INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

IFPRI

IFPRI Discussion Paper 01425

March 2015

# The Impact of "At-the-Border" and "Behind-the-Border" Policies on Cost-Reducing Research and Development

Julien Berthoumieu

Antoine Bouët

Markets, Trade and Institutions Division

## INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI), established in 1975, provides evidence-based policy solutions to sustainably end hunger and malnutrition and reduce poverty. The Institute conducts research, communicates results, optimizes partnerships, and builds capacity to ensure sustainable food production, promote healthy food systems, improve markets and trade, transform agriculture, build resilience, and strengthen institutions and governance. Gender is considered in all of the Institute's work. IFPRI collaborates with partners around the world, including development implementers, public institutions, the private sector, and farmers' organizations, to ensure that local, national, regional, and global food policies are based on evidence. IFPRI is a member of the CGIAR Consortium.

## AUTHORS

**Julien Berthoumieu** is a PhD candidate in Economics at the University of Bordeaux, Pessac, France.

**Antoine Bouët** (a.bouet@cgiar.org) is a senior research fellow in the Markets, Trade and Institutions Division of the International Food Policy Research Institute and professor of Economics in the Laboratoire d'Analyse et de Recherche Économiques et Finance Internationales at the University of Bordeaux, Pessac, France.

**Notices**

1. IFPRI Discussion Papers contain preliminary material and research results and are circulated in order to stimulate discussion and critical comment. They have not been subject to a formal external review via IFPRI's Publications Review Committee. Any opinions stated herein are those of the author(s) and are not necessarily representative of or endorsed by the International Food Policy Research Institute.

2. The boundaries and names shown and the designations used on the map(s) herein do not imply official endorsement or acceptance by the International Food Policy Research Institute (IFPRI) or its partners and contributors.

# Contents

## Table

## ABSTRACT

This research paper is aimed at understanding why border trade policies are today complemented with behind-the-border policies like output subsidies, R&D subsidies, and public R&D investments. This is a new type of protectionism that becomes prominent since the 2006-2008 economic crisis. In this paper we analyze the impact of various policies on domestic cost-reducing research and 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, and minimum price agreements) as well as "behind-the-border" policies (output subsidies, R&D subsidies, and public R&D investments). We demonstrate new theoretical findings, in particular the increasing then decreasing impact of quotas on R&D, as well as the impact of production subsidies, public R&D investments, and minimum price agreements on private R&D. We conclude that R&D subsidies are appealing policy instruments because they support not only domestic R&D expenditures but also domestic production and profits without reducing consumers' surplus. A welfare analysis gives a different point of view: it suggests that either production subsidies or import tariffs are superior. These results hold under both types of competition (Cournot and Bertrand). We conclude with a discussion of policy implications.

**Keywords: research and development; trade policy; tariff on imports; quota; VER; minimum price; output subsidy; R&D subsidy**

*JEL classification: F13, O30*

# ACKNOWLEDGMENTS

We thank an anonymous referee and participants at a Laboratoire d'Analyse et de Recherche Économiques et Finance Internationales (LAREFI) seminar in January 2014 for their comments. The authors acknowledge financial support from the CGIAR Research Program on Policy, Institutions, and Markets (PIM) activity "Analysis of global and regional trade policy agreements and unilateral trade policy reforms". Of course all errors are ours.

# 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 has a significant influence on a country's market shares and exports, as well as its production and employment levels. Determining the right policies to improve the competitiveness of 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 or a sector to sell goods and/or services in a given market in relation to other firms or sectors located in other countries. A distinction is often made between price and nonprice 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 and 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. The objective of this paper is to evaluate the impact of various policy instruments, both "at-the-border" and "behind-the-border" policies, on domestic firms' R&D. We also evaluate the impact of these instruments on other variables such as domestic production and profits, consumers' surplus, and public revenues. Finally, we conduct a welfare analysis.

We concentrate our effort on cost-reducing R&D investment. R&D may be also undertaken with other objectives in mind, such as the design of a new product. This would lead to a very different modeling of R&D, which would represent another research paper; however, studying the impact of various policy instruments on cost-reducing R&D already leads to many interesting results.

The impact of economic policy on R&D has been studied in the economic literature. The reference model is an article by Spencer and Brander (1983) that analyzes the impact of an R&D subsidy in an international Cournot duopoly: the researchers describe a long-term strategic interaction between firms that 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 domestic 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 domestic R&D investment while reducing foreign R&D. Again, in this theoretical structure, any increase in domestic 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 domestic 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 commitment. 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, domestic 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 global R&D overinvestment, or "collaboration," by sharing the extra profits coming from

R&D investment. Each government implements an R&D subsidy, which increases domestic 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 in which 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, Bouët concludes that an import tariff may increase domestic investment in R&D, while a VER may decrease domestic R&D investment. In this model, the Southern firm is ready to restrain its exports because 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 and 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 paper is to study the potential impact of various policy instruments on domestic R&D investments: import tariffs, production subsidies, R&D subsidies, public investment in R&D, import quotas, VERs, and minimum prices. While trade policy is traditionally understood as a set of policy instruments implemented "at the border," such as import tariffs, quotas, and VERs, we study the impact of other barriers implemented "behind the border," such as production subsidies, R&D subsidies, public investment in R&D, and 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 27 million reals with a below-market interest rate in order to invest in innovation and new "process design" (*Economist* 2013). This is what Evenett (2013) describes as "protectionism's quiet return": according to his research, 431 protectionist measures were adopted throughout the world between June 2012 and May 2013, 95 of them being subsidies of different forms and 64 being tariff increases.

Another form of behind-the-border policy is the implementation of business clusters, initiated or even subsidized by a government. A business cluster is a geographic concentration of firms interconnected in a particular field: it is based on Porter's (2000) model. In France, the *pôles de compétitivité* are business clusters recognized by the government: they connect private companies with universities and private or public research centers. In 2008, 71 *pôles de compétitivité* existed in France; they received US$1.3 billion in public subsidies between 2005 and 2008.

We also study the impact of minimum price agreements 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 percent antidumping duty.

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, domestic profits, and domestic consumption. These results are robust to a change in the mode of competition (Cournot or Bertrand). Moreover, R&D subsidies may be more easily implemented than other policies. The use of instruments such as quotas is forbidden by the World Trade Organization (WTO), and the use of tariffs is not totally free: they are bound. Production subsidies are not prohibited; according to WTO law they are "actionable," but their implementation is under severe control because they may be implemented only in specific circumstances for a limited period of time. Instruments such as R&D subsidies or minimum prices are not prohibited by the WTO as long as they do not have a negative impact on international trade. It may be difficult to demonstrate that a policy such as an R&D subsidy has a negative impact on trade flows, and even if this is the case, international institutions are relatively tolerant. For example, in 2012 the European Commission approved French state assistance in the car sector even though it concluded that the measure would affect international trade flows (Evenett 2013). In our model we show that these policies have a negative impact on international trade, but they are behind-the-border policies and therefore are much less visible. WTO members are not obligated to notify the organization of implementation of such policies, unlike changes in tariffs or the implementation of quotas or export taxes or subsidies (at-the-border policies), which do have to be brought to the attention of the WTO.

The model 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 Bertrand competition. A generalization to Bertrand competition is important. These models have been highly criticized for their lack of robustness, in particular in terms of the mode of competition.[1] Therefore, it is important to study the impact of the same policy instruments under Cournot and Bertrand modes of competition.

