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Summary *– The objective of this paper is to analyze the effects public regulatory tools for food safety, notably maximum admitted contamination thresholds and official controls performed at importing country's borders on both developing countries' market access and consumers' health. An Industrial Economics approach is developed that endogenizes the sanitary risk associated with imports by explicitly taking into account the interaction between the public regulatory tools and the strategic response of producers/exporters. Producers' strategic reaction is shown to crucially depend on the characteristics of the economic environment. Moreover, a regulatory reinforcement may exacerbate producers/exporters exclusion without improving consumers' health protection.*

Keywords*: maximum admitted contamination thresholds, official border controls, consumers' health, producers/ exporters' exclusion.*

Standards sanitaires et phytosanitaires : la protection de la santé des consommateurs justifie-t-elle l'exclusion des producteurs des pays en développement ?

Résumé – L'objectif de ce papier est d'analyser les effets des instruments publics de réglementation de la sécurité sanitaire des aliments, notamment des seuils maximaux de contamination autorisés et des contrôles officiels à la frontière de pays importateurs, sur l'accès au marché des pays en développement et sur la santé des consommateurs. Une approche d'Economie Industrielle est ainsi développé qui endogénise le risque sanitaire associé aux importations en tenant en compte explicitement des interactions entre les instruments publics de régulation et la réponse stratégique de producteurs/exportateurs. On montre que la réaction stratégique de producteurs dépend crucialement des caractéristiques de l'environnement économique. D'ailleurs, un renforcement de la réglementation peut exacerber l'exclusion de producteurs/ exportateurs sans améliorer la protection de la santé des consommateurs.

Mots-clés : seuils maximaux de contamination autorisés, contrôles officiels à la frontière, santé des consommateurs, exclusion des producteurs/exportateurs.

JEL Classification: L15, Q12, Q18, F14

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1. Introduction

The major sanitary crises of the 1990s resulted in a tightening of national and international regulations aimed at ensuring the sanitary safety of food product supply on the agricultural and food business markets. As a result, a considerable number of standards, both public regulations and private standards, emerged which specify the minimum conditions for the agricultural and food business sectors to supply safe products. Public regulations and standards emerged at a multilateral level (*e.g.* the *Codex Alimentarius* standards), national and regional level (European, in particular). More specifically, European food safety regulation is based on a set of regulations concerning both upstream minimum quality standards on production means and practices (Good Agricultural Practices or GAP) and final products' minimum safety requirements, notably regulations setting the maximum admitted level of contaminants (pesticide residues, heavy metals, aflatoxins, etc.).

European regulation has been progressively reinforced, notably by strengthening the maximum admitted thresholds of pesticide residues and contaminants (aflatoxins, heavy metals, etc.). Food safety regulation of imports constitutes a crucial point of the European food safety legislation and aims at assuring that imported products comply with the same norms that are imposed to European producers. European regulation is considered as the most exigent at international level and notably stricter than the standards set by the *Codex Alimentarius*.

Despite the reinforcement of the European regulation, food safety incidents are still reported and contaminated quantities are sold on the market. Hence, several reports and studies (EFSA, 2009 and 2010) as well as the alerts reported by the European Rapid Alert System for Food and Feed (RASFF) point out the gap existing between the increasingly strict European food safety legislation and the contamination rate of products entering the European market. Hence, as for the products imported from third countries, EFSA reports point out an increase of the contamination rate of the inspected samples, which raises from 6.8% in 2007 to 7.6% in 2008 (EFSA, 2010, p. 64; EFSA, 2009, p. 29). Increasing contamination rates of products entering the European market may be partially explained by inefficiencies of the European border inspection system. Controls and compliance tests performed at European borders are designed to sanction insufficient compliance efforts and reject the merchandise that does not comply with the importing countries' food safety requirements. Nevertheless, despite an increasing harmonization of controls across European countries, the control system is still, to a certain extent, heterogeneous and imperfect (Whitakert *et al.*, 1995; Willems *et al.*, 2005; Hammoudi *et al.*, 2010). As a consequence, despite the tightening of regulations, contaminated products may enter the European market, thus constituting a risk for consumers' health and finally implying the ineffectiveness of European legislation aimed at assuring consumers' health protection.

