Vertical Differentiation, Uncertainty, Product R&D and Policy Instruments in a North-South Duopoly

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Abstract

This paper analyzes the impact of several trade policy instruments on product Research and Development (R&D) investment in a North-South duopoly. The Northern firm invests in product R&D owing to a competitive disadvantage compared to the Southern firm which benefits from a lower labor cost. But the outcome of R&D expenditures is uncertain. There is a probability that R&D expenditures are successful. In this case, there is vertical differentiation between the two firms. But R&D expenditures may be unsuccessful. This article studies the impact of policy instruments implemented by the Northern government: an import tariff, a production subsidy, an R&D subsidy, a standard of quality, a minimum-price and an import quota. The results show that the Northern firm's R&D expenditures increase with each policy instrument except for the import quota. The paper also provides a welfare analysis in order to verify whether or not the Northern government is encouraged to implement these policy instruments.

JEL Classifications: F13, O30

Keywords: Trade Policy Instruments; Product Research and Development; North-South Duopoly; Vertical Differentiation.

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1. Introduction

In the aftermath of the global economic crisis when many developed and developing countries still pain to recover completely, decision makers' attention is increasingly drawn to structural reforms needed to raise their countries' competitiveness as one of the main drivers of economic prosperity.[3] Determining and implementing the right policies for improving competitiveness is a challenging issue and has been for years, especially in high-income economies facing a growing competition from low-income ones. According to the 2014-2015 Global Competitiveness Report by Schwab (2014), economies which have successfully managed to stay the most competitive "*are able to develop … and constantly introduce new and higher value-added products and services into the market.*"[4] Not surprisingly, the majority of these economies have registered the highest research and development (R&D) expenditures as percentage of GDP (Source: World Bank WDI). Since process and/or product innovation is essential to economic growth, determining whether high-income countries' governments can continue to support their domestic firms' R&D activities becomes crucial. In light of the foregoing, the objective of this paper is to evaluate the impact of several trade policy instruments on R&D investment. We also examine the impact of these instruments on firms' profits, consumers' surplus and public revenues. We conclude our study by conducting a welfare analysis.

Product R&D influences features of finished goods such as quality. There is vertical differentiation. Mussa and Rosen (1978) design an important model with product R&D and product quality. They compare the levels of quality under two market structures: monopoly and competition. The main conclusion is that producers sell less quality goods under monopoly compared to competition. Such a result explains why the cost for consumers under monopoly increases with their taste for quality. Prices are also higher under monopoly. Shaked and Sutton (1982) also study the choice of quality under a theoretical model where firms set, first, the optimal level of quality, and then, the optimal level of price. Under duopoly, firms select different levels of quality, while they select the same level when the number of firms is greater than two.

The economic literature has already studied similar issues by focusing on cost-reducing/process R&D. Firms invest in both R&D product and R&D process empirically (Capon et al., 1992; Landau and Rosenberg, 1992). Studies show that firms invest in product R&D at the beginning of the lifecycle and invest in process R&D at the end (Utterback and Abernathy, 1975; Klepper, 1996). It explains why firms invest more in product R&D (Chenavaz, 2011). We, however, focus on product R&D, which is more important than process R&D in countries such as Germany, the United States and Japan according to empirical data (Fritsch and Meschede, 2001; Nagaoka and Walsh, 2009).[5] Product R&D is particularly higher than process R&D in high-tech industries like automobile or electricity (Scherer and Ross, 1990; Fritsch and Meschede; 2001; Park, 2001; Toshimitsu, 2003; Jinji and Toshimitsu, 2013). Nevertheless, there are relatively few studies related to our analysis (Park, 2001; Zhou et al., 2002; Jinji, 2003; Jinji and Toshimitsu, 2006; Jinji and Toshimitsu, 2013; Ishii, 2014). These authors develop theoretical models of international trade with vertically differentiated products. The main

[3] Competitiveness (in international trade) may be defined as a measure of a country's advantage or disadvantage in selling its products on international markets (Source: OECD).
[4] The most competitive countries are: Switzerland, Singapore, the United States, Finland, Germany, Japan, Hong Kong, the Netherlands, the United Kingdom and Sweden.
[5] Fritsch and Meschede (2001) note that product R&D accounts for 61 percent of all R&D expenditures for German firms. Nagaoka and Walsh (2009) show that process innovations accounted for only 25 percent and 17 percent of all R&D projects in the US and Japan respectively.

objective is identifying optimal strategic product R&D policies. The economic literature also studies the case of vertical differentiation under an asymmetric framework between a high-tech firm from a rich country and a low-tech firm from a developing country (Das and Donnenfeld, 1989; Park, 2001; Zhou, Spencer and Vertinsky, 2002; Moraga-Gonzalez and Viaene, 2005; Ishii, 2014).

Park (2001) designs a duopoly with a high-tech firm and a low-tech firm. They compete in a Bertrand or Cournot fashion on a third market. They produce vertically differentiated products, whose quality is determined endogenously through product R&D investments.[6] The main result of the paper is that the governments' incentives targeting their domestic firms' R&D activities depend on the nature of market competition. Under Bertrand competition, the optimal strategic policy is to tax (respectively subsidize) the high-tech's (respectively low tech's) firm product R&D. Results are reversed in case of Cournot competition. Furthermore, the author discusses briefly the case when different instruments are combined to serve the high-tech firm's government strategic policy. A combination of an export subsidy and a R&D tax is demonstrated to be optimal. The model of Zhou, Spencer and Vertinsky (2002) is very similar to Park (2001) in its framework and results by regarding unilateral optimal strategic product R&D policies. They extend the analysis by examining the governments' incentives when there is policy coordination between the two countries. The authors find that when firms compete in prices, the jointly optimal policy is to subsidize (tax) product R&D activities of the high-quality (low-quality) producing firm. Under Cournot competition on the other hand, the optimal policy is to implement a R&D tax in both countries. Nevertheless, empirical examples of R&D taxes are really scarce (Audretsch and Yamawaki, 1988; Gabriele, 2002; Impullitti, 2010).

While both of these papers' analysis applies to competition between firms with large asymmetries in R&D costs, as it is the case for firms from developed and developing countries, Jinji (2003) studies strategic product R&D policy choices in a third-market trade model where domestic and foreign firms are identical, facing same product R&D costs. In his vertically differentiated duopoly framework, the author shows that governments' optimal strategies involve different subsidy/tax schedules which depend on the competition mode. This result is qualitatively similar to Park (2001) and Zhou et al. (2002) except for the high-quality exporter's identity which is undetermined. Either firm can produce and export the high-quality good, so that their respective government will choose to tax or subsidize their product R&D investment accordingly. Meanwhile, Jinji and Toshimitsu (2006) study strategic product R&D policies when firms have asymmetric R&D costs. Their analysis differs from Park (2001) and Zhou et al. (2002) since a small technology gap between firms is assumed. The quality ordering is endogenously determined. The firm with superior technology produces the high-quality good while its competitor produces the low-quality one. This is achieved by implementing a firm-specific subsidy schedule that depends on the nature of market competition. Jinji and Toshimitsu (2013) extend previous studies by including a third exporting firm/country in their model. Firms export their entire production to a fourth country. They have different R&D capabilities, but their R&D cost functions are identical as long as their products qualities are below their R&D capabilities. Contrary to earlier studies, authors find that the optimal strategic R&D policy is influenced by the nature of market competition only in the case of the high-quality exporter. The governments of the middle and low-quality exporter would respectively tax and subsidize their domestic firm's R&D under both price and

[6] Park (2001) assumes that the difference in terms of product R&D costs between firms is large enough so that firms with lower quality improvement costs (high-tech firms) produce and export higher-quality goods compared to low-tech competitors.

quantity competition. If firms coordinate, the joint optimal R&D policies differ depending on the countries' coordination pairs and competition mode. Finally, Ishii (2014) develops a theoretical third-country trade model of price competition with less stringent demand and cost functions. As opposed to his predecessor, Ishii (2014) finds that the optimal R&D policy does not necessarily depend only on the competition mode, given that in certain situations, both governments' optimal policy involves a product R&D subsidy even when firms compete in a Bertrand fashion.

Contrary to the above mentioned studies, which focus primarily on determining the optimal strategic product R&D policies, we explore the impact of a wider panel of trade policy instruments on product R&D investment and welfare. These instruments are: an import tariff, a production subsidy, a R&D subsidy, a minimum quality standard, a minimum-price and an import quota. We focus on "behind-the-border" policies such as subsidies and "at-the-border" policies such as import tariffs and quotas. Currently, governments use "behind-the-border" policies more frequently for three reasons: (i) they are a means to give domestic firms an advantage over foreign firms; (ii) they escape the notice of the World Trade Organization (WTO) which is more effective in prohibiting instruments representing a direct barrier against international trade flows; (iii) according to the WTO, import tariffs are bound and cannot be increased above a certain level. Evenett (2013) describes the rise in trade policy instruments as the *"protectionism's quiet return"* and mentions that *"non-traditional forms of protections still dominate crisis-era protectionism* [p. 28]*."* Traditional forms such as tariffs only represent less than 40 percent of the protectionism measures implemented since 2008. Nevertheless, using the example of the automobile industry in 2014, European Union's ad-valorem import tariff on Indian and Russian's exports equals to 10 percent (Source: MacMap HS6). Furthermore, developed countries still implement import quotas in the automobile industry. The number of quantitative restrictions in force on automobile vehicles imports in 2015 is 18 in Australia, 6 in Canada, 4 in the European Union, 12 in Japan, 8 in New-Zealand and 7 in Switzerland (Source: WTO). Such high levels may legitimize the fact that we study the impact of an import tariff and of an import quota.

Our model designs a North-South duopoly where firms with asymmetric production costs compete in prices on both markets. We assume that the Northern country's government is the only one policy active. The Northern firm bears higher production costs and has an incentive to invest in product R&D. The outcome of this investment is uncertain. If successful, the Northern firm produces a higher-quality version of the same good compared to its Southern competitor. If the Northern firms' R&D outcome is unsuccessful, then no quality improvement is implemented and the goods are horizontally differentiated due to their different cost structure. Our modeling of product R&D uncertainty is based on Bouët (2001). We believe it yields more realistic results, which is one of the contributions of our paper to the existing literature. Our model involves a three-stage game where first, the Northern firm's government selects the optimal instrument level by anticipating the Northern firm's product R&D investment and price levels. Second, the Northern firm decides on product R&D expenditures that maximize its expected profit. In the final stage, firms set their levels of price. Our framework relates to the automobile industry where Northern firms invest in product R&D in order to face a growing competition from Southern firms that benefit from lower production costs.

The main finding of our analysis is that each policy instrument increases the Northern firm's R&D expenditure except for the import quota. Therefore, a government whose only aim is to enhance non-price competitiveness by encouraging product R&D investments should implement one of these policy instruments. Nevertheless, the latter may have opposite effects on the expected consumer surplus, public revenues and welfare. We illustrate this result through numerical simulations.

The rest of this paper is organized as follows. Section 2 describes the theoretical model. Section 3 presents an example under linear demand functions. Section 4 analyzes the impact of six different policy instruments on the Northern firms' R&D investment. Section 5 conducts a welfare analysis and compares the efficiency of the policy instruments. Section 6 concludes.