A criticism may be raised against this theoretical structure because it is a partial equilibrium model: there must be other industries from which resources would be drawn away, and these could be industries that have a comparative advantage. In short, this partial equilibrium model does not allow us to draw any general equilibrium conclusions. However, we can consider sectors whose economic size is not too large. We can also argue that this theoretical structure is much more tractable than a general equilibrium model.

We analyze the impact of six policy instruments (three at-the-border policies—a tariff, a quota, and a VER—and three behind-the-border policies—a production subsidy, an R&D subsidy, and a public R&D investment) under Cournot competition and five (two at-the-border policies—a tariff and a minimum price—and three behind-the-border policies—a production subsidy, an R&D subsidy, and a public R&D investment) under Bertrand competition. Some of these effects have never been studied before in this theoretical framework, specifically the quota, the minimum price, the production and R&D subsidies, and the public investment in R&D.

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

[1] See Brander and Spencer (1985), where the optimal policy is an export subsidy under Cournot, and Eaton and Grossman (1986), where the optimal policy is an export tax under Bertrand. Other modeling features are identical.

## 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 R&D. In this paper, we use a general form of this model.[2]

**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 $c = c_l$.[3] 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 $v$.

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

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

The larger the R&D investment, the higher the likelihood that $c = c_l$. However, returns of the R&D investment are decreasing. This assumption is important because it conditions a broad set of results, in particular all the ways a policy instrument affects R&D (positively or negatively).

**Assumption 2:** $\alpha'(r) = \mathrm{d}\alpha(r)/\mathrm{d}r > 0$, $\alpha''(r) = \mathrm{d}^2\alpha(r)/\mathrm{d}r^2 \leq 0$. An implicit assumption is that the foreign firm learns the outcome of domestic R&D in a first stage. This is the simplest and most straightforward assumption. However, in future research we may consider another situation in particular: whether the domestic firm has an incentive to share information with its rival about R&D success or failure. The expressions of profit are as follows:

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

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

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

$$x = (c-p)/p' \tag{4}$$

$$y = (c^* - p)/p' \tag{5}$$

**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: $|\Pi_{xx}| > |\Pi_{xy}|$, $|\Pi^*_{yy}| > |\Pi^*_{yx}|$.[4] 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.

---

[2] In two appendixes, which may be requested from the authors, we use linear forms for demand function and an iso-elastic function for R&D success in order to illustrate our different conclusions.

[3] A modeling option is that a minimum amount of investment in R&D is needed to achieve a successful reduction of the cost. Indeed it may be realistic to consider that too small of an effort in R&D is pure waste. However, this assumption would complicate the modeling by introducing a threshold effect without any major modification of results. This is why we do not consider this option.

[4] We use subscripts to denote partial derivatives.

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

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

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

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 the following:

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

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

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

Equation (8) implies that $x_l > x_h$. When the domestic firm's marginal cost is low (that is, 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 because consumers' surplus decreases with $p$ and increases with $X$.

We denote $\hat{\pi}$ the domestic firm's maximum profit such that the domestic firm produces the optimal level of output $\hat{x}$. Such level of profit depends on the domestic firm's marginal cost: $\hat{\pi} = \hat{\pi}(c_i)$. Note that we have $\hat{\pi}(c_i) = \pi[\hat{x}(c_i)] = -\hat{x}(c_i)^2 p'$ (see the domestic firm's first-order condition). Then, the domestic firm's profit decreases with its marginal cost:

$$\frac{\mathrm{d}\hat{\pi}(c_i)}{\mathrm{d}c_i} = \frac{\partial \pi[\hat{x}(c_i)]}{\partial c_i} + \frac{\partial \pi[\hat{x}(c_i)]}{\partial \hat{x}(c_i)} \frac{\mathrm{d}\hat{x}(c_i)}{\mathrm{d}c_i} = -2\hat{x}(c_i)p' \frac{\pi^*_{yy}}{\Delta} < 0 \tag{11}$$

Such result implies that the domestic firm's profit is stronger when its marginal cost is low: $c_i = c_l$. As far as the foreign firm's profit is concerned, we find a symmetric result: it is greater when the domestic firm's marginal cost is high.

$$\frac{\mathrm{d}\hat{\pi}^*(c_i)}{\mathrm{d}c_i} = \frac{\partial \pi^*[\hat{y}(c_i)]}{\partial c_i} + \frac{\partial \pi^*[\hat{y}(c_i)]}{\partial \hat{y}(c_i)} \frac{\mathrm{d}\hat{y}(c_i)}{\mathrm{d}c_i} = 2\hat{y}(c_i)p' \frac{\pi^*_{yx}}{\Delta} > 0 \tag{12}$$

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

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

The first-order condition of (13) leads to the following:

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

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.

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

A simple interpretation of (14) stems from rewriting this equation as $r = \Phi(v; \pi_l - \pi_h)$, with $\Phi_1 = \partial\Phi/\partial v < 0$ and $\Phi_2 = \partial\Phi/\partial(\pi_l - \pi_h) > 0$. These signs come directly from downward concavity of $\alpha(r)$. So the domestic firm's R&D depends only 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 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 policies (at-the-border and behind-the-border policies) implemented by the domestic government. In section 3, we study the impact of six policies: three policies implemented at the border (an import duty, a quota on imports, and a voluntary export restraint, or VER) and three behind-the-border policies (a production subsidy, an R&D subsidy, and an additional public R&D investment). 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 SIX POLICY OPTIONS UNDER COURNOT COMPETITION

In this section, we consider six 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 into the foreign country. Moreover, there is no R&D in the foreign country, so 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 (labor) advantage and a rich country where R&D is the only way to react to low marginal production costs.

### A Tariff on Imports under Cournot

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

$$\Pi^*(x, y, t) = yp(x + y) - c^*y - ty - F^*. \tag{16}$$

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

$$y = (c^* + t - p)/p'. \tag{17}$$

Let us study the economic impact of the tariff $t$ on outputs, price, and profits. Previously, we studied the impact of the domestic firm's marginal cost on each of these variables. Then it is straightforward to qualify the tariff impact because the effect is the same as the foreign firm's marginal cost: the domestic government's tariff increases (decreases) the domestic (foreign) firm's output and reduces the total level of output. It increases the market price. Then, the domestic consumers' surplus decreases with the tariff. Furthermore, the domestic (foreign) firm's profit increases (decreases) with the tariff.

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 ($\pi_l$ and $\pi_h$) 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 concave demand function, the effect is either positive or negative.

**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. Noting that $\pi$ does not depend on $t$ ($\partial\pi/\partial t = 0$), let us call $\hat{x}(t) = \operatorname{argmax}_{x>0} \pi(x, y, t)$ and $\hat{\pi}(t) = \pi[\hat{x}(t)]$.[5] We get

$$\frac{\mathrm{d}\hat{\pi}(t)}{\mathrm{d}t} = \frac{\partial\pi[\hat{x}(t)]}{\partial\hat{x}(t)}\frac{d\hat{x}(t)}{dt}. \tag{18}$$

Note that $\pi = x(p - c)$. Thanks to (4), we get $\pi[\hat{x}(t)] = -\hat{x}(t)^2p'$. A simple derivation gives $\partial\pi[\hat{x}(t)]/\partial\hat{x} = -2\hat{x}(t)p' - \hat{x}(t)^2p'' = -\hat{x}(t)\pi_{xx} > 0$. Note also that $\mathrm{d}\hat{x}(t)/\mathrm{d}t = -\Pi_{xy}/\Delta$. So we have $\mathrm{d}\hat{\pi}/\mathrm{d}t = \hat{x}(t)\,\Pi_{xx}\Pi_{xy}/\Delta > 0$.