Hence, the reinforcement of European regulation does not seem to be sufficient to protect consumers' health. The reason is often identified in the imperfections of the border control system.

To the best of our knowledge, there exists no empirical or theoretical contribution that explicitly takes into account the relation between the regulation and the control system. A "traditional" swathe of the literature addresses the question of the effect of sanitary regulation on third countries' market access and points out that the strengthening and harmonization of European regulations (notably those of the maximum levels of contaminants) has resulted in increasing difficulties for developing countries to access to the European market. Hence, the costs of compliance with regulation and the infrastructural and institutional deficiencies of developing countries may reduce the capacity to comply with importing countries' requirements and thus result in a reduction of exported volumes or farmers' exclusion from the most restrictive (and lucrative) market. Standards thus constitute a great burden especially for small firms (Henson *et al.*, 2000; Chen *et al.*, 2006, Dolan et Humphrey, 2000; Farina et Reardon, 2000; Reardon *et al.*, 1999; Henson et Jaffee, 2006). The few contributions that take into account the role of the control system are often developed in a context of moral hazard and aim at analyzing the contracts and the inspections procedures that private agents implement in order to assure the safety of procurement (Stardbird and Amanor-Boadu, 2007; Stardbird, 2005; Fox and Hennessy, 1999). Fox and Hennessy (1999) examined the effect of random and terminal inspections on the behaviour of a producer afflicted with random contamination over time. In the same vein, Stardbird and Amanor-Boadu (2007) and Stardbird (2005) aim at characterizing the conditions for the effectiveness of a private control system in detecting non-compliant products delivered by suppliers to downstream agents [1]. Indeed, the main idea is to avoid suppliers' underinvestment in quality and the delivery of "unsafe" goods [2]. Even if the role of the control system in providing the incentive to deliver safe goods is taken into account, to the best of our knowledge, the dynamic nature of the regulatory environment is often neglected. In other words, the most contributions examine the impact of the inspection system in a stationary regulatory context. Nevertheless, it is worthy to notice, that the interaction between food safety norms and the control system may affect the incentive for operators to deliver safe food, that in turn affect the sanitary risk.

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[1] Starbird and Amanor-Boadu (2007) use a principal-agent model in the context of adverse selection to examine how contracts that include traceability can be used to select against producers who cannot meet a processor's safety specifications. The authors show that the motivation to select against unsafe producers depends on the magnitude of the failure costs and the proportion of the failure costs allocated to producers. Starbird (2005) examines the influence of inspection policies set by the principal on the efforts exerted by agent (producer) concerning product safety. The authors show that inspection policies affect the producer's willingness to exert higher effort to ensure safety.
[2] The main question in this type of studies is how the principal can induce enough quality (safety) care from the agent or how to deter suppliers who would deliver unsafe food.

Given this premises, we propose an Industrial Economics approach that makes it possible to endogenize the sanitary risk associated with imports by explicitly taking into account the interaction between the public regulatory strategy (maximum admitted contamination threshold) and producers/exporters' strategic reaction in terms of investments in the quality of production practices [3].

Hence, legislations often regulate final products' characteristics ("obligations of results") and do not explicitly specify the means that producers have to mobilize in order to comply with norms. Nevertheless, exporting countries' producers has to undertake important investments in the quality of production practices in order to comply with regulations set by the importing country. In our model, by anticipating the level of regulation and the effectiveness of the border control systems, producers choose the level of investment to undertake in order to maximize the probability to comply with norms and thus access the destination market. The level of investment in turn affects the sanitary risk. Analyzing the relation among the regulation, the effectiveness of the control system and the risk associated with imports requires taking into account the strategic response of producers. The objective of this paper is thus to analyze the effects of these public regulatory tools (maximum admitted level of contamination and border inspections) on both developing countries' access to the destination market and consumers' health in the importing country.