2. General Framework

We develop a theoretical model of international trade with product innovations in a North-South duopoly with a firm from a Northern country and another from a Southern country. Each firm sells one share of its output domestically and exports the other share to the foreign market. The Southern firm has a cheaper labor force compared to its competitor. Assuming that the Northern firm is located in a developed country, while its Southern trade partner is from an emerging country, considering that the latter has lower labor costs is not unrealistic. The Northern firm has, therefore, an incentive to invest in Research and Development (R&D) and vertically differentiate its product since the Southern firm benefits from a competitive advantage.

Such a framework relates to an empirical example, for instance the automobile industry. Firms export their finished good to foreign markets. The North-South duopoly works because Northern automobile firms face the competition of Southern automobile firms. A significant example is Tata, an Indian firm which sells on its domestic market and exports to Northern markets. The firm operates *"in over 175 markets"* and has *"over 6,600 sales and service touch points* [Source: Tata 69th Annual Report 2013-2014, p. 16].*"* The European Union represents an important market. Maruti Suzuki is another good example. The competition of Southern automobile firms is growing owing to lower production costs compared to Northern firms. The Indian market symmetrically represents a great opportunity for Northern automobile firms like Renault and Honda. For example, Renault sold 43,384 vehicles between January and April 2015 (Source: The Economic Times). It also launched a new car model called "Kwid" for the Indian market on September 2015. Furthermore, the automobile industry is a good example because firms invest in product R&D. As we said previously, the economic literature shows that firms invest more in product R&D than in process R&D for high-tech industries (Scherer and Ross, 1990; Fritsch and Meschede; 2001; Park, 2001; Toshimitsu, 2003; Jinji and Toshimitsu, 2013). R&D expenditures are generally higher for Northern firms compared to Southern firms. It explains why the quality of Northern automobile firms' vehicles is generally higher compared to Southern automobile firms'. But a limit of our model is that we consider a simple case where the Southern firm does not invest in R&D at all.

In our model, the outcome of the Northern firm's R&D investment is uncertain. If successful, two different quality-levels of the same commodity variety are on markets. Goods produced by both firms are similar in quality, otherwise. Consider a probability of R&D success.

Assumption 1: There is a Bertrand competition on each market. Firms select the optimal levels of price.

We denote as p_n (p_s) the price set by the Northern firm on the Northern (Southern) market and x_n (x_s) the Northern firm's domestic sales (exports). We also denote as p_n^* (p_s^*) the Southern firm's price on the Northern (Southern) market and y_n (y_s) the Southern firm's exports (domestic sales). We use the superscript d to denote the case of a successful R&D (i.e. with vertical differentiation) and the superscript h, otherwise. For example, p_n^d (p_n^h) denotes the Northern firm's price when the R&D outcome is successful (unsuccessful).

Assumption 2: In case of an unsuccessful R&D investment, each firm produces a similar quality good. But we introduce horizontal differentiation in order to avoid a Bertrand paradox. Demand functions are: $x_i^h = x_i^h(p_i^h, p_i^{*h})$, $y_i^h = y_i^h(p_i^h, p_i^{*h})$, for each market i such as $i = n, s$. Domestic sales and exports decrease (increase) with the domestic (foreign) firm's price: $\partial x_i^h/\partial p_i^h < 0$, $\partial x_i^h/\partial p_i^{*h} > 0$, $\partial y_i^h/\partial p_i^h > 0$, $\partial y_i^h/\partial p_i^{*h} < 0$. Own effects are stronger than crossed effects: $|\partial x_i^h/\partial p_i^h| > \partial x_i^h/\partial p_i^{*h}$, $\partial y_i^h/\partial p_i^h < |\partial y_i^h/\partial p_i^{*h}|$.

Assumption 3: In case of a successful R&D investment, firms produce vertically differentiated goods. Each country's consumer has a preference for quality denoted by θ that increases with the degree of differentiation of the good produced by the domestic firm, denoted by ϕ: $\theta = \theta(\phi)$. Demand for a given good depends therefore on its price, the foreign firm's product price, the degree of differentiation and the preference for quality displayed by the consumer: $x_i^d = x_i^d[p_i^d, p_i^{*d}, \theta(\phi)]$, $y_i^d = y_i^d[p_i^d, p_i^{*d}, \theta(\phi)]$, with $i = n, s$. The demand for the Northern (Southern) firm's finite good increases (decreases) with the degree of differentiation: $\partial x_i^d[p_i^d, p_i^{*d}, \theta(\phi)]/\partial\phi > 0$, $\partial y_i^d[p_i^d, p_i^{*d}, \theta(\phi)]/\partial\phi < 0$.

Assumption 4: The probability of R&D success is denoted by α with $0 < \alpha < 1$. The probability that the R&D investment fails is therefore $(1 - \alpha)$. The probability of success depends on the R&D investment level denoted by r: $\alpha = \alpha(r)$. It increases with the R&D level: $\alpha'(r) > 0$. Nevertheless, the returns are decreasing: $\alpha''(r) \leq 0$.

This assumption is really important since it influences a broad set of our results, in particular the impact of any policy instrument on the Northern firm's R&D.

Assumption 5: The total cost of the Northern firm's R&D investment is vr, where v denotes the unit cost of the R&D investment. Whatever the R&D investment outcome, the Northern firm faces such a cost.

When no trade policy instruments are implemented, our model involves a two-stage game. First, the Northern firm selects the level of R&D investment that maximizes its expected profit by anticipating the levels of price. Second, each firm sets the levels of price that maximize its profit. The equilibrium solution is obtained by backward induction from the second stage of price competition. We analyze separately the case where the R&D outcome is unsuccessful and subsequently where it is successful.

2.1. Unsuccessful R&D

First consider the case where the R&D is unsuccessful. Let us assume that firms produce slightly horizontally differentiated goods to avoid a Bertrand paradox. We denote as C^h and C^{*h} the total production costs of the Northern and Southern firm respectively, that depend on the firm's output:

$C^h = C^h(x_n^h, x_s^h)$, $C^{*h} = C^{*h}(y_n^h, y_s^h)$. Note that transport costs are integrated in the total production costs.

Assumption 6: Each firm's total production cost increases with its level of output. Then, marginal costs are positive: $\partial C^h(x_n^h, x_s^h)/\partial x^h > 0$, $\partial C^{*h}(y_n^h, y_s^h)/\partial y^h > 0$.

We denote by Π^h (Π^{*h}) the Northern (Southern) firm's profit:

$$\Pi^h = p_n^h x_n^h(p_n^h, p_n^{*h}) + p_s^h x_s^h(p_s^h, p_s^{*h}) - C^h[x_n^h(p_n^h, p_n^{*h}), x_s^h(p_s^h, p_s^{*h})] - vr \quad (1)$$

$$\Pi^{*h} = p_n^{*h} y_n^h(p_n^h, p_n^{*h}) + p_s^{*h} y_s^h(p_s^h, p_s^{*h}) - C^{*h}[y_n^h(p_n^h, p_n^{*h}), y_s^h(p_s^h, p_s^{*h})] \quad (2)$$

Each firm selects the optimal level of price that maximizes its profit. First Order Conditions involve the following reaction functions: $p_i^h(p_i^{*h}) = C_{x_i}^h - x_i^h/x_{i_{p_i}}^h$, $p_i^{*h}(p_i^h) = C_{y_i}^{*h} - y_i^h/y_{i_{p_i^*}}^h$, for each market i such as $i = n, s$.[7]

Assumption 7: Own effects are negative to satisfy Second Order Conditions on each market: $\Pi_{p_i p_i}^h < 0, \Pi_{p_i^* p_i^*}^{*h} < 0$.However, cross effects are positive: $\Pi_{p_i p_i^*}^h > 0, \Pi_{p_i^* p_i}^{*h} > 0$. Own effects are stronger than cross effects: $|\Pi_{p_i p_i}^h| > \Pi_{p_i p_i^*}^h$, $|\Pi_{p_i^* p_i^*}^{*h}| > \Pi_{p_i^* p_i}^{*h}$.

The stability condition is verified on each market: $B_i^h = \Pi_{p_i p_i}^h \Pi_{p_i^* p_i^*}^{*h} - \Pi_{p_i p_i^*}^h \Pi_{p_i^* p_i}^{*h} > 0$.

We denote by $\widehat{\Pi}^h$ and $\widehat{\Pi}^{*h}$ the maximum profits such as firms set optimal prices $\hat{p}_n^h$, $\hat{p}_n^{*h}$, $\hat{p}_s^h$ and $\hat{p}_s^{*h}$: $\widehat{\Pi}^h = \Pi^h(\hat{p}_n^h, \hat{p}_s^h)$, $\widehat{\Pi}^{*h} = \Pi^{*h}(\hat{p}_n^{*h}, \hat{p}_s^{*h})$.

2.2. Successful R&D

Consider now the case of a successful R&D investment. Goods are vertically differentiated.

Assumption 8: The Northern firm's total production cost denoted by C^d now depends on the degree of vertical differentiation: $C^d = C^d\{x_n^d[p_n^d, p_n^{*d}, \theta(\phi)], x_s^d[p_s^d, p_s^{*d}, \theta(\phi)], \phi\}$. Producing a high quality good is costly: $\partial C^d/\partial\phi > 0$. The marginal cost also increases with the degree of vertical differentiation: $\partial^2 C^d/(\partial x_i^d \partial\phi) > 0$.

The economic literature considers that quality improvement influences variable costs or fixed costs (Maskus et al., 2013; Cheng, 2014). Here we consider an endogenous variable cost for the Northern firm.

We denote by Π^d (Π^{*d}) the Northern (Southern) firm's profit with a successful R&D i.e. with vertical differentiation.

Assumption 9: The Northern firm is encouraged to differentiate its product with respect to the product of its competitor. The Northern firm's profit increases with the degree of differentiation: $\mathrm{d}\Pi^d/\mathrm{d}\phi > 0$. The profit is stronger in case of a successful R&D: $\Pi^d > \Pi^h$. The Northern firm would not be encouraged to invest in R&D, otherwise. We also consider that the marginal profit is stronger when the R&D is successful: $p_i^d - C_{x_i}^d > p_i^h - C_{x_i}^h$.

[7] Subscripts denote partial derivatives.

We have:

$$\Pi^{d} = p_n^d x_n^d[p_n^d, p_n^{*d}, \theta(\phi)] + p_s^d x_s^d[p_s^d, p_s^{*d}, \theta(\phi)] - C^d\{x_n^d[p_n^d, p_n^{*d}, \theta(\phi)], x_s^d[p_s^d, p_s^{*d}, \theta(\phi)], \phi\} - vr \quad (3)$$

$$\Pi^{*d} = p_n^{*d} y_n^d[p_n^d, p_n^{*d}, \theta(\phi)] + p_s^{*d} y_s^d[p_s^d, p_s^{*d}, \theta(\phi)] - C^{*d}\{y_n^d[p_n^d, p_n^{*d}, \theta(\phi)], y_s^d[p_s^h, p_s^{*d}, \theta(\phi)]\} \quad (4)$$

Each firm sets the optimal level of price. First Order Conditions involve the following reaction functions: $p_i^d(p_i^{*d}) = C_{x_i}^d - x_i^d / x_{i_{p_i}}^d, p_i^{*d}(p_i^d) = C_{y_i}^{*d} - y_i^d / y_{i_{p_i^*}}^d$, for each market i such as $i = n, s$.