Suppose that the demand function is linear: $p'' = 0$. We obtain $\mathrm{d}\hat{\pi}(t)/\mathrm{d}t = 2\hat{x}(t)/3$. So in that case, the impact of an import tariff is proportional to the optimal domestic firm's supply $\hat{x}$. This supply is

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

all the bigger when 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 does the optimal level of R&D.

If the demand function is not linear, $\Pi_{xx}\Pi_{xy}/\Delta$ depends on $x$ and $y$. The first-order effect remains the impact of the domestic firm's marginal cost on $\hat{x}$, and generally, that is, in almost all the functional forms studied, the difference in profit $DP = (\pi_l - \pi_h)$ increases with the tariff. For illustration let us adopt two specific nonlinear demand functions.

- First consider a concave demand function: $p(X) = a - X^2$, with $p' = -2X < 0$ and $p'' = -2 < 0$. It is easy to prove that $\frac{\mathrm{d}^2\hat{\pi}}{\mathrm{d}t\mathrm{d}c} < 0$.
- Now consider a convex demand function: $p(X) = a - X^{1/2}$, with $p' = -X^{-1/2}/2 < 0$ and $p'' = X^{-3/2}/4 > 0$. We can also show that $\frac{\mathrm{d}^2\hat{\pi}}{\mathrm{d}t\mathrm{d}c} < 0$.

Then, in each case, the positive effect of the tariff on the domestic firm's profit $\mathrm{d}\hat{\pi}/\mathrm{d}t$ is lower when its marginal cost is high. Hence, $(\pi_l - \pi_h)$ and $r$ increase with the tariff $t$.

We can summarize the effect of a tariff on imports in this way: it raises the domestic firm's profit and generates 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.

## A Production Subsidy under Cournot

Let us study the economic impact of the production subsidy $s$ on outputs, price, and profits. Note that a production subsidy has the same impact as a decrease in the domestic marginal cost. It is straightforward to show that the domestic government's production subsidy increases (decreases) the domestic (foreign) firm's output and increases the total level of output. It reduces the market price. Then, the domestic consumers' surplus increases with the production subsidy. Furthermore, the domestic (foreign) firm's profit increases (decreases) with the production subsidy. Domestic public revenues decrease.

**Proposition 2:** Under Cournot competition, the domestic government's production subsidy $s$ either increases or decreases the domestic firm's R&D investment. It increases the domestic firm's R&D investment under a linear inverse demand function. Under many specific nonlinear demand functional forms considered here, the effect is an increase in domestic R&D.

**Proof:** Because of the impact of the domestic firm's marginal cost on its profit, we have

$$\frac{\mathrm{d}\hat{\pi}(c,s)}{\mathrm{d}s} = 2\hat{x}(c,s)p'\frac{\pi^*_{yy}}{\Delta} > 0.$$

Let us study the effect of the domestic firm's marginal cost on the previous expression. Under a linear inverse demand function, $p'$ is constant. In that case, the only term that depends on the marginal cost is $\hat{x}(c,s)$. In section 2, we proved that $\mathrm{d}x/\mathrm{d}c$ is negative. Then, the positive effect of the subsidy on profit $\pi$ is greater when the domestic firm's marginal cost is low, $c = c_l$. The difference in profit increases with the subsidy, which means that the domestic firm's R&D increases with $s$.

Unfortunately, as with the tariff on imports, under a nonlinear demand function it is more complicated to find a general result because in this case $p'$ and $\pi^*_{yy}/\Delta$ depend on the domestic firm's marginal cost. Let us use the same specific concave and convex demand functions as with the tariff. In the two cases, we find that the positive effect of $s$ on $\pi$ is stronger when the marginal cost is low.[6] Then, the domestic firm's R&D investment increases with the production subsidy as compared to free trade.

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,

[6] Calculations may be requested from the authors.

the production subsidy is likely to increase R&D because it is likely that it has a greater 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.

### 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 $\sigma$. The domestic firm's profit is

$$\Pi(x, y, \sigma) = xp(x + y) - cx - F - (v - \sigma)r. \tag{19}$$

The foreign firm's profit expression remains (3). 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 to $\mathrm{d}x/\mathrm{d}\sigma = 0$. Therefore, in the short run, the R&D subsidy does not modify outputs, price, or profits.

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

$$E[\Pi(r)] = \alpha(r)\pi_l + [1 - \alpha(r)]\pi_h - F - (v - \sigma)r. \tag{20}$$

The first-order condition leads to

$$\alpha'(r) = \frac{v-\sigma}{\pi_l-\pi_h}. \tag{21}$$

The second-order condition does not change.

**Proposition 3:** In Cournot competition, an R&D subsidy implemented by the domestic government increases the domestic firm's R&D investment compared to the situation without subsidy.

**Proof:** According to (21), $\alpha'(r)$ decreases in $\sigma$. Therefore, Assumption 2 implies that the subsidy $\sigma$ 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 firm's expected profit and consumers' surplus. However, it decreases the domestic government's public revenues.

### An Additional Public Investment in R&D under Cournot

It can be argued that the previous policy instrument is unrealistic. The modeling of R&D is here based on a distinction between R&D in volume ($r$) and price of R&D ($v$), which may be difficult to identify in reality. Consequently, it is likely that a public intervention aimed at directly increasing R&D would take another form. We suppose now that the domestic government's intervention consists of an additional public investment in volume $\bar{r}$.

**Proposition 4:** In Cournot competition, a government's intervention in the form of an additional public R&D investment $\bar{r}$ in volume decreases the domestic firm's R&D investment compared to the situation without subsidy, increases the domestic firm's profit, and decreases public revenue. Total R&D (public and private) is unchanged. Consumers' surplus and the foreign firm's profit are unchanged.

This additional public R&D investment $\bar{r}$ in volume does not change the levels of the domestic firm's profit under both states of nature (R&D success and failure) compared to free trade. However, it changes the first-order condition for the domestic firm when it determines its optimal level of R&D $r$. This condition becomes $r$ such that $\alpha'(\bar{r} + r) = -v/(\pi_l - \pi_h)$. Because the right member of this equation is unchanged, and $\alpha'$ is decreasing, the additional public R&D investment $\bar{r}$ in volume decreases the private investment $r$ by the same amount. Total R&D (private and public) is unchanged, and the probability of both states of nature is unchanged. The domestic firm's profit is augmented because the cost of its R&D is less. It is a pure transfer from the government to the private firm. Consequently, consumers' surplus and the foreign firm's profit are unchanged.

### A Quota on Imports under Cournot

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

We suppose that the quota is binding and denote the quota level (that is, the foreign firm's maximum exports) as $q$. Profit expressions are now as follows:

$$\Pi(x,q) = xp(x+q) - cx - F - v.r \tag{22}$$

$$\Pi^*(x,q) = qp(x+q) - c_l q - F^* \tag{23}$$

In the short run, only the domestic firm can maximize its profit. As the quota is binding, the first-order condition (5) does not hold. 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 $c = c_i$, and $\forall i = l, h$ is the foreign firm's exports under free trade.