In this vain, our paper relates to the wider debate initiated by Otsuki *et al.* (2001). Considering the tightening of European regulation (notably the EU harmonized maximum levels for aflatoxins), the authors argue that the strict levels applied therein would not result in a significant reduction in health risk to consumers, yet would impose serious costs and/or technical difficulties on the suppliers that must achieve compliance with the regulation (Otsuki *et al.*, 2001). We enrich this debate by contributing with two original elements. First, we take into account the effects of changes in the regulatory environment (*e.g.* a tightening of the maximum level of contaminants or an improvement of the import control system's effectiveness) on economic agents' strategic behaviour and the related adjustments of exported volumes to changing market requirements. Hence, an exporter "strategic reaction function" is determined in order to analyze the microeconomic effects of changes in the regulatory environment of the importing countries on exporter's strategic behaviour, notably on the incentive to invest in the quality of upstream agricultural practices. Second, we consider the role of the control system. Hence, imperfections in the control systems have to be taken into account when analyzing the effectiveness of food safety regulation, since they may be source (even in a context of increasingly stringent regulations) of opportunistic behaviours by supply chain participants. Hence, producers/exporters may anticipate

[3] To the best of our knowledge, the issue of endogenous sanitary risk as a function of agents' strategic behaviour is relatively neglected by the economic literature (Hammoudi *et al.*, 2009). Nevertheless, some recent studies (Giraud-Héraud *et al.*, 2012 and 2010), have pointed out that the level of sanitary risk crucially depends on firms' strategic behaviour on the market (suppliers' selection, production volume) and on consumers' behaviour towards the sanitary risk, notably on consumers' risk perception.

short-term control system's imperfections and may have incentive to under-invest in the quality of production practices. This may have negative consequences both of exporting country's market access and on consumers' health.

We show how exporters' strategic behaviour (quality investments on agricultural practices) is affected by the characteristics of their environment, notably by producers/exporters' size as well as by the characteristics of the importing country's regulatory environment, notably the stringency of the maximum admitted level of contaminants and the effectiveness of the border inspection system. Moreover, we point out that the effect of a regulatory reinforcement on exporters' exclusion from the export market depends both on exporters' characteristics (notably, the size) and on the effectiveness of the border inspection system. Producers do not react all in the same way to a regulatory reinforcement. Hence, the strategic reaction depends on the characteristics of the economic environment. Notably, a relatively high exporter's size and a sufficiently effective control system at importing country's border imply an increase in imported volumes as a result of a strengthening of the maximum level of contaminants. On the contrary, a relatively small exporters' size or an insufficient degree of effectiveness of the control system reduce the incentive for producers/exporters to invest in the quality of upstream production practices and thus imply a decrease of compliance with importing country's requirements and a reduction of imported volumes. At these conditions, a reinforcement of the regulation reduces the market access capacity. From the point of view of importing country, a tightening of importing country's regulatory requirements does not necessarily imply an improvement of consumers' health protection. More specifically, a regulatory reinforcement implies a decrease of consumers' health protection when producers/exporters size is sufficiently small; moreover, control system imperfections exacerbate this effect by extending it to the case whereby larger-sized producers are concerned. Finally, a regulatory reinforcement may imply more small-sized producers/exporters' exclusion from the export market without improving consumers' health protection, if imports are sourced from exporters, whose size is not sufficiently large. Exclusion of producers/exporters may thus be unjustified by the objective of consumers' health protection.

The reminder of the paper is organized as follows. Section 2 presents the model. Section 3 illustrates the effects of a regulatory reinforcement on producers/exporters' access to the export market. Section 4 then analyzes the effects of a regulatory reinforcement on consumers' health protection. Finally, Section 5 simultaneously considers the effects of a regulatory reinforcement on both producers' exclusion and consumers' health.

2. Model

We consider a (developing) exporting country E, a (developed) importing country I, and the export supply chain of E constituted by producers/exporters that supply the country I with a given product.

2.1. Contamination risk

We assume that the exported product may be contaminated at the production stage by the existence of a certain proportion, in the final product, of a substance that is harmful for consumers' health. The public authority fixes a threshold s, with $0 \le s \le 1$, that represents the maximum admitted level of contamination for each unit of product sold. This threshold aims at protecting consumers' health. We denote this threshold "sanitary norm", which is fixed by the importing country. An increase in the stringency of this norm (reduction of s on the interval $[0,1]$) implies *de facto* a reinforcement of the sanitary regulation in the importing country.