Assumption 10: Own effects are negative and cross effects are positive on each market: $\Pi_{p_i p_i}^d < 0, \Pi_{p_i^* p_i^*}^{*d} < 0, \Pi_{p_i p_i^*}^d > 0, \Pi_{p_i^* p_i}^{*d} > 0$. Own effects are stronger than cross effects: $\left|\Pi_{p_i p_i}^d\right| > \Pi_{p_i p_i^*}^d, \left|\Pi_{p_i^* p_i^*}^{*d}\right| > \Pi_{p_i^* p_i}^{*d}$.

The stability condition is verified on each market: $B_i^d = \Pi_{p_i p_i}^d \Pi_{p_i^* p_i^*}^{*d} - \Pi_{p_i p_i^*}^d \Pi_{p_i^* p_i}^{*d} > 0$.

We denote by $\widehat{\Pi}^d$ and $\widehat{\Pi}^{*d}$ the maximum profits such as firms set optimal prices $\hat{p}_n^d$, $\hat{p}_n^{*d}$, $\hat{p}_s^d$ and $\hat{p}_s^{*d}$: $\widehat{\Pi}^d = \Pi^d(\hat{p}_n^d, \hat{p}_s^d), \widehat{\Pi}^{*d} = \Pi^{*d}(\hat{p}_n^{*d}, \hat{p}_s^{*d})$.

2.3. Choice of R&D Investment

Let us call $E[.]$ the expectation operator with respect to the R&D outcome. We denote by π (π^*) the Northern (Southern) firm's profit, fixed and R&D costs excluded: $\pi = \Pi + F + vr, \pi^* = \Pi^* + F^*$, where F and F^* denote fixed costs. We also use the superscripts d and h for the two cases. The Northern firm's expected profit is:

$$E[\Pi(r)] = \alpha(r)\hat{\pi}^d + [1 - \alpha(r)]\hat{\pi}^h - F - vr \quad (5)$$

The Northern firm selects the optimal R&D investment level that maximizes such an expected profit. From the First Order Condition, we have:

$$\alpha'(r) = v / (\hat{\pi}^d - \hat{\pi}^h) \quad (6)$$

A simple interpretation of the previous equation stems from rewriting the Northern firm's R&D investment as a function of the difference in profit $(\hat{\pi}^d - \hat{\pi}^h)$ and of the R&D unit cost v: $r = \psi[v, (\hat{\pi}^d - \hat{\pi}^h)]$, with $\partial\psi / \partial(\hat{\pi}^d - \hat{\pi}^h) > 0, \partial\psi / \partial v < 0$. Therefore, we can study the impact of policy instruments on the R&D investment by analyzing its impact on the difference in profit.

3. A Linear Example

Let us use now linear examples for demand functions and total cost functions to have an easier demonstration. First consider the following function of consumers' preference for quality on each market:

$$\theta(\phi) = \phi\eta \quad (7)$$

The parameter η denotes the sensitivity of the preference for quality with respect to the degree of differentiation, with $0 < \eta \leq 1$. Demands now depend on $\phi\eta$. For each market i, we set the following demand functions:

$$x_i = \begin{cases} x_i^h\left(p_i^h, p_i^{*h}\right) = a_i - b_i p_i^h + p_i^{*h}, \text{ if } \phi = 0 \\ x_i^d\left(p_i^d, p_i^{*d}, \phi\eta\right) = a_i(1+\phi\eta) - b_i(1-\phi\eta)p_i^d + (1+\phi\eta)p_i^{*d}, \text{otherwise.} \end{cases} \quad (8)$$

$$y_i = \begin{cases} y_i^h\left(p_i^h, p_i^{*h}\right) = a_i + p_i^h - b_i p_i^{*h}, \text{if } \phi = 0 \\ y_i^d\left(p_i^d, p_i^{*d}, \phi\eta\right) = a_i(1-\phi\eta) + (1-\phi\eta)p_i^d - b_i(1+\phi\eta)p_i^{*d}, \text{otherwise.} \end{cases} \quad (9)$$

The following condition is necessary: $b_i > (1+\phi\eta)/(1-\phi\eta)$. Note that in previous studies, authors first set a utility function to infer demand functions (Sutton, 1997; Symeonidis, 2003). Our methodology is reversed. We first set demand functions. The expression of consumers' surplus is then given by integrating the demand functions. The consumers' surplus increases with $\phi\eta$ (Mussa and Rosen, 1978).

We use linear functions for production costs:

$$C = \begin{cases} C^h = c^h\left(x_n^h + x_s^h\right) + g x_s^h + F, \text{ if } \phi = 0 \\ C^d = c^d(\phi)\left(x_n^d + x_s^d\right) + g x_s^d + F, \text{ otherwise.} \end{cases} \quad (10)$$

$$C^* = \begin{cases} C^{*h} = c^*\left(y_n^h + y_s^h\right) + g^* y_n^h + F^*, \text{ if } \phi = 0 \\ C^{*d} = c^*\left(y_n^d + y_s^d\right) + g^* y_n^d + F^*, \text{ otherwise.} \end{cases} \quad (11)$$

The term c^d denotes the Northern firm's marginal cost that depends on the degree of differentiation ϕ, in case of a successful R&D. We have: $c^d > c^h$, with c^h the Northern firm's constant marginal cost in case of an unsuccessful R&D. The term c^* denotes the Southern firm's constant marginal cost that does not depend on the R&D outcome. The terms g and g^* denote constant unit transport costs.

Each firm selects the optimal levels of prices that maximize its profit. Under a successful R&D, we have:

$$\hat{p}_n^d = \frac{a_n(2b_n+1)+2b_n^2c^d(\phi)+b_n(c^*+g^*)+\phi\eta\left[a_n(2b_n-1)-2b_n^2c^d(\phi)+b_n(c^*+g^*)\right]}{(4b_n^2-1)(1-\phi\eta)} \quad (12)$$

$$\hat{p}_n^{*d} = \frac{a_n(2b_n+1)+b_nc^d(\phi)+2b_n^2(c^*+g^*)-\phi\eta\left[a_n(2b_n-1)+b_nc^d(\phi)-2b_n^2(c^*+g^*)\right]}{(4b_n^2-1)(1+\phi\eta)} \quad (13)$$

$$\hat{p}_s^d = \frac{a_s(2b_s+1)+2b_s^2\left[c^d(\phi)+g\right]+b_sc^*+\phi\eta\left[a_s(2b_s-1)-2b_s^2\left(c^d(\phi)+g\right)+b_sc^*\right]}{(4b_s^2-1)(1-\phi\eta)} \quad (14)$$

$$\hat{p}_s^{*d} = \frac{a_s(2b_s+1)+b_s\left[c^d(\phi)+g\right]+2b_s^2c^*-\phi\eta\left[a_s(2b_s-1)+b_s\left(c^d(\phi)+g\right)+2b_s^2c^*\right]}{(4b_s^2-1)(1+\phi\eta)} \quad (15)$$

The Northern (Southern) firm's prices increase (decrease) with the degree of differentiation. When two goods are vertically differentiated, the higher quality good is more expensive. The difference in price between the two goods increases with the degree of differentiation.

The levels of domestic sales and exports for each firm are:

$$\hat{x}_n^d = \frac{b_n\left\{a_n(2b_n+1)-(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)+\phi\eta\left[a_n(2b_n-1)+(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)\right]\right\}}{(4b_n^2-1)} \quad (16)$$

$$\hat{y}_n^d = \frac{b_n\left\{a_n(2b_n+1)+b_nc^d(\phi)-(2b_n^2-1)(c^*+g^*)-\phi\eta\left[a_n(2b_n-1)+b_nc^d(\phi)+(2b_n^2-1)(c^*+g^*)\right]\right\}}{(4b_n^2-1)} \quad (17)$$

$$\hat{x}_s^d = \frac{b_s\{a_s(2b_s+1)-(2b_s^2-1)[c^d(\phi)+g]+b_sc^*+\phi\eta[a_s(2b_s-1)+(2b_s^2-1)(c^d(\phi)+g)+b_sc^*]\}}{(4b_s^2-1)} \quad (18)$$

$$\hat{y}_s^d = \frac{b_s\{a_s(2b_s+1)+b_s[c^d(\phi)+g]-(2b_s^2-1)c^*-\phi\eta[a_s(2b_s-1)+b_s(c^d(\phi)+g)+(2b_s^2-1)c^*]\}}{(4b_s^2-1)} \quad (19)$$

The Northern (Southern) firm's domestic sales and exports increase (decrease) with the degree of differentiation. The Northern firm's market share increases on both markets as compared to the situation without vertical differentiation.

Finally, consider that each firm's profit equals to the sum of the profit earned on the domestic market and the profit earned on the foreign market: $\hat{\pi}^d = \hat{\pi}_n^d + \hat{\pi}_s^d; \hat{\pi}^{*d} = \hat{\pi}_n^{*d} + \hat{\pi}_s^{*d}$.We have:

$$\hat{\pi}_n^d = \frac{b_n\{a_n(2b_n+1)-(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)+\phi\eta[a_n(2b_n-1)+(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)]\}^2}{(4b_n^2-1)^2(1-\phi\eta)} \quad (20)$$

$$\hat{\pi}_s^d = \frac{b_s\{a_s(2b_s+1)-(2b_s^2-1)[c^d(\phi)+g]+b_sc^*+\phi\eta[a_s(2b_s-1)+(2b_s^2-1)(c^d(\phi)+g)+b_sc^*]\}^2}{(4b_s^2-1)^2(1-\phi\eta)} \quad (21)$$

$$\hat{\pi}_n^{*d} = \frac{b_n\{a_n(2b_n+1)+b_nc^d(\phi)-(2b_n^2-1)(c^*+g^*)-\phi\eta[a_n(2b_n-1)+b_nc^d(\phi)+(2b_n^2-1)(c^*+g^*)]\}^2}{(4b_n^2-1)^2(1+\phi\eta)} \quad (22)$$

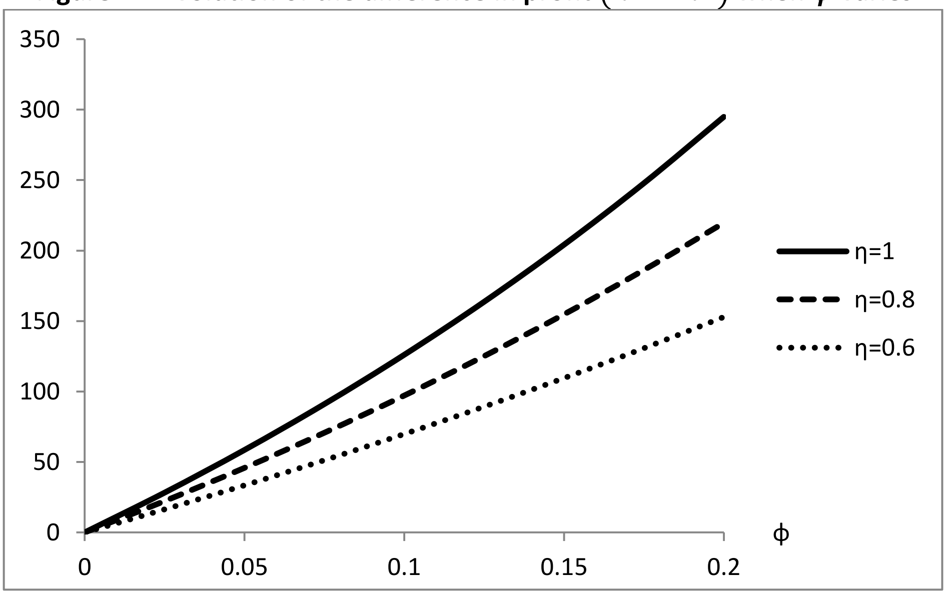
$$\hat{\pi}_s^{*d} = \frac{b_s\{a_s(2b_s+1)+b_s[c^d(\phi)+g]-(2b_s^2-1)c^*-\phi\eta[a_s(2b_s-1)+b_s(c^d(\phi)+g)+(2b_s^2-1)c^*]\}^2}{(4b_s^2-1)(1+\phi\eta)} \quad (23)$$

The Northern (Southern) firm's profit increases (decreases) with the degree of differentiation. Therefore, the difference in profit $(\hat{\pi}^d - \hat{\pi}^h)$ is positive.