The second case corresponds to a very binding quota that 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: $\boldsymbol{y_l < q \leq y_h}$.** If the domestic firm has a low marginal cost $c_l$, the quota is greater than the foreign firm's optimal response. The domestic firm's profit does not change. However, if the domestic firm has a high marginal cost $c_h$, the quota is binding and the foreign firm must export less than the Nash equilibrium level. The domestic firm's profit is increased because $\pi_y = xp' < 0$. Denoting $\pi_i^q$ 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 does not change (decreases) if the domestic firm's marginal cost is low (high).

**Second case: $\boldsymbol{q \leq y_l}$.** 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

$$\alpha'(r^q) = \frac{v}{\pi_l^q - \pi_h^q}\,. \tag{24}$$

**Proposition 5:** 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 again consider two cases.

Consider the first case ($y_l < q \leq y_h$). The quota increases the domestic firm's profit only when its marginal cost is high, such that the profit differential decreases: $\pi_l^q - \pi_h^q < \pi_l - \pi_h$. Therefore, a

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

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 the 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: $DP^{q=0} > DP \Leftrightarrow (1/2)(c_h - c_l)[a - (c_h + c_l)/2] > (4/9)(c_h - c_l)(a - c_h)$, which is always verified.

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

Note: $\hat{x}(q, c_i) = \text{argmax}_{x>0}\, \pi(x, q, c_i)$. The foreign firm's first-order constraint disappears because the quota is binding. We have $\hat{\pi}(q, c_i) = \pi[\hat{x}(q, c_i), q, c_i]$.

The Envelope Theorem implies $\mathrm{d}\hat{\pi}(q, c_i)/\mathrm{d}q = \partial\pi(x, q, c_i)/\partial q = \hat{x}(q, c_i)p' < 0$. The domestic firm's maximum profit increases when the quota becomes more restrictive. With a linear ($p'$ constant) or a concave ($p'' < 0$) demand function, 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 but not sufficient condition 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 cases it is greater because the effect through $\hat{x}(q, c_i)$ is a first-order effect). With a convex demand function, we find some examples in which a binding quota increases R&D.[8] We find other examples in which 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.

### A VER under Cournot

Quantitative restrictions can also take the form of a voluntary export restraint (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 it must increase the foreign firm's expected profit. 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 that $y_l \leq q < y_h$. Therefore, a VER decreases the domestic firm's R&D investment because it only increases the firm's profit if the domestic marginal cost is high; it decreases the marginal gain of an R&D investment (see previous subsection). Bouët 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 6:** Under Cournot competition, a VER reduces the domestic firm's R&D investment with respect to free trade.

---

[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 profit differential equals $DP^q = 555.37$, which means that R&D is increased compared to free trade. With a prohibitive quota $q = 0$, the profit differential equals $DP^q = 620.99$. We did not find any value of $b$ that 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 as 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.

## 4. BERTRAND COMPETITION

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

**Assumption 1b:** The firms supply slightly differentiated goods. Competition is of the Bertrand type. Each firm's output depends on both firms' prices. Denoting $p$ (respectively, $p^*$) as the domestic (respectively, foreign) firm's price, $x = x(p, p^*)$, $y = y(p, p^*)$, $X = X(p, p^*) = x(p, p^*) + y(p, p^*)$. 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 as follows:

$$\Pi(p, p^*) = px(p, p^*) - cx(p, p^*) - F - vr \tag{25}$$

$$\Pi^*(p, p^*) = p^*y(p, p^*) - c_l y(p, p^*) - F^* \tag{26}$$

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

$$\mathrm{p} = \mathrm{c} - \mathrm{x}/\mathrm{x_p} \tag{27}$$

$$p^* = c^* - y/y_{p^*} \tag{28}$$

**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) firm's marginal profits increase with 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:

$$\Gamma = \Pi_{pp}\Pi^*_{p^*p^*} - \Pi_{pp^*}\Pi^*_{p^*p} > 0 \tag{29}$$

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

$$\pi_i = p_i x(p_i, p_i^*) - c_i x(p_i, p_i^*) \text{ with } p_i = c_i - x/x_p, \forall i = l, h \tag{30}$$

The domestic firm's maximum profit is expressed as $\hat{\pi}(c_i) = \pi[\hat{p}(c_i)] = -x_p[\hat{p}(c_i) - c_i]^2$. Deriving this expression leads to

$$\frac{\mathrm{d}\hat{\pi}(c_i)}{\mathrm{d}c_i} = \frac{\partial \pi[\hat{p}(c_i)]}{\partial c_i} + \frac{\partial \pi[\hat{p}(c_i)]}{\partial \hat{p}(c_i)} \frac{\mathrm{d}\hat{p}(c_i)}{\mathrm{d}c_i} = x_p[\hat{p}(c_i) - c_i]\left(1 - \frac{\pi_{pp^*}\pi^*_{p^*p}}{\Gamma}\right). \tag{31}$$

The sign of the previous expression is either positive or negative because the sign of $\left(1 - \pi_{pp^*}\pi^*_{p^*p}/\Gamma\right)$ is unknown. However, we make the assumption that $\mathrm{d}\hat{\pi}(c_i)/\mathrm{d}c_i < 0$. Otherwise, it is not worth investing in cost-reducing R&D for the domestic firm. We also have

$$\frac{\mathrm{d}\hat{\pi}^*(c_i)}{\mathrm{d}c_i} = \frac{\partial \pi^*[\hat{p}^*(c_i)]}{\partial c_i} + \frac{\partial \pi^*[\hat{p}^*(c_i)]}{\partial \hat{p}^*(c_i)} \frac{\mathrm{d}\hat{p}^*(c_i)}{\mathrm{d}c_i} = x_p[\hat{p}^*(c_i) - c^*] \frac{\pi^*_{p^*p^*}\pi^*_{p^*p}}{\Gamma} > 0. \tag{32}$$

The foreign firm's profit is increasing with the domestic firm's marginal cost $c_i$.

Differentiating the first-order conditions and setting again $c = c_i$, we obtain the following:

$$\frac{\mathrm{d}p}{\mathrm{d}c} = \frac{x_p \pi^*_{p^*p^*}}{\Gamma} > 0 \tag{33}$$

$$\frac{\mathrm{d}p^*}{\mathrm{d}c} = -\frac{x_p \pi^*_{p^*p}}{\Gamma} > 0 \tag{34}$$

$$\frac{\mathrm{d}x}{\mathrm{d}c} = x_p \frac{\mathrm{d}p}{\mathrm{d}c} + x_{p^*} \frac{\mathrm{d}p^*}{\mathrm{d}c} = \frac{x_p\left(x_p \pi^*_{p^*p^*} - x_{p^*} \pi^*_{p^*p}\right)}{\Gamma} < 0 \tag{35}$$

$$\frac{\mathrm{d}y}{\mathrm{d}c} = y_p \frac{\mathrm{d}p}{\mathrm{d}c} + y_{p^*} \frac{\mathrm{d}p^*}{\mathrm{d}c} = \frac{x_p \cdot \left(y_p . \pi^*_{p^*p^*} - y_{p^*} . \pi^*_{p^*p}\right)}{\Gamma} \tag{36}$$

$$\frac{\mathrm{d}X}{\mathrm{d}c} = \left(x_p + y_p\right) \frac{\mathrm{d}p}{\mathrm{d}c} + \left(x_{p^*} + y_{p^*}\right) \frac{\mathrm{d}p^*}{\mathrm{d}c} \tag{37}$$

An increase in the domestic firm's marginal cost of output increases each firm's price. The effect on the domestic firm's output is negative. We cannot draw a conclusion about the sign of $\mathrm{d}y/\mathrm{d}c$ and $\mathrm{d}X/\mathrm{d}c$. However, considering a symmetry in the effects of a variation in a firm's price on the other firm's output ($x_p = y_{p^*}$ and $x_{p^*} = y_p$), then $\mathrm{d}X/\mathrm{d}c < 0$; in that case, a decrease 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 or an additional public R&D investment in volume is the same as that seen under Cournot competition. We introduce only a tariff on imports, a production subsidy, and a minimum price; introducing quantitative restrictions in Bertrand competition is a very complex issue (see Krishna 1989). Moreover, it implies a mixed strategy equilibrium. Therefore, in place of quantitative restrictions, we introduce minimum price commitments.