Each producer/exporter has a given size q that corresponds to his production capacity. The import demand of country I addressed to the exporting country is constant and given by Q [4]. Price is exogenous and given by w [5]. We assume that each producer/exporter sells to the destination market a certain quantity x that represents its optimal quantity, given the capacity constraint q. We consider free entry until demand Q is satisfied. $N(s)$ represents the number of producers/exporters that is necessary to assure the import demand Q of country I addressed to the exporting country E.

2.2. Costs of production practices quality investments

Each producer may invest in the quality of production practices in order to reduce the level of contamination of food. We denote k the level of quality of production practices, with $0 \le k \le 1$. For a given level of investment k, the total production cost for the producer is given by:

$$C(k) = Fk^2 \tag{1}$$

According to (1), the investment in the quality of production practices implies a fixed production cost FK^2 (*e.g.* infrastructure and equipments installation,

[4] It is not here about the total import demand of country I, but of a part of this demand that is addressed (in the form of an "order") by importers that source from country E. As a consequence, the level of transactions (exchanged volume Q) only very partially affects the price of the exchanged product. This hypothesis is justified by the actual variety, at international level, of suppliers concurring in satisfying the import demand of country I.

[5] We assume here that the price w of transaction between exporters of the developing country E and importers of the developed country I does not depend on the level of s. This hypothesis is not very restrictive when we refer to very moderate evolutions of maximum admitted contaminations thresholds. More generally, the influence of variations in the contamination rate on the price of transactions between developing countries' exporters and developed countries' importers remains an important question that, to the best of our knowledge, empirical literature has not settled yet. More specifically, two elements plead for the hypothesis of a non-significant influence of s on w. First, the regulation of contamination thresholds is not a factor of product differentiation, since the threshold s concern the whole set of commercialized products. Second, even if requirements becomes stricter and the price of the product on the international market increases, developed countries' importers do not systematically pass this increase on the price paid to developing countries' exporters (Fulponi, 2007; Dolan *et al.*, 2000).

implementation of training, certification costs, etc.) [6]. The values of the parameter F may reflect the investments that are necessary for a producer to comply with a given quality level k of production practices. The F values may partially depend on the state of public infrastructures (roads, scientific and technical capacity, domestic normalization and control systems, etc.); the parameter F may thus be interpreted as an indicator of exporting country's level (or state) of infrastructures and services [7]. Hence, the lower the state of infrastructures, the higher the production costs associated with a quality level k of production practices.

2.3. Relation between production practices and contamination risk

We illustrate in this section the relation that exists between the investment k and the contamination rate of the final product. We consider that a producer, who chooses the level of investment k, anticipates the probability that a product unit complies with a given norm s. Let us denote by $f(s,k)$, the probability that a product unit (that is produced according to the practice k), complies with the norm s. This function may also be interpreted as the proportion of supply q that complies with the norm s. This function verifies $\frac{\partial f(s,k)}{\partial k} > 0$, *i.e.* at a given level of norm s, an increase in the effort k increases the probability of compliance for each product unit. Moreover $\frac{\partial f(s,k)}{\partial s} > 0$, *i.e.* a norm reinforcement (s decreases), decreases the compliance probability, for a given level of investment k. We assume that this function is given by [8]:

$$f(s,k) = 1 - (1 - s)(1 - k) \tag{2}$$

By using (2), we easily verify that at a given norm s, when the investment is null ($k = 0$), the compliance probability solely depends on the level of the norm s ($f(s,k) = s$), whereas a maximal level of effort ($k = 1$) implies a certain compliance with the norm s ($f(s,k) = 1$). When the laxest norm is in force ($s = 1$), no effort is required to comply ($f(s,k) = 1$), whereas the strictest norm ($s = 0$) implies that the compliance probability only depends on the level of investment ($f(s,k) = k$).

[6] In fact, sanitary norms imply both fixed and variable compliance costs (see for example Shafaeddin, 2009; CTA, 2003). For the sake of simplicity and without loss of generality, we only consider fixed costs.
[7] This interpretation of the parameter F makes it possible to take into account the role of weaknesses/inefficiencies of infrastructures and services that characterizes developing countries economic environment and may amplify compliance costs associated with investments in the quality of production practices (Henson and Humphrey, 2009; Fulponi, 2007; ONUDI, 2005; Henson *et al.*, 2000).
[8] This function makes it possible to take into account both the negative effect of a norm reinforcement and the positive effect of the level of effort on the compliance probability; hence, in the spirit of Starbird (2005), an higher level of effort leads to an higher probability of complying with the standard.

