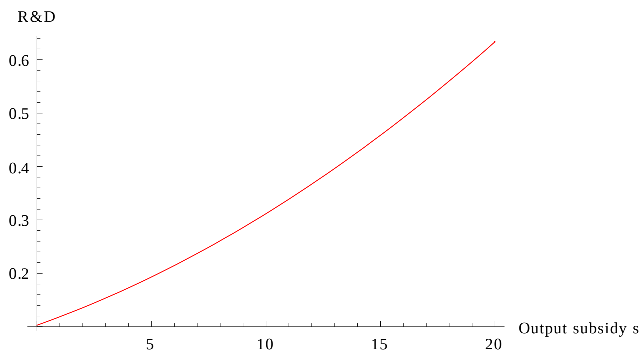
Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum. The right side shows the evolution of optimal R&D when the import tariff varies.

8.3. Bertrand – Production Subsidy

Consider that the domestic government implements a production subsidy s, the domestic firm's profit function becomes: $\Pi = \mathrm{p}1x - c\,x - rv + sx$. Both firms' equilibrium prices are: $p1 = \frac{2a+ab+2c+b\mathrm{cb}-2s}{4-b^2}, p2 = \frac{2a+ab+bc+2\mathrm{cb}-bs}{4-b^2}$. The level of R&D selected by the domestic firm is : $r = \left(\frac{(-2+b^2)(\mathrm{cb}-\mathrm{ch})k(2a(2+b)+(-2+b(2+b))\mathrm{cb}+(-2+b^2)(\mathrm{ch}-2s))}{(-4+b^2)^2 v}\right)^{\frac{1}{1-k}}$. R&D is increasing with the output subsidy s (see Figure ??). Figure illustrates how domestic firm's profit, consumers' surplus and public revenues are changed when the production subsidy s is changed. The domestic firm's profit is incerasing with s; consumers' surplus is increasing with s while public revenues are decreasing with s (the cost of the production subsidy is increasing with s).

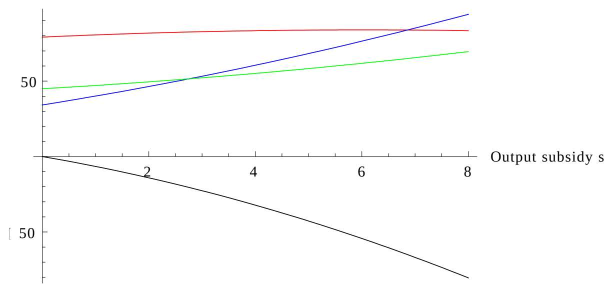
Graph 8. R&D investment according to production subsidy s – Bertrand case



Source: authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left-side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum. The right side shows the evolution of optimal R&D when the import tariff varies.

Graph 9. Evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum according to the production subsidy s – Bertrand case



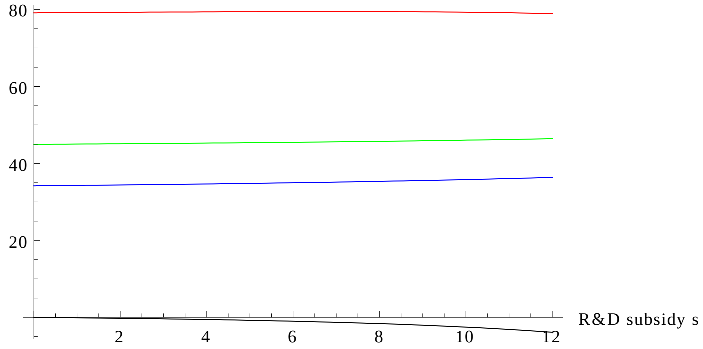
Source : authors' calculation

Note : Here we consider a=24 ; c_b=3 ; c_h=6 ; k=0,5 ; v=27,5 ; on the left-side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum. The right side shows the evolution of optimal R&D when the import tariff varies.

8.4. Bertrand – R&D Subsidy

Consider that the domestic government implements an R&D subsidy s, the domestic firm's profit becomes: $\Pi = \text{p}1x - cx - r(v - s)$. Both firms' equilibrium price are unchanged as compared to free trade. The level of R&D selected by the domestic firm is: $r = \left(\frac{(-2+b^2)(\text{cb}-\text{ch})((2+b)(2a+b\text{cb})+b^2\text{ch}-2(\text{cb}+\text{ch}))k}{(-4+b^2)^2(v-s)}\right)^{\frac{1}{1-k}}$. Investment in R&D is increasing with the R&D subsidy. As indicated from figure the domestic firm's expected profit and the domestic consumers' surplus are increasing with s while public revenues is decreasing.

Graph 10. Evolution of the domestic firm's profit, of consumers' surplus, of public revenues and of their un-weighted sum according to the R&D subsidy s – Bertrand case



Source : authors' calculation

Note : Here we consider a=24 ; cb=3 ; ch=6 ; k=0,5 ; v=27,5 ; on the left-side the black curve corresponds to public revenues, the blue one to the domestic firm's profit, the green one to consumers' surplus, and the red one to their un-weighted sum.