### *A Tariff on Imports under Bertrand*

The domestic firm's profit expression remains (25). For the foreign firm, we have

$$\Pi^*(p, p^*, t) = p^* y(p, p^*) - c^* y(p, p^*) - t y(p, p^*) - F^*. \tag{38}$$

The foreign firm's first-order condition changes:

$$p^* = c^* + t - y/y_{p^*} \tag{39}$$

Let us study the economic impact of a change in the tariff under Bertrand competition. As under Cournot competition, this is similar to the effect of change in $c$. An increase in the tariff increases each price. The effect on the domestic (foreign) firm's output and profit is uncertain (negative).

In the long run, the domestic firm chooses the R&D investment that maximizes its expected profit. The first-order conditions remains (14), with new definitions for $\pi_l$ and $\pi_h$.

**Proposition 7:** Under Bertrand competition, a tariff on imports increases R&D investment if the inverse demand functions are linear. Under convex or concave demand functions, the effect is either positive or negative.

**Proof:** Note that the impact of a change in the tariff on the domestic firm's profit equals the impact of a change in the foreign firm's marginal cost. According to Equation (32), we have

$$\frac{\mathrm{d}\hat{\pi}(t)}{\mathrm{d}t} = [\hat{p}(t) - c]\frac{y_{p^*}\pi_{pp}\pi_{pp^*}}{\Gamma} > 0.$$

With linear demand functions, $x_{pp} = 0$. So $\mathrm{d}\hat{\pi}(t)/\mathrm{d}t = 2x_p[\hat{p}(t) - c]\, y_{p^*}\pi_{pp^*}/\Gamma$. We know that in this case $x_p$, $\Pi_{pp^*}$, $y_{p^*}$, and $\Gamma$ are constant, and that $(p - c)$ decreases in $c$ since $\mathrm{d}p/\mathrm{d}c < 1$.[10] Therefore, $\mathrm{d}\hat{\pi}(t)/\mathrm{d}t$ is larger when $c = c_l$.

If the demand function is not linear, $y_{p^*}\Pi_{pp^*}/\Gamma$ depends on $p$ and $p^*$. The first-order effect remains the impact on $[\hat{p}(t) - c]$, and generally the difference in profit $DP = (\pi_l - \pi_h)$ increases with the tariff. We studied the case of various demand functional forms, either concave or convex, but we did not identify a case in which $(\pi_l - \pi_h)$ and $r$ decrease with the tariff $t$. Let us illustrate with two examples.

- First, consider the following concave demand functions: $x(p, p^*) = (a - p + bp^*)^{1/2}$ and $y(p, p^*) = (a + bp - p^*)^{1/2}$, with $0 < b < 1$. It is easy to prove that $\frac{\mathrm{d}^2\hat{\pi}}{\mathrm{d}t\mathrm{d}c} < 0$.
- Second, consider the following convex demand functions: $x(p, p^*) = (a - p + bp^*)^2$ and $y(p, p^*) = (a + bp - p^*)^2$, with $0 < b < 1$. It is easy to prove that $\frac{\mathrm{d}^2\hat{\pi}}{\mathrm{d}t\mathrm{d}c} < 0$.

This is why we conclude that, in general, the tariff increases the domestic firm's R&D investment.

### *A Production Subsidy under Bertrand*

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

$$\Pi(p, p^*, s) = x(p, p^*)p - cx(p, p^*) + sx(p, p^*) - F - vr. \tag{40}$$

Let us study the economic impact of the production subsidy under Bertrand competition. The production subsidy corresponds to a decrease in the domestic firm's marginal cost. Then, each firm's optimal price decreases with the production subsidy. The total level of output increases with the production subsidy when considering a symmetry in the effects ($x_p = y_{p^*}$ and $x_{p^*} = y_p$). The consumers' surplus increases with the production subsidy. The domestic (foreign) firm's output and profit increase (decrease) with the production subsidy. Domestic public revenues decrease as compared to free trade.

**Proposition 8:** Under Bertrand competition, the domestic firm's R&D increases or decreases with the production subsidy as compared to free trade. The effect is always positive under linear demand functions. We used various specific concave and convex demand functional forms to obtain a positive impact of production subsidy on domestic R&D:

$$\frac{\mathrm{d}\hat{\pi}(c_i, s)}{\mathrm{d}s} = -x_p[\hat{p}(c) - c]\left(1 - \frac{\pi_{pp^*}\pi^*_{p^*p}}{\Gamma}\right) > 0$$

[10] According to (47), we have $\mathrm{d}p/\mathrm{d}c = x_p\left[y_{p^*p^*}(p^* - c^*) + 2y_{p^*}\right]/\Gamma > 0$. Developing $\Gamma$, we find $\Gamma = x_p\left[y_{p^*p^*}(p^* - c^*) + 2y_{p^*}\right] + \left[x_{pp}(p - c) + x_p\right]\left[y_{p^*p^*}(p^* - c^*) + 2y_{p^*}\right] - \left[x_{pp^*}(p - c) + x_p\right]\left[y_{p^*p}(p^* - c^*) + y_p\right] > 0$. However, under linear or concave demand functions, we know that $\left[x_{pp}(p - c) + x_p\right]\left[y_{p^*p^*}(p^* - c^*) + 2y_{p^*}\right] > \left[x_{pp^*}(p - c) + x_p\right]\left[y_{p^*p}(p^* - c^*) + y_p\right]$, which leads to $\mathrm{d}p/\mathrm{d}c < 1$. But under convex demand functions, we cannot prove that $\left|x_{pp}(p - c) + x_p\right| > \left[x_{pp^*}(p - c) + x_p\right]$.

Under linear demand functions, we know that $[\hat{p}(c_i) - c_i]$ decreases with $c_i$. Other terms do not depend on the domestic firm's marginal cost. Then, the positive effect of the subsidy on the firm's profit is greater when the marginal cost is low. The production subsidy increases the difference in profit and the domestic firm's R&D investment.

However, as under Cournot competition, it is complex to derive general results from nonlinear demand functions. We use the same specific concave and convex demand functions as in the previous subsection. In both cases, we find that the positive effect of the production subsidy on the firm's profit is stronger when the marginal cost is low.[11] We conclude that a production subsidy is likely to increase the domestic firm's R&D.