2.4. Control system at importing country's borders

The access to the importing country's market is subjected to a border control procedure. We assume that this procedure is imperfect. Notably, this imperfection is assumed to depend on test sensitivity errors[9]. Let us denote by β, $0 \leq \beta \leq 1$, the probability that a contaminated sample is correctly detected as contaminated (*i.e.* the probability of a positive test, given that the sample is contaminated). Hence $(1-\beta)$ denotes the probability of a false negative test (the test indicated the contaminated sample as safe). The parameter β thus measures the degree of effectiveness of the control system at importing country's borders. For a level β of border control system effectiveness and a norm s, the probability that an exported product unit passes the inspection at the importing country's border $g(s, k)$ is given by:

$$g(s,k) = f(s,k) + (1-\beta)\,[1 - f(s,k)] \tag{3}$$

At a given norm s and level of investment k, the probability $g(s, k)$ that a product unit passes the inspection decreases in β. In the absence of control ($\beta = 0$), the product certainly passes the inspection ($g(s,k) = 1$). If the control procedure is perfect ($\beta = 1$), the probability to pass the inspection equals the *objective* compliance probability ($f(s, k)$).

It is worthy to notice that strategic issues are associated with the functions $f(s, k)$ and $g(s, k)$ in determining the exporting country's performance. A producer/exporter takes into account border inspection system imperfections when determining his optimal level of investment k. The producer/exporter's strategic behaviour is thus based on the function $g(s, k)$ and may be interpreted as ruled by a short-term rationality, whilst the function $f(s, k)$ may be interpreted as an indicator of exporting country's capacity to access the export market and considered by public authorities as a criterion of domestic long-term performance.

2.5. The border rejection costs

We assume that the quantity that does not pass the border inspection is rejected at importing country's border. Border rejections imply a marginal rejection cost r for the producer/exporter (cost associated with each unit of product rejected).

The probability that one unit is rejected is given by $\{1 - g(s,k)\}$. The expected rejected quantity $q^R(s,k)$ and the expected quantity that passes the inspection $q^I(s,k)$ for each producer/exporter are thus respectively given by:

$$q^R(s,k) = x[1 - g(s,k)] \tag{4}$$

[9] As noted by Stardbird and Amanor-Boadu (2006), diagnostic error is also a function of the specificity of the test, *i.e.* the probability of a negative test for contamination given the lot is uncontaminated. Even if both sensitivity and specificity errors are likely to be anticipated by producers/exporters and affect (reduce) compliance efforts, and thus may result in contaminated quantities entering the destination market, here, for the sake of simplicity and without loss of generality, we only focus on sensitivity errors, which *directly* negatively affect consumers' health protection.

$$q^I(s,k) = xg(s,k) \tag{5}$$

with $q^R(s,k) + q^I(s,k) = x$.

The control procedure imperfection implies a certain expected contaminated quantity $q^C(s,k)$ that does not comply with the norm s but passes the inspection, given by:

$$q^C(s,k) = x(1-\beta)\,[1 - f(s,k)] = x(1-\beta)\,(1-s)\,(1-k) \tag{6}$$

The expression (6) consists in the quantity ($x[1 - f(s,k)]$) that does not comply with the norm s but is not detected by the control system, due to imperfections, with a probability $(1-\beta)$.

3. Norms reinforcement, marginalization and exclusion from export market

3.1. The optimal level of investment in the quality of production practices

Producers/exporters are assumed to observe the conditions to access the importing country's market, *i.e.* the effectiveness of the border control system and the level of norm, and then adjust the quality level of production practices to this environment. We assume that producers/exporters are risk neutral and each producer/exporter maximizes his expected profit. The producer/exporter's optimal behaviour consists in determining the quantity to produce and the level of investment that maximise his profit, given the relations (4) and (5). The expected profit $\pi(F,r,w,q,\beta,s,k)$ of a producer/exporter is given by:

$$\pi(F,r,w,q,\beta,s,k) = wq^I(s,k) - rq^R(s,k) - C(k) \tag{7}$$

Given the values of the couple (β,s) and of the other parameters (level of infrastructures F and producers' size q), each producer/exporter chooses the quantity to produce and the optimal level of investment by maximizing the expression (7) with respect to the variable k [10].