Under an unsuccessful R&D, we can find equilibrium expressions of prices, outputs and profits by setting $\phi = 0$ and $c^d(\phi) = c^h$.

Figure 1 illustrates a positive impact of the degree of differentiation on the difference in profit.

Figure 1 – Evolution of the difference in profit $(\hat{\pi}^d - \hat{\pi}^h)$ when ϕ varies



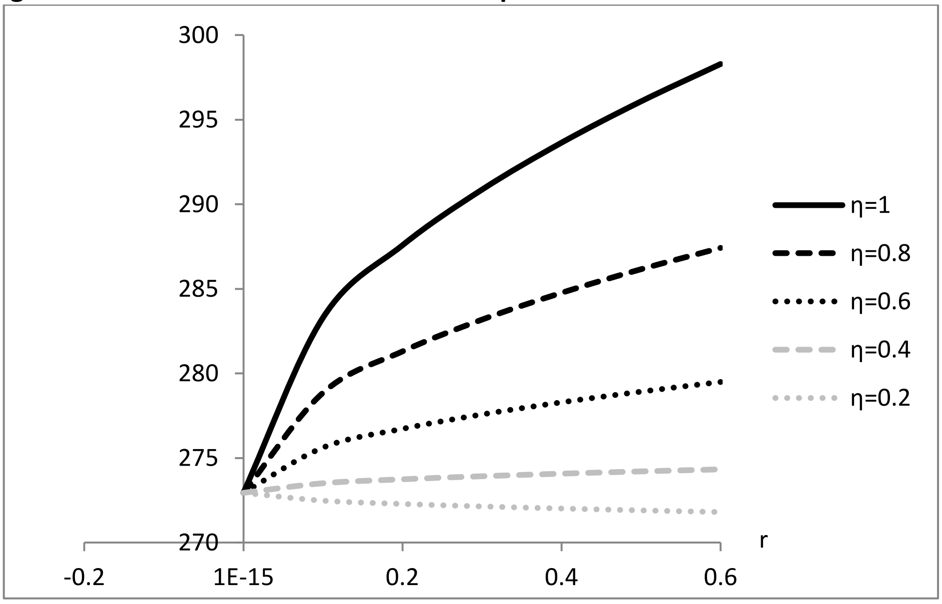
Source: authors.
Note: We set: $c^d(\phi) = c^h + \phi, a_n = 40, a_s = 30, b_n = b_s = 2, c^h = 6, c^* = 3, g = g^* = 1, F = F^* = 0$.

The Northern firm selects the optimal level of R&D investment that maximizes its expected profit by taking into account the previous results. We know now the expressions of $\hat{\pi}^d$and $\hat{\pi}^h$. We use the following function for the probability of R&D success:

$$\alpha(r) = r^k, \text{ with } 0 < k < 1 \tag{24}$$

Previously, we proved that the Northern firm is encouraged to invest in R&D because the difference in profit increases with the degree of differentiation. Let us study now the impact on the consumers' surplus. As illustrated in figure 2, the impact is negative for a low sensitivity η of consumers' preference for quality improvement (for example if $\eta = 0.2$). The lower η, the lower the consumers' preference for quality. Since vertical differentiation increases the Northern firm's price, the effect on the consumers' surplus is then negative. The impact is positive, otherwise.

Figure 2 – Evolution of the consumers' surplus when the R&D investment varies

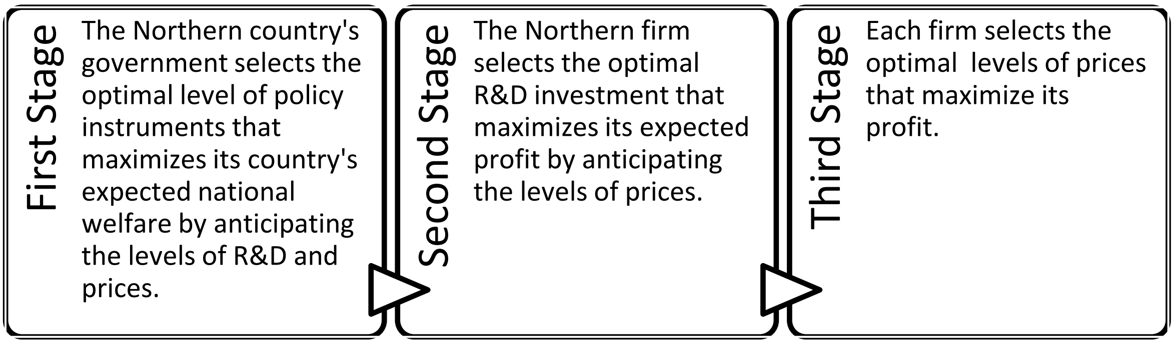


Source: authors.
Note: We set: $c^d(\phi) = c^h + \phi,\ a_n = 40, a_s = 30, b_n = b_s = 2, c^h = 6, c^* = 3, g = g^* = 1, \phi = 0.2, F = F^* = 0.$

4. Policy Instruments

Let us study the impact of six policy instruments: an import tariff, a production subsidy, an R&D subsidy, a quality standard, a minimum-price and an import quota. The Northern country's government may justify the implementation of these instruments by the increasing competition from an emerging country firm that benefits from a competitive advantage. Policy instruments aim to enhance the Northern firm's non-price competitiveness by increasing the probability of a successful R&D outcome and to increase the Northern country's national welfare. The structure of the model is the following.

Figure 3 –Structure of the model



Source: authors.

The Northern country's government implements trade policy instruments that maximize the expected national welfare. The expression of the national welfare is:

$$E(\mathrm{W}) = E(\Pi) + E(\mathrm{CS}) + E(\mathrm{PR}) \tag{25}$$

The term W denotes the Northern country's national welfare; CS denotes the Northern country's consumers' surplus; and PR denotes the governmental surplus i.e. public revenues. First, we look for the equilibrium price levels. We then evaluate the impact of each policy instrument on the R&D investment.

4.1. An Import Tariff

Consider that the Northern country's government implements an import tariff. We denote as t the specific tariff on the Southern firm's exports. The Southern firm's profit earned on the Northern market changes as compared to free trade:

$$\pi_n^* = \begin{cases} \pi_n^{*h} = p_n^{*h} y_n^h\left(p_n^h, p_n^{*h}\right) - (c^* + g^* + t) y_n^h\left(p_n^h, p_n^{*h}\right), \text{ if } \phi = 0 \\ \pi_n^{*d} = p_n^{*d} y_n^d\left(p_n^d, p_n^{*d}, \phi\eta\right) - (c^* + g^* + t) y_n^d\left(p_n^d, p_n^{*d}, \phi\eta\right), \text{ otherwise.} \end{cases} \tag{26}$$

The tariff is a further marginal cost for the Southern firm, its economic impact is the same as that of an increase of g^*. As a result, price levels on the Northern market increase. The tariff also increases the Northern firm's domestic sales and profit, while it impacts negatively on the Southern firm's exports and profit.[8] Total sales on the Northern market decrease, therefore the implementation of an import tariff has a direct negative impact on the Northern country's consumer surplus. These results hold no matter the outcome of the R&D investment.

The Northern firm selects the optimal level of R&D that maximizes its expected profit by taking into account the previous results.

Proposition 1: Under the specific functions, the Northern firm's R&D investment increases with its domestic government's import tariff as compared to free trade.

[8] We note that there is no impact whatsoever on the Northern (Southern) firm's foreign (domestic) sales and prices. An increase (decrease) of the Northern (Southern) firm's profit is therefore due to an increase (decrease) of the profit earned on its domestic (foreign) market.

Proof: Let us study the impact of the tariff on the difference in profit $[\hat{\pi}_n^d(\phi,\eta,t)-\hat{\pi}_n^h(t)]$[9]. To simplify the expressions, we set: $\hat{\pi}_n^d=\hat{\pi}_n^d(\phi,\eta,t)$. We have:

$$\frac{\mathrm{d}^2\hat{\pi}_n^d}{\mathrm{d}t\mathrm{d}\phi}=\frac{b_n^{3/2}\hat{\pi}_n^{d^{1/2}}\left\{2\eta+\left[\left(\mathrm{d}\hat{\pi}_n^d/\mathrm{d}\phi\right)\hat{\pi}_n^{d^{-1}}+\eta(1-\phi\eta)^{-1}\right](1+\phi\eta)\right\}}{\left(4b_n^2-1\right)(1-\phi\eta)^{1/2}}>0$$

The previous expression is positive because, from Assumption 9, we have: $\mathrm{d}\hat{\pi}_n^d/\mathrm{d}\phi>0$. The other terms are positive. Therefore, the vertical differentiation increases the positive impact of the tariff on the Northern firm's profit earned on its domestic market. It can be deduced then, that the difference in profit increases with the tariff as compared to free trade. The Northern firm's R&D expenditure also increases. The tariff leads to a gain for the Northern firm such as the latter is encouraged to invest more to benefit from a stronger gain. This can be explained by the intensity of competition from the Southern firm. Since the tariff reduces imports from the low-cost firm, the Northern firm is encouraged to increase its R&D investment in order to increase the probability of vertical differentiation and further reduce imports from its competitor. As a result, the cost of the tariff on the Southern firm's profit earned on the Northern market is bigger in case of a successful R&D, because the effect is all the more negative on its market share.

Nevertheless, we cannot demonstrate that these results hold under general forms for demand functions. The effect of the tariff on the difference in profit is always positive under any other linear form for demand functions. But under nonlinear forms, the results are unknown. See Appendix A.

4.2. A Production Subsidy

Consider now that the Northern country's government decides to subsidize the Northern firm's output (its domestic sales and exports). We denote as s the specific production subsidy. The Northern firm's profit expressions change compared to free trade:

$$\pi_n=\begin{cases}\pi_n^h=p_n^h x_n^h\left(p_n^h,p_n^{*h}\right)-\left(c^h-s\right)x_n^h\left(p_n^h,p_n^{*h}\right), \text{ if } \phi=0\\ \pi_n^d=p_n^d x_n^d\left(p_n^d,p_n^{*d},\phi\eta\right)-\left[c^d(\phi)-s\right]x_n^d\left(p_n^d,p_n^{*d},\phi\eta\right), \text{ otherwise.}\end{cases} \tag{27}$$

$$\pi_s=\begin{cases}\pi_s^h=p_s^h x_s^h\left(p_s^h,p_s^{*h}\right)-\left(c^h+g-s\right)x_s^h\left(p_s^h,p_s^{*h}\right), \text{ if } \phi=0\\ \pi_s^d=p_s^d x_s^d\left(p_s^d,p_s^{*d},\phi\eta\right)-\left[c^d(\phi)+g-s\right]x_s^d\left(p_s^d,p_s^{*d},\phi\eta\right), \text{ otherwise.}\end{cases} \tag{28}$$

In contrast to the specific tariff, the implementation of a production subsidy has repercussions on both the Northern and Southern markets. Its economic impact is the same as that of a decrease of the marginal cost for the Northern firm. This results in a drop in prices on both markets. While, the impact of the subsidy on the Northern firm's output and profit is positive, its Southern competitor's domestic sales, exports and profit levels decrease. Nevertheless, the overall sales on the Northern and Southern markets both increase. There is a direct positive impact on the Northern consumer surplus.