### *A Minimum Price under Bertrand*

We now introduce a minimum price, denoted by $\underline{p}^*$, implemented by the domestic government. The foreign firm cannot sell its goods at a price below $\underline{p}^*$. We suppose that this is a binding constraint for the foreign firm such that profits become as follows:

$$\Pi\left(p, \underline{p}^*\right) = px\left(p, \underline{p}^*\right) - cx\left(p, \underline{p}^*\right) - vr - F \tag{41}$$

$$\Pi^*\left(p, \underline{p}^*\right) = \underline{p}^* y\left(p, \underline{p}^*\right) - c^* y\left(p, \underline{p}^*\right) - F^* \tag{42}$$

In the short run, only the domestic firm chooses the price 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 (32), we have $p_l^* < p_h^*$. If the domestic government implements a minimum price such that $\underline{p}^* \leq p_l^*$, it has no effect on the equilibrium between both firms, so we consider only $\underline{p}^* > p_l^*$. Therefore, we consider two cases: $p_l^* < \underline{p}^* \leq p_h^*$ and $\underline{p}^* > p_h^*$.

**First case: $p_l^* \leq \underline{p}^* < p_h^*$.** If the domestic firm's marginal cost is high, its profit remains the same as under free trade because the foreign firm does not sell below $p_h^*$. However, if this marginal cost is low, the minimum price increases the domestic firm's 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: $\underline{p}^* \geq p_h^*$.** 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

$$\alpha'(r^{\underline{p}}) = \frac{v}{\pi_l^{\underline{p}^*} - \pi_h^{\underline{p}^*}}. \tag{43}$$

---

[11] Under the specific concave demand functions $x(p, p^*) = (a - p + bp^*)^{1/2}$ and $y(p, p^*) = (a + bp - p^*)^{1/2}$, with $0 < b < 1$, we find $\frac{\mathrm{d}^2\hat{\pi}}{\mathrm{d}s\mathrm{d}c} = -\frac{3}{2(5^{3/2})(a-c+bc_l+s)} < 0$. Under the specific convex demand functions $x(p, p^*) = (a - p + bp^*)^2$ and $y(p, p^*) = (a + bp - p^*)^2$, with $0 < b < 1$, we find $\frac{\mathrm{d}^2\hat{\pi}}{\mathrm{d}s\mathrm{d}c} = -\frac{3(a-c+bc_l+s)}{8} < 0$.

**Proposition 9:** Under Bertrand competition, when $p_l^* < \underline{p}^* \leq p_h^*$, the minimum price increases R&D investment as compared to free trade. When $\underline{p}^* > p_h^*$, in general, R&D investment increases as compared to free trade. The effect is positive with linear or concave demand functions but is positive or negative 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.

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 $\pi_h^{\underline{p}} > \pi_h$. $\hat{\pi}\left(\underline{p}^*, c\right)$ is the domestic firm's maximum profit, such that the following program is solved: $\max_{p>0} \pi\left(p, \underline{p}^*, c\right)$. There is no constraint due to the minimum price. The Envelope Theorem implies

$$\frac{\mathrm{d}\hat{\pi}\left(\underline{p}^*, c\right)}{\mathrm{d}\underline{p}^*} = \frac{\partial \pi\left[p, \underline{p}^*, c\right]}{\partial \underline{p}^*} = x_{\underline{p}^*}(\hat{p} - c) > 0. \tag{44}$$

1. Searching for the effect of the domestic firm's marginal cost on this expression, we conclude the following:
2. Under linear demand functions, $x_{p^*}$ is constant and does not depend on the domestic firm's marginal cost. $(\hat{p} - c)$ decreases with $c_i$ since $\mathrm{d}p/\mathrm{d}c < 1$. Then, the positive effect of the minimum price on the domestic firm's maximum profit is stronger when its marginal cost is low: the minimum price increases the difference in profit and the domestic firm's R&D investment.
3. Under concave demand functions (for own and cross effects: $x_p$ and $x_{p^*}$), $x_{pp} < 0$ and $x_{p^*p^*} < 0$, which implies that $x_{p^*}$ decreases with $p^*$. We 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 (31), we can prove that $\mathrm{d}p/\mathrm{d}c < 1$ with concave demand functions, which implies that $(\hat{p} - c)$ is also greater when the domestic firm's marginal cost is low. The positive effect of the minimum price on the domestic firm's maximum profit is greater when its marginal cost is low.
4. Under convex demand functions (for both own and cross effects: $x_p$ and $x_{p^*}$), $x_{pp} > 0$ and $x_{p^*p^*} > 0$, which implies that $x_{p^*}$ increases in $p^*$ (but always decreases in $p$). Convexity implies that $x_{p^*}$ is more sensitive to $p^*$ than $p$. The effect of the marginal cost on $x_{p^*}$ is either positive or negative. Furthermore, we cannot prove that $(\hat{p} - c_i)$ is greater with a low marginal cost because we cannot prove that $\mathrm{d}p/\mathrm{d}c < 1$. Therefore, we cannot verify that the positive effect of the minimum price on the domestic firm's maximum profit is greater when its marginal cost is low. However, only a high degree of convexity could imply that the minimum price decreases R&D investment.

Considering the second case, under a linear or a concave demand function, the term $x_{\underline{p}^*}(\hat{p} - c_i)$ 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 draw a conclusion.

## 5. DISCUSSION

We now summarize and discuss Propositions 1 to 9. Table 5.1 provides a summary of the results presented in sections 2, 3, and 4.

**Table 5.1 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 domestic consumers' surplus | | Impact on domestic public revenues | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | B | C | B | C | B | C | B | C | B |
| Tariff on imports | +? | +? | + | + | – | +/– | – | –? | + | + |
| Production subsidy | +? | +? | + | + | – | – | + | +? | – | – |
| R&D subsidy | + | + | + | + | – | – | + | + | – | – |
| Public R&D investment | - | - | + | + | 0 | 0 | 0 | 0 | - | - |
| 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: C = Cournot; B = Bertrand; na = not available; R&D = research and development; VER = voluntary export restraint. "+" (respectively, "–") means that the impact is positive (respectively, negative). "+?" ("-?") means that the result is either positive or negative with a high presumption to find a positive (respectively, negative) effect. "+/–" means that the result is either positive or negative according to the demand functional form or the magnitude of the policy instrument.

An R&D subsidy systematically increases R&D investment. However, if this public intervention does not take the form of a reduction in the private cost of R&D but of an additional public R&D investment in volume, the R&D policy reduces private R&D such that total R&D is unchanged. In general, a production subsidy and a tariff increase R&D investment. These results hold both under Cournot and Bertrand competition. Under Cournot competition, a quota has either a positive or negative effect, depending on its restrictiveness. A VER always decreases R&D investment. Under Bertrand competition, a minimum price is likely to increase R&D investment.

Table 5.1 also summarizes the effect of each instrument on the domestic firm's profit, domestic consumers' surplus, and domestic public revenues, as well as on the foreign firm's profit. Every instrument increases the domestic firm's profit under both Cournot and Bertrand modes of competition. However, every instrument decreases the foreign firm's profit except for

- a tariff under Bertrand competition, because it increases the foreign firm's price, leading to a collusive impact, and
- a VER under Cournot competition, because it decreases the domestic firm's R&D investment in response to the foreign firm's export restriction.