Proposition 1

The optimal level of investment $k^*(F,r,w,q,\beta,s)$ in the quality of production practices is given by:

$$k^*(F,r,w,q,\beta,s) = Min\left\{\frac{\beta(1-s)\,(w+r)q}{2F}\ ,\ 1\right\}$$

where $k^*(F,r,w,q,\beta,s)$ decreases in F and s and increases in q and β.

Proof in the Appendix.

[10] We easily verify that the expected profit is an increasing function of x. Each producer/exporter thus chooses to sell his entire production capacity ($x^* = q$).

Proposition 1 shows how the optimal level of investment in the quality of production practices depends on the characteristics of the environment; notably, the producer/exporter reacts to the characteristics of the environment: the exporting country's level of infrastructures *F,* the producers/exporters' size *q* and the importing country's regulatory environment (degree of effectiveness of the control system and maximum admitted contamination threshold). We assume the following hypothesis [11]:

$$\left| \begin{array}{l} F > \hat{F}(r,w,q) \\ \hat{F}(r,w,q) = \dfrac{1}{2}q(w+r) \end{array} \right. \qquad \text{(H1)}$$

We can verify that the optimal level of investment decreases in *F* (the lower the level of infrastructures, *i.e.* *F* increases, the lower the optimal level of investment) and decreases in s ($\partial k^*(F,r,w,q,\beta,s)/\partial s < 0$). Hence, the laxer the norm (*i.e.* s increases), the lower the level of investment. Moreover, the optimal level of investment increases in the producer/exporter size q ($\partial k^*(F,r,w,q,\beta,s)/\partial q > 0$). Hence, the higher the size *q*, the higher the incentive for producers/exporters to invest in the quality of production practices; these positive effects related to the size are explained by scale economies. Moreover, we verify that an increase in the size *q* implies a positive effect on the individual (or national) compliance probability ($\partial f(s,k^*)/\partial q > 0$) and a reduction of the ratio ($t(s,k) = \dfrac{q^C(s,k)}{q^I(s,k)}$) that represents the proportion of the contaminated quantity on the quantity that passes the inspection and, *de facto*, a reduction of the total contaminated quantity $Q^C(s,k) = N(s)q^C(s,k)$ [12].

Finally, the optimal level of investment increases in the effectiveness of the control system ($\partial k^*(F,r,w,q,\beta,s)/\partial \beta > 0$). In other words, the lower the effectiveness of the border control system, the lower the incentive for producers/exporters to invest in the quality of production practices. Hence, as previously specified, the producer/exporter anticipates (and takes advantage of) control system's imperfections and by reducing the level of quality effort.

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[11] Without loss of generality, we hypothesize that the level of investments (infrastructures and equipment installation, personnel training programmes, certification costs, etc.), which are necessary to comply with a quality *k* production practice, is sufficiently high ($F > \hat{F}(r,w,q)$), so that the investment effort *k* does never attain its maximal level ($k^* = 1$). Since the parameter F may be interpreted as an indicator of the exporting country's level of infrastructures, we consider that the exporting country's level of infrastructures is relatively weak.

[12] Q represents importing country's demand. For each producer/exporter, only the quantity $q^I(s,k)$ passes the inspection at importing country's border. Hence, the market is stabilized at $N(s) = Q/q^I(s,k)$. The total contaminated quantity being given by $Q^C(s,k) = N(s)q^C(s,k)$, we have $Q^C(s,k) = Qt(s,k)$. Variations of $Q^C(s,k)$ follows those of $t(s,k)$. By using (3), (5) and (6), we easily verify that $\partial t(s,k^*)/\partial q < 0$.