Proposition 2: The Northern firm's R&D investment either increases or decreases with its domestic government's production subsidy. Nevertheless, by using numerical simulations, we only find cases where the effect is positive.

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[9] Since a specific tariff has no impact on $\hat{\pi}_s^d$ and $\hat{\pi}_s^h$, an increase (or decrease) of the difference in profit $\hat{\pi}^d-\hat{\pi}^h$ is due to an increase (or decrease) of $\hat{\pi}_n^d-\hat{\pi}_n^h$.

Proof: Setting $\hat{\pi}_i^d = \hat{\pi}_i^d(\phi, \eta, s)$ to simplify expressions, we have:

$$\frac{\mathrm{d}^2\hat{\pi}_i^d}{\mathrm{d}s\mathrm{d}\phi} = \frac{b_i^{3/2}(2b_i^2-1)\hat{\pi}_i^{d^{1/2}}\left[(1-\phi\eta)\left(d\hat{\pi}_i^d/d\phi\right)\hat{\pi}_i^{d^{-1}}-\eta\right]}{(4b_i^2-1)(1-\phi\eta)^{1/2}}, \text{ with } i = n, s$$

The sign of the term in brackets is undetermined; therefore, the impact of the subsidy on the difference in profit is uncertain. The expression above would be positive if the following condition were verified: $(1-\phi\eta)\left(d\hat{\pi}_i^d/d\phi\right) > \eta\hat{\pi}_i^d$. The economic explanation behind this inconclusive mathematical result is related to the decrease of price levels following the implementation of the production subsidy by the Northern country's government. While both markets experience a fall in prices, the magnitude of the effect is greater for the Northern firm, owing to a direct impact of the subsidy. As a consequence, the Northern firm is less encouraged to increase its R&D investment since the difference in price-competitiveness between the two firms is lower. Nevertheless, taking numerical values for parameters, we always find a positive impact of the production subsidy on the difference in profit. The Northern firm is generally encouraged to increase its R&D investment because the revenues of the subsidy increase with the level of output. Such a level increases with the vertical differentiation. The effect of the production subsidy on the R&D investment is positive because the output effect is stronger than the price effect.

4.3. An R&D Subsidy

Consider now the case where the Northern country's government subsidizes its domestic firm's R&D investment instead of its production. We denote as σ such a specific subsidy that reduces the total cost of R&D. The Northern firm's expected profit changes compared to free trade:

$$E[\Pi(r,\sigma)] = \alpha(r)\hat{\pi}^d + [1-\alpha(r)]\hat{\pi}^h - (v-\sigma)r \qquad (29)$$

The optimal R&D investment is now:

$$r(\sigma) = \left[\frac{k(\hat{\pi}^d - \hat{\pi}^h)}{v-\sigma}\right]^{\frac{1}{1-k}} \qquad (30)$$

The R&D subsidy does not directly influence prices and outputs. But there is an indirect impact by influencing the Northern firm's R&D expenditures and the probability of R&D success.

Proposition 3: The Northern firm's R&D investment increases with its government's R&D subsidy as compared to the initial situation without subsidy.

Proof: The subsidy σ reduces the denominator of $r(\sigma)$. Then, the R&D investment increases with the R&D subsidy: $\mathrm{d}r(\sigma)/\mathrm{d}\sigma > 0$. The Northern firm is encouraged to increase its R&D investment because the total cost of R&D is lower.

4.4. A Quality Standard

The Northern country's government can decide to implement a quality standard on the domestic market if the R&D investment is successful. In this case, the introduction of a quality standard gives the Northern firm a monopoly power, since its competitor produces a lower quality good and does not meet the standard. Then, the demand for the Northern firm's product no longer depends on the Southern firm's price.

We set $y_n^d = 0$ in order to express p_n^{*d} as a function of p_n^d. We deduce the following demand function for the Northern firm's product sold on its domestic market:

$$x_n^s(p_n^s, \phi\eta) = \{a_n[b_n(1+\phi\eta) + 1 - \phi\eta] - (b_n^2 - 1)(1-\phi\eta)p_n^s\}/b \tag{31}$$

The superscript s denotes the situation where a quality standard is implemented i.e. monopoly for the Northern firm on its domestic market if the R&D is successful. The demand functions for the Northern firm's export product and the Southern firm's domestic product are unchanged.

The equilibrium is the same as under the initial situation of an unsuccessful R&D investment. We have:

$$\pi_n = \begin{cases} \pi^h = p^h x^h(p^h, p^{*h}) - c^h x^h(p^h, p^{*h}), \text{ if } \phi = 0 \\ \pi_n^s = p_n^s x_n^s(p_n^s, \phi\eta) - c^d(\phi) x_n^s(p_n^s, \phi\eta), \text{ otherwise.} \end{cases} \tag{32}$$

With the quality standard, the Northern firm's price on its domestic market is:

$$\hat{p}_n^s(\phi, \eta) = \frac{a_n(b_n+1) + (b_n^2-1)c^d(\phi) + \phi\eta[a_n(b_n-1) - (b_n^2-1)c^d(\phi)]}{2(b_n^2-1)(1-\phi\eta)} \tag{33}$$

Since there is no longer competition from the Southern firm, the Northern firm's price on its domestic market increases as compared to free trade in case of a successful R&D investment. The monopoly situation relates to a case where the Southern firm sets a price level approaching infinity.[10] According to the reaction functions under the initial case with no quality standard, the Northern firm's domestic price increases with the Southern firm's foreign price: $\mathrm{d}p_n^d/\mathrm{d}p_n^{*d} = (1+\phi\eta)/[2b_n(1-\phi\eta)] > 0$. This result entails that the Northern firm's domestic price is higher compared to the initial situation.

The Northern firm's domestic sales are:

$$\hat{x}_n^s(\phi, \eta) = \frac{a_n(b_n+1) - (b_n^2-1)c^d(\phi) + \phi\eta[a_n(b_n-1) + (b_n^2-1)c^d(\phi)]}{2b_n} \tag{34}$$

The Northern firm's domestic sales also increase when a quality standard is implemented. By the same reasoning as above we have: $\mathrm{d}x_n^d/\mathrm{d}p_n^{*d} = x_{p^d}^d\, \mathrm{d}p^d/\mathrm{d}p^{*d} + x_{p^{*d}}^d = (1+\phi\eta)/2 > 0$. However, total sales on the Northern market decrease because the Southern firm leaves the market and the domestic price increases.

Finally, the Northern firm's profit earned on its domestic market equals to:

$$\hat{\pi}_n^s(\phi, \eta) = \frac{a_n(b_n+1) - (b_n^2-1)c^d(\phi) + \phi\eta[a(b_n-1) + (b_n^2-1)c^d(\phi)]}{4b_n(b_n^2-1)(1-\phi\eta)} \tag{35}$$

Given the monopoly situation, the Northern firm's optimal level of profit is greater as compared to free trade, since the maximization process does not involve taking into account any constraints

[10] It refers to the Southern firm's price on the Northern market.

regarding its rival firm. Moreover, the Northern firm sets a higher price and its marginal profit increases. Its output level is also stronger.

We now look for the impact of the quality standard on the Northern firm's R&D investment. The equilibrium level of R&D is given by:

$$r = \left[\frac{k(\hat{\pi}_n^s - \hat{\pi}_n^h)}{v}\right]^{\frac{1}{1-k}} \tag{36}$$

Proposition 4: The Northern firm's R&D investment increases with the quality standard.

Proof: The quality standard only increases the Northern firm's profit if the R&D is successful. With an unsuccessful R&D, such a profit is the same as under the initial situation. Then, the difference in profit increases as compared to free trade: $(\hat{\pi}^s - \hat{\pi}^h) > (\hat{\pi}^d - \hat{\pi}^h)$. The Northern firm is encouraged to increase its R&D investment in order to increase the probability of R&D success and, then, to benefit from the monopoly given the implementation of the quality standard.

4.5. A Minimum-Price

The quality standard relates to a prohibitive quota in case of a successful R&D. The Northern country's government can also implement price restrictions. Consider a minimum-price such as the Southern firm cannot sell its product on the Northern market with a lower price. We denote by p_{min} the minimum-price for the Southern firm. The Northern country's government can select two levels of minimum-price:

- A relatively binding minimum-price such as: $p_n^{*d} < p_{min} \leq p_n^{*h}$. The minimum-price has only an economic impact if the R&D is successful. The effect is null when the R&D is unsuccessful.
- A very binding minimum-price such as: $p_{min} > p_n^{*h}$. The minimum-price has an impact whatever the R&D outcome.

Note that there is a third case where the minimum-price is not binding: $p_{min} \leq p_n^{*d}$. We do not study this case because the effect of the minimum-price would be null. Only the Northern firm selects the optimal level of price that maximizes its profit. Under a successful R&D, we have:

$$\hat{p}_n(\phi, \eta, p_{min}) = \frac{a_n + b_n c^d(\phi) + p_{min} + \phi\eta[a_n - b_n c^d(\phi) + p_{min}]}{2b_n(1-\phi\eta)} \tag{37}$$

The Northern firm's domestic sales and Southern firm's exports are respectively:

$$\hat{x}_n(\phi, \eta, p_{min}) = \frac{a_n - b_n c^d(\phi) + p_{min} + \phi\eta[a_n + b_n c^d(\phi) + p_{min}]}{2} \tag{38}$$

$$\hat{y}_n(\phi, \eta, p_{min}) = \frac{a_n(2b_n+1) + b_n c^d(\phi) - p_{min}(2b_n^2-1) - \phi\eta[a_n(2b_n-1) + b_n c^d(\phi) + p_{min}(2b_n^2-1)]}{2b_n} \tag{39}$$

The Northern firm's domestic price increases as compared to free trade because prices are strategic complements under Bertrand competition. Meanwhile, the Southern firm's export sales decrease with the minimum-price because its level is higher compared to a free trade situation. Conversely, the effect on the Northern firm's output is positive even if its price also increases. The minimum-price increases the Northern firm's market share.

Equilibrium profits are:

$$\hat{\pi}_n^d(\phi,\eta,p_{min}) = \frac{\{a_n - b_n c^d(\phi) + p_{min} + \phi\eta[a_n + b_n c^d(\phi) + p_{min}]\}^2}{4b_n(1-\phi\eta)} \quad (40)$$

$$\hat{\pi}_n^{*d}(\phi,\eta,p_{min}) = \frac{\{a_n(2b_n+1) + b_n c^d(\phi) - p_{min}(2b_n^2-1) - \phi\eta[a_n(2b_n-1) + b_n c^d(\phi) + p_{min}(2b_n^2-1)]\}(p_{min}-c^*)}{2b_n} \quad (41)$$

The Northern firm's profit increases with the minimum-price. The impact is also positive in case of an unsuccessful R&D. However, the instrument reduces the Southern firm's profit earned on the Northern market, because the Southern firm cannot maximize its profit anymore.

Proposition 5: The Northern firm's R&D investment increases with both a relatively and a very binding minimum-price.