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

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

- It is an offensive instrument that can help domestic firms compete against firms from countries that benefit from lower production costs.
- It increases domestic firms' profit and consumers' surplus.
- These results are robust; they hold regardless of the form of the demand function and regardless of the mode of competition (Cournot or Bertrand).
- According to the WTO, import tariffs are bound, meaning that they cannot be increased above a certain level. Production subsidies, quotas, VERs, and minimum prices are forbidden or actionable (permitted only under very specific circumstances). There is 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.
- 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.

However, the issue of the form that this R&D policy takes is crucial. In order to be effective it must be targeted to a reduction in the private cost of R&D. In the model presented here, public R&D investment decreases private R&D investment.

Note that a government may decide to reduce taxes on domestic firms. In 2014, with the so-called Pacte de Responsabilité, the French government is currently conducting precisely this policy, and the functioning of the production subsidy in the framework of this paper is nothing more than the pure equivalent of a tax reduction that reduces production costs.

We complement this discussion by a welfare analysis. We suppose that domestic welfare is the unweighted sum of domestic firms' profit, domestic consumers' surplus, and domestic public revenues. This assumption may be criticized on the basis of political economy considerations. However, this is the simplest and most straightforward assumption.

A welfare analysis is supposed to specify the optimum level of each instrument and the welfare associated with it, enabling selection of the best instrument in terms of achieving the maximum welfare. It looks difficult if not impossible to provide a general demonstration, as domestic welfare is expected based on a probability that is a strictly concave function of R&D. Considering this difficulty, we study a central case scenario in which functional forms have been selected for a demand function (linear, that is $p(X) = a - X$ in the Cournot case; $x(p,p^*) = a - p + bp^*$ and $y(p,p^*) = a + bp - p^*$ in the Bertrand case) and for probability of R&D success $\alpha(r) = r^k$, while specific values have been given to parameters ($a = 24$, $c_l = 3$, $c_h = 6$, $v = 27.5$, $k = 0.5$ in the Cournot case; $a = 24$, $c_l = 3$, $c_h = 6$, $v = 27.5$, $k = 0.5$, $b = 0.5$ in the Bertrand case). Then we modify the values given to these parameters, considering successively increased and decreased parameter $a$, increased and decreased difference between $c_h$ and $c_l$, increased and decreased $v$, increased and decreased $k$, and lastly increased and decreased $b$. This analysis gives the following results.

- The implementation of a quota (or a minimum price under Bertrand) is never the best policy among the four considered here. Either it decreases domestic welfare or it increases domestic welfare, but in this case the best quota is 0 (import prohibition) or the level of quota such that $r = 1$ (R&D is maximum). In particular, a not very restrictive quota always decreases domestic welfare (this is a consequence of Proposition 4).
- Implementing an R&D subsidy, a production subsidy, or a tariff increases welfare.
- The implementation of an R&D subsidy is never the best policy among the four policies considered here.
- The best policy in terms of welfare maximization is either a production subsidy or an import tariff.

In particular, a production subsidy is all the more beneficial compared to a tariff in terms of welfare when $a$ is small, when the difference between $c_h$ and $c_l$ is small, and when $v$ is high. These results hold under both Cournot and Bertrand cases. Finally, under a Bertrand mode of competition, a production subsidy is all the more beneficial in terms of domestic welfare when $b$ is small.

How can these results be interpreted? It is not surprising that a quota is never the best policy, as here it does not generate public revenues. The only effects that the quota leads to are an increase in the domestic firm's profit and a reduction in domestic consumers' surplus. By comparison, an import tariff implies an increase in the domestic firm's profit, a reduction in domestic consumers' surplus, and an increase in public revenues. That a quota is less beneficial than a tariff in terms of welfare if it does not generate public revenues is a traditional result of economic theory.

Then we conclude that the implementation of either an R&D subsidy or a production subsidy or a tariff increases domestic welfare. Again this is not surprising. The literature on strategic trade policy has reached similar conclusions. Here our modeling differs because the result of R&D is uncertain. In previous sections we showed that these three instruments increase domestic R&D, so they increase the probability of the best outcome in terms of welfare.

Finally, let us discuss the finding that, in terms of domestic welfare, an R&D subsidy is always worse than either a tariff or a production subsidy or both. In the selected framework, an R&D subsidy only affects (positively) the probability of R&D success, here denominated $\alpha(r)$. Indeed, this subsidy decreases the domestic firm's total cost, in particular its R&D cost. But in terms of public revenues it costs exactly the same amount, such that domestic welfare is unchanged. In particular, an R&D subsidy does not change the domestic firm's output (in the Cournot case) or its price (in the Bertrand case) once the domestic firm's marginal cost of production is known. The subsidy only modifies the R&D implemented by the domestic firm and consequently the probability of reaching a low marginal cost.

The effects of an import tariff and a production subsidy are fundamentally different. Both instruments not only affect the level of R&D (through an effect on the profit difference) and consequently the probability of R&D success, but they also increase domestic welfare under both states of nature; whatever the domestic marginal cost is, the strategy implemented by the domestic firm is changed by either a tariff or a production subsidy, and it leads to higher welfare under each state of nature. Putting it differently, if W is domestic welfare, $\alpha$ is the probability of success of R&D, $W_l$ is domestic welfare when the domestic firm's marginal cost is $c_l$, and $W_h$ is domestic welfare when the domestic firm's marginal cost is $c_h$, we have $W = \alpha W_l + (1-\alpha)W_h$. An R&D subsidy increases only $\alpha$. An import tariff or a production subsidy increases $\alpha$, $W_l$, and $W_h$. This explains why these instruments have a greater impact on domestic welfare than an R&D subsidy.

## 6. CONCLUDING REMARKS

The objective of this paper was to evaluate the potential impact of various policy instruments, both at the border and behind the border, on domestic R&D. 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. A quota on imports may decrease R&D if it is not too restrictive and may expand it if it is relatively restrictive.

We conclude that an R&D subsidy is an attractive instrument for policymakers because it has an unambiguously positive impact on R&D and because it is less regulated by the WTO as compared to other instruments. These other instruments are either comparatively 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, as many interventions in high-income countries or emerging economies are (or are close to) R&D subsidies.

From a theoretical point of view, this paper 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 study is largely innovative, particularly the analysis of the impact of an import quota (under Cournot competition) and of a minimum price commitment (under Bertrand competition) on R&D.

What is the best instrument among all those considered here? We conclude that, in terms of welfare, either a production subsidy or an import tariff is superior to an R&D subsidy. This conclusion deserves a discussion. First, it is based on a specific government's objective function. The specification of a government's objective is always arbitrary, as it is difficult to state the importance of consumers' surplus, producers' profit, and public revenues in a political process. Second, an important aspect of R&D expenses is externalities, which should be included in a government's objective. Third, dynamic considerations matter because 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 domestic 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; and the transmission of knowledge, inventions, and innovation from research centers (public or private) to the private sector of production. An illustration is the US Bayh-Dole Act, which in 1980 changed the ownership of inventions arising from federally funded research. In our model, this structural policy would imply a modification of the probability of successful R&D: the $\alpha$ function would become more convex and each dollar spent on R&D would lead to a more probable reduction of the marginal cost of production.