Proof: We consider two cases:

- First let us study the impact of the relatively binding minimum-price. In case of an unsuccessful R&D investment, the Northern firm's profit is the same as under free trade. This profit increases as compared to free trade with a successful R&D. Then, the difference in profit increases with the relatively binding minimum-price.
- Now let us study the impact of the very binding minimum-price. The Northern firm's profit increases as compared to free trade whatever the R&D outcome. Since a relatively binding quota increases the difference in profit, we can derivate the Northern firm's profit with respect to the minimum-price and to the degree of differentiation. Setting $\hat{\pi}_n^d = \hat{\pi}_n^d(\phi,\eta,p_{min})$ to simplify expressions, we have:
  $$\frac{\mathrm{d}^2\hat{\pi}_n^d}{\mathrm{d}p_{min}\mathrm{d}\phi} = \frac{{\hat{\pi}_n^d}^{1/2}\left\{2\eta + (1+\phi\eta)(\mathrm{d}\hat{\pi}_n^d/\mathrm{d}\phi){\hat{\pi}_n^d}^{-1} + \eta(1+\phi\eta)(1-\phi\eta)^{-1}\right\}}{[4b_n(1-\phi\eta)]^{1/2}} > 0$$
  The positive impact of the minimum-price increases with the degree of differentiation. Then, the difference in profit also increases with the very binding minimum-price.

Therefore, the Northern firm's R&D investment increases with the minimum-price as compared to free trade. The impact is positive with both the relatively and very binding minimum-price.

4.6. An Import Quota

Let us study the impact of an import quota implemented by the Northern government. We have analyzed the impact of a quality standard that relates to a prohibitive quota when the R&D is successful. But governments can also implement traditional quotas. Consider a binding quota denoted by q that corresponds to the maximum level of exports for the Southern firm. Studying the impact of a quota under Bertrand competition is complex owing to demand functions that depend on each level of price. Under free trade, when the R&D is successful, we can express the Southern firm's price of exports as a function of the Northern firm's price of domestic sales and of the Southern firm's exports: $p_n^{*d} = \left[\left(a_n + p_n^d\right)(1-\phi\eta) - y_n^d\right]/[b_n(1+\phi\eta)]$. Then, with a binding quota, we have:

$$p_n^{*d}\left(p_n^d,\phi\eta,q\right) = [(a_n + p_n^*)(1-\phi\eta) - q]/[b_n(1+\phi\eta)] \quad (42)$$

Such an expression relates to the Southern firm's best-response to the Northern firm's price of domestic sales (Krishna, 1989). It also depends on the level of the quota, since the quota is binding. Then, the Southern firm no longer maximizes its profit with respect to its price of exports. It only reacts to the levels of p_n^d and q.

Integrating the expression of p_n^{*d} in x_n^d, we have:

$$x_n^d(p_n^d, \phi\eta, q) = \{a_n[b_n(1+\phi\eta) + 1 - \phi\eta] - (1-\phi\eta)(b_n^2 - 1)p_n^d - q\}/b_n \quad (43)$$

The demand for the Northern firm's good on the Northern market no longer depends on the level of the Southern firm's price of exports because such a price is a response to the Northern firm's price of domestic sales and to the level of the quota.

The profit expressions on the Northern market are:

$$\pi_n = \begin{cases} \pi_n^h = p_n^h x_n^h(p_n^h, q) - c^h x_n^h(p_n^h, q), \text{if } \phi = 0 \\ \pi_n^d = p_n^d x_n^d(p_n^d, \phi\eta, q) - c^d(\phi) x_n^d(p_n^d, \phi\eta, q), \text{otherwise.} \end{cases} \quad (44)$$

$$\pi_n^* = \begin{cases} \pi_n^{*h} = q p_n^{*h}(p_n^h, q) - (c^* + g^*)q, \text{if } \phi = 0 \\ \pi_n^{*d} = q p_n^d(p_n^d, \phi\eta, q) - (c^* + g^*)q, \text{otherwise.} \end{cases} \quad (45)$$

The quota does not influence the outcome on the Southern market. On the Northern market, the Northern firm selects the optimal price of domestic sales:

$$\hat{p}_n^d(\phi, \eta, q) = \frac{a_n(b_n+1) + c^d(\phi)(b_n^2-1) - q + \phi\eta[a_n(b_n-1) - c^d(\phi)(b_n^2-1)]}{2(b_n^2-1)(1-\phi\eta)} \quad (46)$$

The Northern firm's price of domestic sales increases with a binding quota as compared to free trade owing to the drop in the competition from the Southern country.

The Southern firm's best-response is:

$$\hat{p}_n^{*d}(\phi, \eta, q) = \frac{a_n(2b_n^2+b_n-1) - q(2b_n^2-1) - \phi\eta[a_n(2b_n^2-b_n-1) + c^d(\phi)(b_n^2-1)]}{2b_n(b_n^2-1)(1+\phi\eta)} \quad (47)$$

The Southern firm's price of exports also increases with a binding quota as compared to free trade.

The Northern firm's domestic sales equal to:

$$\hat{x}_n^d(\phi, \eta, q) = \frac{a_n(b_n+1) - c^d(\phi)(b_n^2-1) - q + \phi\eta[a_n(b_n-1) + c^d(\phi)(b_n^2-1)]}{2b_n} \quad (48)$$

The Northern firm's domestic sales increase with a binding quota as compared to free trade.

Finally, the equilibrium profit expressions on the Northern market are:

$$\hat{\pi}_n^d(\phi, \eta, q) = \frac{\{a_n(b_n+1) - c^d(\phi)(b_n^2-1) - q + \phi\eta[a_n(b_n-1) + c^d(\phi)(b_n^2-1)]\}^2}{4b_n(b_n^2-1)(1-\phi\eta)} \quad (49)$$

$$\hat{\pi}_n^{*d}(\phi, \eta, q) = \frac{q\{a_n(2b_n^2+b_n-1) - 2b_n(b_n^2-1)(c^*+g^*) - q(2b_n^2-1) - \phi\eta[a_n(2b_n^2-b_n-1) + c^d(\phi)(b_n^2-1) + 2b_n(b_n^2-1)(c^*+g^*)]\}}{2b_n(b_n^2-1)(1+\phi\eta)} \quad (50)$$

The Northern firm's profit increases with a binding quota as compared to free trade. The Southern firm's profit decreases because it no longer sets the optimal level of price that maximizes its profit. It only sets the best-response to q and p_n^d.

As under Cournot competition, we consider two cases: a relatively binding quota and a very binding quota.

- First case: $\hat{y}_n^d(\phi,\eta) \leq q < \hat{y}_n^h$. The quota is relatively binding because it only reduces the Southern firm's exports when the R&D is unsuccessful. The Northern firm's profit only increases as compared to free trade under this case: $\hat{\pi}_n^h(q) > \hat{\pi}_n^h, \hat{\pi}_n^d(q) = \hat{\pi}_n^d$.
- Second case: $q < \hat{y}_n^d(\phi,\eta)$. The quota is very binding because it reduces the Southern firm's exports under both cases. Then, the Northern firm's profit increases as compared to free trade regardless of the outcome of R&D: $\hat{\pi}_n^h(q) > \hat{\pi}_n^h, \hat{\pi}_n^d(q) > \hat{\pi}_n^d$.

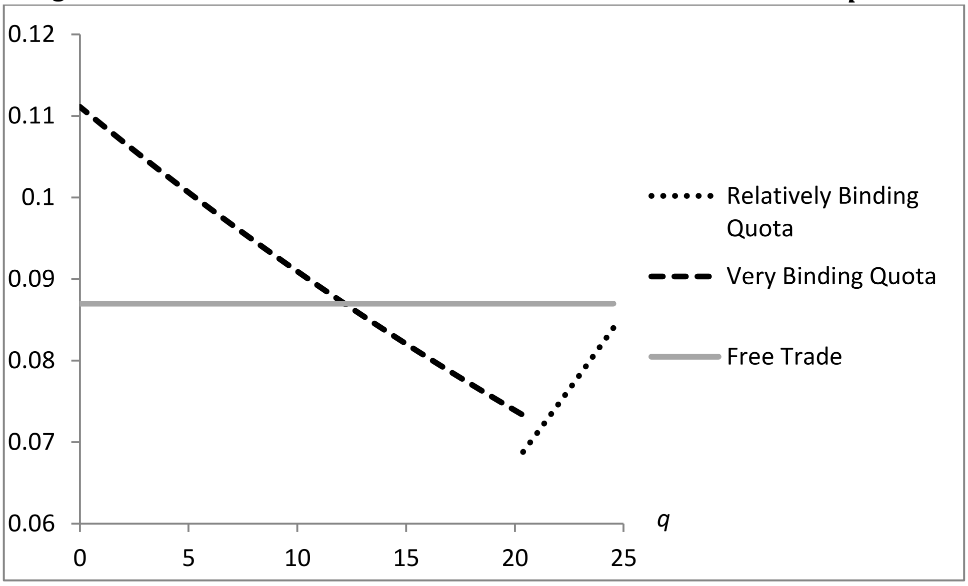
Proposition 6: The Northern firm's R&D investment decreases with a relatively binding quota and either increases or decreases with a very binding quota as compared to free trade.

Proof: Let us consider the two cases:

- With a relatively binding quota, the quota is only binding when the R&D is unsuccessful. The Northern firm's profit only increases under this case. Then, the difference in profit decreases as compared to free trade: $\hat{\pi}_n^d(\phi,\eta,q) - \hat{\pi}_n^h(q) < \hat{\pi}_n^d(\phi,\eta) - \hat{\pi}_n^h$.
- With a very binding quota, the quota is binding under both cases. The Northern firm's profit increases regardless of the outcome of R&D. We have:
  $$\frac{\mathrm{d}\hat{\pi}_n^d(\phi,\eta,q)}{\mathrm{d}q} = -\frac{2\hat{x}_n^d(\phi,\eta,q)}{2(b_n^2-1)(1-\phi\eta)} < 0$$
  The positive effect of a drop in q on π equals to $2\hat{x}_n^d(\phi,\eta,q)/[2(b_n^2-1)(1-\phi\eta)]$. Such an expression increases with ϕ because $\mathrm{d}\hat{x}_n^d(\phi,\eta,q)/\mathrm{d}\phi > 0$. The positive effect of the quota on the Northern firm's profit is greater when the R&D is successful. Then, the difference in profit increases when the level of the quota decreases. But, since a relatively binding quota reduces the R&D, such a result is not sufficient to prove that the difference in profit always increases as compared to free trade. We denote as $\overline{q}$ the quota such as the difference in profit equals to the free trade level. The difference in profit decreases with a very binding quota q such as $q \in (\overline{q}, \hat{y}_n^d)$ if $0 < \overline{q} < \hat{y}_n^d$. The difference in profit always decreases with a very binding quota if $\overline{q} = 0$. It always increases, otherwise.

Then, the Northern firm's R&D investment decreases with a relatively binding quota, and either increases or decreases with a very binding quota. Let us use a numerical example. Figure 4 illustrates the evolution of the Northern firm's R&D Investment when the level of the quota varies. The grey line illustrates the free trade level. Here, we find $\overline{q} \approx 12.1738$, with $0 < \overline{q} < \hat{y}_n^d$. Then, under such a numerical example, the R&D investment decreases with a very binding quota as compared to free trade if $q \in (\overline{q}, \hat{y}_n^d)$. It levels off if $q = \overline{q}$. It increases if $q \in [0, \overline{q})$.