Finally, let us mention a few directions of possible extension of this model. First, it would be interesting to model differently the process of R&D, in particular focusing on innovation in terms of products and not cost. The design of a new product is another way to tackle competition from abroad. Second, it would be interesting to study retaliation, as the implementation of a tariff in the home country may imply a retaliatory tariff in the foreign country (with potential WTO permission), the implementation of a production subsidy may lead to a countervailing duty in the foreign country, and so on. This extension would require a change in the theoretical structure of this model and the introduction of domestic exports to the foreign country. A third possible extension could consist of the introduction of asymmetrical information: the government may not know the probability of R&D success or the level of marginal cost reachable if R&D succeeds. Another option is that the R&D is similar to an effort undertaken by the firm, and the government may not be in a position to control this level of effort. All these potential extensions are interesting and could be studied in future research.

## REFERENCES


Bouët, A. 2001. "Research Development, Voluntary Export Restriction and Tariffs." *European Economic Review* 45: 323–336.

Bouët, A., and P. Cassagnard. 2013. "Strategic Trade Policy under Asymmetric Information with Screening." *Economic Modelling* 32: 286–293.

Brander, J. A., and B. J. Spencer. 1985. "Export Subsidies and International Market Share Rivalry." *Journal of International Economics* 18 (1–2): 83–100.

Eaton, J., and G. M. Grossman. 1986. "Optimal Trade and Industrial Policy under Oligopoly." *Quarterly Journal of Economics* 101 (2): 383–406.

*Economist*. 2013. "The Hidden Persuaders." October 12.

Evenett, S. J. 2013. *Protectionism's Quiet Return*. GTA's Pre-G8 Summit Report. London: Global Trade Alert, Centre for Economic Policy Research.

Haaland, J. I., and H. J. Kind. 2008. "R&D Policies, Trade and Process Innovation." *Journal of International Economics* 74: 170–187.

Krishna, K. 1989. "Trade Restrictions as Facilitating Practices." *Journal of International Economics* 26: 251–270.

Krugman, P. 1984. "Import Protection as Export Promotion: International Competition in the Presence of Oligopoly and Economics of Scale." In *Monopolistic Competition and International Trade*, edited by H. Kierzkowski, 180–193. Oxford, UK: Clarendon Press.

Leahy, D., and J. P. Neary. 1996, "International R&D Rivalry and Industrial Strategy without Government Commitment." *Review of International Economics* 4 (3): 322–338.

———. 1997. "Public Policies towards R&D in Oligopolistic Industries." *American Economic Review* 86 (4): 642–662.

Matschke, X. 2003. "Tariff and Quota Equivalence in the Presence of Asymmetric Information." *Journal of International Economics* 61: 209–223.

Porter, M. 2000. "Location, Competition, and Economic Development: Local Clusters in a Global Economy." *Economic Development Quarterly* 14 (1): 15–34.

Qiu, L. D., and Z. Tao. 1998. "Policy on International R&D Cooperation: Subsidy or Tax?" *European Economic Review* 42: 1727–1750.

Reitzes, J. D. 1991. "The Impact of Tariffs and Quotas on Strategic R&D Behavior." *International Economic Review* 32 (4): 985–1007.

Spencer, B., and J. A. Brander. 1983. "International R&D Rivalry and Industrial Strategy." *Review of Economic Studies* 50: 702–722.

# RECENT IFPRI DISCUSSION PAPERS

**For earlier discussion papers, please go to www.ifpri.org/pubs/pubs.htm#dp.**
**All discussion papers can be downloaded free of charge.**

1424. *Market imperfections for tractor service provision in Nigeria:* International Perspectives and Empirical Evidence. Hiroyuki Takeshima, 2015.

1423. *Agriculture, nutrition, and the Green Revolution in Bangladesh*. Derek D. Headey and John Hoddinott, 2015.

1422. *Rural finance and agricultural technology adoption in Ethiopia: Does institutional design matter?* Gashaw Tadesse Abate, Shahidur Rashid, Carlo Borzaga, and Kindie Getnet, 2015.

1421. *Is more inclusive more effective? The "new-style" public distribution system in India*. Avinash Kishore and Suman Chakrabarti, 2015.

1420. E*xplicitly integrating institutions into bioeconomic modeling*. Kimberly A. Swallow and Brent M. Swallow, 2015.

1419. *Time allocation to energy resource collection in rural Ethiopia: Gender-disaggregated household responses to changes in firewood availability*. Elena Scheurlen, 2015.

1418. *Communities' perceptions and knowledge of ecosystem services: Evidence from rural communities in Nigeria*. Wei Zhang, Edward Kato, Prapti Bhandary, Ephraim Nkonya, Hassan Ishaq Ibrahim, Mure Agbonlahor, and Hussaini Yusuf Ibrahim, 2015.

1417. *2011 social accounting matrix for Senegal.* Ismaël Fofana, Mamadou Yaya Diallo, Ousseynou Sarr, and Abdou Diouf, 2015.

1416. *Firm heterogeneity in food safety provision: Evidence from Aflatoxin tests in Kenya*. Christine Moser and Vivian Hoffmann, 2015.

1415. *Mechanization outsourcing clusters and division of labor in Chinese agriculture*. Xiaobo Zhang, Jin Yang, and Thomas Reardon, 2015.

1414. *Conceptualizing drivers of policy change in agriculture, nutrition, and food security: The Kaleidoscope Model.* Danielle Resnick, Suresh Babu, Steven Haggblade, Sheryl Hendriks, and David Mather, 2015.

1413. *Value chains and nutrition: A framework to support the identification, design, and evaluation of interventions.* Aulo Gelli, Corinna Hawkes, Jason Donovan, Jody Harris, Summer Allen, Alan de Brauw, Spencer Henson, Nancy Johnson, James Garrett, and David Ryckembusch, 2015.

1412. *Climate change adaptation assets and group-based approaches: Gendered perceptions from Bangladesh, Ethiopia, Mali, and Kenya.* Noora Aberman, Snigdha Ali, Julia A. Behrman, Elizabeth Bryan, Peter Davis, Aiveen Donnelly, Violet Gathaara, Daouda Kone, Teresiah Nganga, Jane Ngugi, Barrack Okoba, and Carla Roncoli, 2015.

1411. *Information networks among women and men and the demand for an agricultural technology in India.* Nicholas Magnan, David J. Spielman, Kajal Gulati, and Travis J. Lybbert, 2015.

1410. *Measurement of agricultural productivity in Africa South of the Sahara: A spatial typology application.* Bingxin Yu and Zhe Guo, 2015.

1409. *Eliciting farmers' valuation for abiotic stress-tolerant rice in India.* Anchal Arora, Sangeeta Bansal, and Patrick S. Ward, 2015.

1408. *Understanding the policy landscape for climate change adaptation: A cross-country comparison using the net-map method.* Noora Aberman, Regina Birner, Eric Haglund, Marther Ngigi, Snigdha Ali, Barrack Okoba, Daouda Koné, Tekie Alemu, 2015.

1407. *Evolving public expenditure in Chinese agriculture definition, pattern, composition, and mechanism*. Bingxin Yu, Kevin Chen, Yumei Zhang, and Haisen Zhang, 2014.

1406. *Fertility, agricultural labor supply, and production.* Bjorn Van Campenhout, 2014.

1405. *Impact simulation of ECOWAS rice self-sufficiency policy*. Ismaël Fofana, Anatole Goundan, and Léa Vicky Magne Domgho, 2014.

1404. *Political economy of state interventions in the Bangladesh food-grain sector.* Nurul Islam, 2014.

**INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE**

**www.ifpri.org**

**IFPRI HEADQUARTERS**

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org