Figure 4 – Evolution of the Northern firm's R&D Investment When q Varies



Source: authors.

Note: $c^d(\phi) = c^h + \phi, \alpha(r) = r^k, a_n = 40, a_s = 30, b_n = b_s = 2, c^h = 6, c^* = 3, g = g^* = 1, \phi = 0.2, \eta = 1, v = 500, k = 0.5, F = F^* = 0$.

5. Welfare Analysis

We have examined the impact of six policy instruments on the Northern firm's R&D investment. Let us study the economic impact of each instrument by analyzing their impact on expected profits, consumers' surplus and public revenues.

5.1. General Framework under Free Trade

Each expected variable depends on the equilibrium expression of the R&D investment $\hat{r}$.

Expected profits are:

$$E\left[\widehat{\Pi}(\hat{r})\right] = \alpha(\hat{r})\hat{\pi}^d + [1 - \alpha(\hat{r})]\hat{\pi}^h - vr, \; E\left[\widehat{\Pi}^*(\hat{r})\right] = \alpha(\hat{r})\hat{\pi}^{*d} + [1 - \alpha(\hat{r})]\hat{\pi}^{*h} \tag{51}$$

Let us study each country's expected consumers' surplus. We need to express the domestic (foreign) price as a function of the domestic (foreign) sales by turning the domestic (foreign) demand function and considering the foreign (domestic) price as a parameter. We have:

$$E\left[\widehat{\mathrm{CS}}(\hat{r})\right] = \alpha(\hat{r})\left[\int_0^{\hat{x}_n^d} p_n^d(x_n^d)\mathrm{d}x_n^d - p_n^d(\hat{x}_n^d)\hat{x}_n^d + \int_0^{\hat{y}_n^d} p_n^{*d}(y_n^d)\mathrm{d}y_n^d - p_n^{*d}(\hat{y}_n^d)\hat{y}_n^d\right] + [1 - \alpha(\hat{r})]\left[\int_0^{\hat{x}_n^h} p_n^h(x_n^h)\mathrm{d}x_n^h - p_n^h(\hat{x}_n^h)\hat{x}_n^h + \int_0^{\hat{y}_n^h} p_n^{*h}(y_n^h)\mathrm{d}y_n^h - p_n^{*h}(\hat{y}_n^h)\hat{y}_n^h\right] \tag{52}$$

$$E\left[\widehat{\mathrm{CS}}^*(\hat{r})\right] = \alpha(\hat{r})\left[\int_0^{\hat{x}_s^d} p_s^d(x_s^d)\mathrm{d}x_s^d - p_s^d(\hat{x}_s^d)\hat{x}_s^d + \int_0^{\hat{y}_s^d} p_s^{*d}(y_s^d)\mathrm{d}y_s^d - p_s^{*d}(\hat{y}_s^d)\hat{y}_s^d\right] + [1 - \alpha(\hat{r})]\left[\int_0^{\hat{x}_s^h} p_s^h(x_s^h)\mathrm{d}x_s^h - p_s^h(\hat{x}_s^h)\hat{x}_s^h + \int_0^{\hat{y}_s^h} p_s^{*h}(y_s^h)\mathrm{d}y_s^h - p_s^{*h}(\hat{y}_s^h)\hat{y}_s^h\right] \tag{53}$$

Under free trade, the Northern country's expected national welfare equals the sum of its expected profit and domestic consumers' surplus: $E\left[\widehat{\mathrm{W}}(\hat{r})\right] = E\left[\widehat{\Pi}(\hat{r})\right] + E\left[\widehat{\mathrm{CS}}(\hat{r})\right]$. Same goes for the Southern country's expected welfare: $E\left[\widehat{\mathrm{W}}^*(\hat{r})\right] = E\left[\widehat{\Pi}^*(\hat{r})\right] + E\left[\widehat{\mathrm{CS}}^*(\hat{r})\right]$.

5.2. Discussion

Table 1 illustrates the economic impact of each policy instrument. We also study the impact on the Northern country's expected public revenues.[11]

Table 1 – Economic Impact of Each Policy Instrument

Instrument	r	$E(\Pi)$	$E(\Pi^*)$	$E(\mathrm{CS})$	$E(\mathrm{CS}^*)$	$E(\mathrm{PR})$
Import Tariff	+	+	−	+/−	+/−	+
Production Subsidy	+	+	−	+	+/−	−
R&D Subsidy	+	+	−	+	+/−	−
Quality Standard	+	+	−	+/−	+/−	0
Minimum-Price	+	+	−	+/−	+/−	0
Import Quota	+/−	+/−	+/−	+/−	+/−	0

Source: authors.

Each policy instrument increases the Northern firm's R&D expenditures except for the import quota. A government that aims to enhance non-price competitiveness by encouraging product R&D investments should implement one of these policy instruments. Furthermore, the Northern (Southern) firm's expected profit always increases (decreases) with each policy instrument. This result relates to the "profit-shifting" mentioned in the economic literature. Nevertheless, policy instruments may have opposite impacts on expected consumers' surplus and public revenues. The Northern country's expected public revenues increase with the import tariff, decrease with the production subsidy and the R&D subsidy, and level off with the quality standard and the minimum-price. The impact of each policy instrument on the Southern country's consumers' surplus is ambiguous. There is no direct impact because policy instruments only influence the Northern market. But there is an effect via the evolution of the probability of R&D success. Each policy instrument increases the Northern firm's R&D. The effect on the Southern country's expected consumers' surplus is either positive or negative because the result depends on the sensitivity of the preference for quality. The effect is positive with a strong sensitivity, but may become negative, otherwise. See Figure 2.

Let us study the impact on the Northern country's consumers' surplus. It increases with the production subsidy and the R&D subsidy. The R&D subsidy has an indirect positive impact by increasing the probability of R&D success. The production subsidy has a direct impact by reducing the price levels. On the other hand, the impact of the import tariff, the quality standard and the minimum-price may be either positive or negative because of a direct negative impact due to the increase of price levels and an indirect positive impact due to the increase of the probability of R&D success.

The economic impact of a quota is ambiguous because it reduces the competition from the Southern country but it either increases or reduces the Northern firm's R&D investment. Then, the effect on each expected profit and consumer surplus is uncertain.

Appendix B illustrates the evolution of the Northern country's expected consumers' surplus when the Northern government implements an import tariff such as $t = 1$, a quality standard, a relatively

[11] $$E\left[\widehat{\mathrm{PR}}(\hat{r})\right] = \begin{cases} t\{\alpha(\hat{r})\hat{y}_n^d + [1-\alpha(\hat{r})]\hat{y}_n^h\} > 0, \text{with the import tariff} \\ -s\{\alpha(\hat{r})(\hat{x}_n^d + \hat{x}_s^d) + [1-\alpha(\hat{r})](\hat{x}_n^h + \hat{x}_s^h)\} < 0, \text{with the production subsidy} \\ -\sigma\hat{r} < 0, \text{with the Research and Development subsidy} \end{cases}$$

binding minimum-price such as $p_{min} = p^{*d} + z$, a very binding minimum-price such as $p_{min} = p^{*h} + z$, where z is a positive constant, and a prohibitive import quota. The effect of the tariff is often negative. Nevertheless, we find a case where the expected consumers' surplus increases with the tariff. The effect is positive for $\eta \geq 2.3$ when $b = 3$. We also find a case where the quality standard increases the expected consumer surplus for $\eta \geq 1.25$ when $b = 3$. Finally, the relatively binding minimum-price increases the expected consumer surplus for $\eta \geq 1.5$ when $b = 2$, and $\eta \geq 1.75$ when $b = 3$, while the very binding minimum-price increases it for $\eta \geq 1.25$ when $b = 2$. Under these cases, the indirect positive impact via the probability of R&D success is stronger than the direct negative impact. Such a result can be offset against traditional results that mention a negative impact of "at-the border" policy instrument on the consumers' surplus. The condition is that consumers have a high sensitivity on their preference for quality. Unlike an import tariff or a quality standard, we do not find any case where a very binding quota increases the Northern country's expected consumer surplus by using numerical simulations.

5.3. Optimal Policy Instruments under Numerical Simulations

According to the economic impact of each policy instrument, we have to verify whether or not the Northern country's government is encouraged to implement it. Let us study the impact on the Northern country's expected national welfare. We can also compare each instrument. Appendix C illustrates the optimal level of each instrument and the expected national welfare as compared to free trade. The results are obtained under numerical simulations because analytical demonstrations seem too complex.

- The Northern country's government is encouraged to implement an import tariff and a production subsidy. The tariff seems to be the favorite policy instrument because: (i) it increases the Northern firm's profit via the "profit-shifting"; (ii) it also increases its R&D investment; (iii) it involves further public revenues for the government; (iv) it may increase the expected consumers' surplus when their preference for quality is high, and the negative effect is low, otherwise.
- The positive impact of the production subsidy is lower even if it is the favorite policy instrument for the Northern consumer since it reduces prices and increases the probability of vertical differentiation. The reason is that it involves public expenditures, especially if the R&D is successful.
- The quality standard reduces the Northern country's expected national welfare under two cases. These cases occur when the preference for quality η and the degree of differentiation ϕ are low. The effect is positive, otherwise. The Northern country's government has a preference for the import tariff because we consider that the quality standard does not yield public revenues. Furthermore, in this case, the Northern country's government does not maximize the expected national welfare.
- Under four cases, the Northern country's government is not encouraged to implement the minimum-price because the optimal level equals the level of price under free trade when the R&D is successful. Then, the expected Northern welfare is the same as under free trade. This welfare increases with the minimum-price, otherwise. The main difference with the import tariff is that we do not consider that the minimum-price influences public revenues.

- Under two cases, the optimal R&D subsidy is negative. Then, the Northern country's government is encouraged to tax the Northern firm's R&D expenditure. Note that the effects on the expected welfare are low because it influences directly only the probability of R&D success.
- The quota increases the Northern country's expected national welfare under seven cases. In these cases, the optimal quota is a prohibitive quota such as the Northern firm benefits from a monopoly on its domestic market. But the quota reduces the expected national welfare under five cases. In these cases, the Northern government is encouraged to remains under free trade.

The results show that the import tariff seems to be the favorite policy instrument for the Northern government. The Northern government can increase its domestic firm's expected profit, its consumers' surplus and public revenues at the same time, only by implementing an import tariff. However, there is a limit. Tariffs represent traditional forms of trade policy. Currently, governments reduce their tariff rates by implementing free trade agreements and use modern forms of protectionism like subsidies, quality standards or minimum-prices. Furthermore, according to the WTO, tariffs are bound and cannot be increased above a certain level. Nevertheless, as we said in introduction, the level of European Union's ad-valorem import tariff is high. It may legitimize our results.

6. Concluding Remarks

In this paper, we establish a theoretical model of international trade in a two-country duopoly with a Northern and Southern firm to examine the impact of several trade policy instruments on product R&D investment and welfare. The Southern firm is considered to have a competitive advantage due to lower production costs, encouraging the Northern competitor to invest in quality improvement. Unlike related studies but just as relevant and realistic, we suppose that the outcome of this investment is uncertain: there is a given probability for the Northern firm's product R&D to be successful. The Northern country's government is the only one policy active, having the choice between several policy instruments: an import tariff, a production subsidy, an R&D subsidy, a minimum quality standard, a minimum-price and an import quota. Firms compete in prices on both markets.

Through our three-stage game, we show that each policy instrument increases the Northern firm's product R&D investment except for a relatively binding import quota. Therefore, if the Northern country's government only aim is to enhance non-price competitiveness by encouraging product R&D investments, we provide evidence in favor of implementing these policy instruments. However, it is also argued that the effect of some of these instruments may hinder consumers' surplus, public revenues and welfare. Their implementation might not therefore be socially optimal. This result is backed by numerical simulations allowing for a change in parameters' levels. Based on these simulations and a comparison of the impact of these instruments, it appears that the Northern country's government would favor the implementation of an import tariff. By this means, the Northern firm's expected profit, consumer surplus and public revenues could increase. Nevertheless, the real implications of this result are limited, as the ongoing trend in the international arena is towards the reduction of this trade barrier.

The analysis we conducted is relevant to international trade between developed and developing countries, high and low cost firms, where the latter do not necessarily have the capacities to undergo quality improvement and finance product R&D activities. We believe to have contributed in the existing literature by building such a framework, including uncertainty in it and analyzing the impact of a relatively wide panel of instruments. There is still room for further research. An extension to our work would be to consider competition in quantities instead of prices and see how the competition mode modifies our results. Changing the setting of the model by analyzing trade between identical firms in a North-North or South-South duopoly is also possible to have important implications and constitute future research topics.

Acknowledgments

Authors are grateful for a Research Grant from the French Ministry of Research.

Appendix

A. Impact of an Import Tariff under General Forms for Demand Functions

We use general forms for demand functions. Nevertheless, we still consider constant marginal costs and linear forms for total costs. According to First Order Conditions, we have: $\hat{\pi}_n^h(t) = \pi_n^h[\hat{p}_n^h(t)] = -x_{n_{p_n}}^{\ h}[\hat{p}_n^h(t) - c^h]^2, \hat{\pi}_n^d(t) = \pi_n^d[\hat{p}_n^d(t)] = -x_{n_{p_n}}^{\ d}[\hat{p}_n^d(t) - c^d(\phi)]^2$. We have:

$$\frac{\mathrm{d}\hat{\pi}_n^h(t)}{\mathrm{d}t} = \frac{\partial \pi_n^h[\hat{p}_n^h(t)]}{\partial t} + \frac{\partial \pi_n^h[\hat{p}_n^h(t)]}{\partial \hat{p}_n^h(t)} \frac{\mathrm{d}\hat{p}_n^h(t)}{\mathrm{d}t} = [\hat{p}_n^h(t) - c^h] \frac{y_{n_{p_n^*}}^{\ h} \pi_{np_np_n}^h \pi_{np_np^*n}^h}{B^h} > 0$$

$$\frac{\mathrm{d}\hat{\pi}_n^d(t)}{\mathrm{d}t} = \frac{\partial \pi_n^d[\hat{p}_n^d(t)]}{\partial t} + \frac{\partial \pi_n^d[\hat{p}_n^d(t)]}{\partial \hat{p}_n^d(t)} \frac{\mathrm{d}\hat{p}_n^d(t)}{\mathrm{d}t} = [\hat{p}_n^d(t) - c^d(\phi)] \frac{y_{n_{p_n^*}}^{\ d} \pi_{np_np_n}^d \pi_{np_np^*n}^d}{B^d} > 0$$

The previous expressions are positive. But it seems complex to compare such expressions. We have: $\left|y_{n_{p_n^*}}^{\ d}\right| > \left|y_{n_{p_n^*}}^{\ h}\right|$. We also made the assumption that the marginal profit is higher when the R&D is successful; see Assumption 9. Then: $[\hat{p}_n^d(t) - c^d(\phi)] > [\hat{p}_n^h(t) - c^h]$. However, it is complex to compare the two last terms $\pi_{np_np_n}^d \pi_{np_np_n^*}^d / B^d$ and $\pi_{np_np_n}^h \pi_{np_np_n^*}^h / B^h$, especially under nonlinear forms. First order effects are on $y_{n_{p_n^*}}^{\ d}$, then on $[\hat{p}_n^d(t) - c^d(\phi)]$. The probability that the tariff increases the difference in profit remains high. But we cannot demonstrate that the effect is always positive.

B. Impact of "At-The-Border" Policy Instruments on Expected Consumer Surplus

Table 2 – Evolution of the Domestic Country's Expected Consumer Surplus with an Import Tariff, a Quality Standard and a Minimum-price

	Import Tariff such as $t = 1$		Quality Standard		Relatively Binding Minimum-Price such as $p_{min} = p_n^{*d} + z$		Very Binding Minimum-Price such as $p_{min} = p_n^{*h} + z$	
η	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$
0.25	-8.21229	-7.79463	-34.616494	-2.2947648	-0.0780794	-0.0364256	-2.5257042	-1.8376590
0.5	-8.00433	-7.70639	-41.051067	-2.2834541	-0.1433769	-0.0732299	-4.6014483	-2.4831033
0.75	-7.56517	-7.51798	-47.378099	-1.6045324	-0.1773104	-0.0998316	-5.9272671	-3.0294014
1	-6.79448	-7.18616	-54.273503	-0.2009661	-0.1641472	-0.1098467	-3.9357802	-2.8019087
1.25	-5.55152	-6.65085	-62.693874	1.9948237	-0.0813091	-0.0941329	4.9719231	-0.8482512
1.5	-3.63511	-5.82695	-74.036347	5.0610028	0.1040853	-0.0393999	25.972551	(b)
1.75	(a)	-4.59141	(a)	9.0850318	(a)	0.0740211	(a)	(b)
2	(a)	-2.76199	(a)	14.159265	(a)	0.2758692	(a)	(b)
2.25	(a)	-0.06126	(a)	20.369621	(a)	0.6122734	(a)	(b)
2.5	(a)	3.946958	(a)	27.768879	(a)	1.1570145	(a)	(b)

	Prohibitive Import Quota $q = 0$	
η	$b_i = 2$	$b_i = 3$
0.25	-109.31687	-50.643907
0.5	-105.74391	-49.701643
0.75	-99.622142	-48.052939
1	-90.910905	-45.681178
1.25	-79.584335	-42.584499
1.5	-65.667615	-38.790345
1.75	(a)	-34.380851
2	(a)	-29.538119
2.25	(a)	-24.627170
2.5	(a)	-20.353072

Source: authors.

Note: We set: $c^d(\phi) = c^h + \phi, a_n = 40, a_s = 30, c^h = 6, c^* = 3, \phi = 0.2, g = g^* = 1, F = F^* = 0, z = 0.1$. (a) The condition $b > (1 + \phi\eta)/(1 - \phi\eta)$ no longer holds. (b) The Southern firm's exports are negative under a successful R&D.

C. Welfare Analysis

Table 3 – Optimal Policy Instruments and Evolution of the Northern Country's Expected National Welfare

			Policy Instrument	Optimal Instrument	$\Delta E(\mathrm{W})$
$\phi = 0.2$	$b_n = b_s = 2$	$\eta = 0.5$	Import Tariff	16.5508033	183.823613
			Production Subsidy	3.22254028	7.78716801
			R&D Subsidy	18.4727963	0.01100592
			Quality Standard	-	5.49442936
			Minimum-Price	16.2666667	1.1875101
			Import Quota	0	85.1563207
		$\eta = 1$	Import Tariff	16.9565435	200.726885
			Production Subsidy	4.00647595	11.4775243
			R&D Subsidy	49.946966	0.53559784
			Quality Standard	-	38.4275181
			Minimum-Price	16.2667	23.4199971
			Import Quota	0	109.717667
		$\eta = 1.5$	Import Tariff	14.9758	253.037868
			Production Subsidy	6.08087264	23.6015963
			R&D Subsidy	70.417448	3.77024901
			Quality Standard	-	89.7016017
			Minimum-Price	18.9758242	204.613391
			Import Quota	0	157.365722

	$b_n = b_s = 3$	$\eta = 0.5$	Import Tariff	6.66184031	47.8342226
			Production Subsidy	2.48623055	6.96309294
			R&D Subsidy	10.5534091	0.00081367
			Quality Standard	-	1.53924438
			Minimum-Price	(a)	0
			Import Quota	19.7142	-4.20592691
		$\eta = 1$	Import Tariff	6.6160529	48.4196891
			Production Subsidy	2.77308089	8.46939228
			R&D Subsidy	51.8968807	0.15109548
			Quality Standard	-	8.65796407
			Minimum-Price	10.5714286	2.93224468
			Import Quota	0	-2.14866568
		$\eta = 1.5$	Import Tariff	6.5438914	52.5547558
			Production Subsidy	3.54120136	13.0938693
			R&D Subsidy	75.3998268	1.23266161
			Quality Standard	-	21.534977
			Minimum-Price	10.5438	20.896489
			Import Quota	0	6.74781467

Source: authors.

Note: We set: $c^d(\phi) = c^h + \phi, a_n = 40, a_s = 30, c^h = 6, c^* = 3, g = g^* = 1, F = F^* = 0$. (a) The optimal minimum-price equals to the foreign firm's price under free trade when the R&D is successful. Then, the domestic welfare does not vary as compared to free trade.

Table 3 (continued) – Optimal Policy Instruments and Evolution of the Northern Country's Expected National Welfare

			Policy Instrument	Optimal Instrument	$\Delta E(\mathrm{W})$
$\phi = 0.1$	$b_n = b_s = 2$	$\eta = 0.5$	Import Tariff	16.5512526	182.0127
			Production Subsidy	3.08585143	7.21336599
			R&D Subsidy	-1.50253967	1.4456E-05
			Quality Standard	-	-4.37703793
			Minimum-Price	(a)	0
			Import Quota	0	79.8616143
		$\eta = 1$	Import Tariff	16.5559191	183.987986
			Production Subsidy	3.23209595	7.83206911
			R&D Subsidy	21.1926214	0.01556657
			Quality Standard	-	6.01761683
			Minimum-Price	16.2666667	1.29264868
			Import Quota	0	85.4552477
		$\eta = 1.5$	Import Tariff	16.6589619	189.45532
			Production Subsidy	3.5269523	9.15483585
			R&D Subsidy	37.6040891	0.14054856
			Quality Standard	-	20.4346502
			Minimum-Price	23.8968944	74.3164759
			Import Quota	0	95.4051722
	$b_n = b_s = 3$	$\eta = 0.5$	Import Tariff	6.68469614	47.9021165
			Production Subsidy	2.44161052	6.74865203
			R&D Subsidy	-17.1143338	0.00039848
			Quality Standard	-	-0.1565244
			Minimum-Price	(a)	0
			Import Quota	19.7142	-4.34909786
		$\eta = 1$	Import Tariff	6.6619414	47.8489397
			Production Subsidy	2.49138048	6.99199091
			R&D Subsidy	16.120011	0.00213532
			Quality Standard	-	1.69255641
			Minimum-Price	(a)	0
			Import Quota	19.7142	-4.19334793
		$\eta = 1.5$	Import Tariff	6.63455079	47.9540953
			Production Subsidy	2.59829226	7.53834851
			R&D Subsidy	37.4234915	0.03524563
			Quality Standard	-	4.67789577

			Minimum-Price	10.5714286	0.41408715
			Import Quota	19.7142	-4.00875094

Source: authors.

Note: We set: $c^d(\phi) = c^h + \phi, a_n = 40, a_s = 30, c^h = 6, c^* = 3, g = g^* = 1, F = F^* = 0$. (a) The optimal minimum-price equals to the foreign firm's price under free trade when the R&D is successful. Then, the domestic welfare does not vary as compared to free trade.

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