3.2. Regulatory reinforcement and effects on producers/exporters' exclusion from the export market

Tightening the regulatory environment always has a negative effect on producers/exporters' profit. Hence, a regulatory reinforcement always implies a reduction of producer's profit ($\partial\pi(F,r,w,q,\beta,s)/\partial s > 0$); the same effect arises if the control system effectiveness is improved ($\partial\pi(F,r,w,q,\beta,s)/\partial\beta < 0$). The effects of tightening the regulation on producers' exclusion from the export market are illustrated by the following proposition.

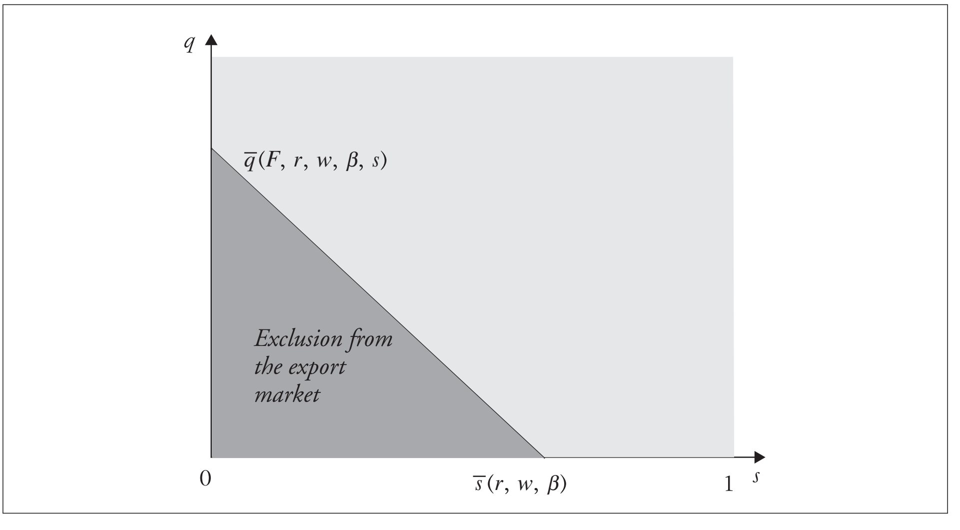
Proposition 2

An exporter is excluded from the market ($\pi(F,r,w,q,\beta,s) < 0$) *if his size is relatively small* ($q < \overline{q}(F,r,w,\beta,s)$)*, the control system relatively reliable* ($\beta > \overline{\beta}(r,w)$)*, and the maximum admitted contamination threshold relatively strict* ($s < \overline{s}(r,w,\beta)$)*.*

Proof in the appendix.

Proposition 2 shows how the effects of a regulatory reinforcement on producers/exporters' exclusion from the export market depend on the extent of this reinforcement, as well as on the degree of effectiveness of the border inspection system and on producers/exporters' size. Tightening the regulation generates an exclusion effect on producers/exporters (*i.e.* $\pi(F,r,w,q,\beta,s) < 0$) only if the norm s is strengthened below the threshold $\overline{s}(r,w,\beta)$ in the presence of a sufficiently effective border control system ($\beta > \overline{\beta}(r,w)$); this exclusion effect notably concerns small producers, whose size is lower than $\overline{q}(F,r,w,\beta,s)$. In other words, countries, whose exporters are characterized by a relatively low size, will be excluded from importing countries, when these latter require a sufficiently strict norm and implement a relatively effective control at borders (Figure 1).

Figure 1. **Tightening the norm and effects on producers/exporters' exclusion from the export market if $\beta > \overline{\beta}(r,w)$:**



Tightening the norm never implies the exclusion effect, when strong imperfections characterize the border inspection system or producers/exporters' size is sufficiently high (*i.e.* higher than the threshold $\overline{q}(F,r,w,\beta,s)$). It is worthy to notice that the critical size $\overline{q}(F,r,w,\beta,s)$ is a function of the economic environment, notably it depends on the exporting country's state of infrastructures (the lower the level of infrastructures, the higher is the threshold size) and of the importing country's regulatory environment. This implies that changes in the regulatory environment *finally* influence, *via* the critical size, the exclusion-effect; notably increasing the degree of control effectiveness ($\partial\overline{q}(F,r,w,\beta,s)/\partial\beta > 0$) and reinforcing the norm ($\partial\overline{q}(F,r,w,\beta,s)/\partial s < 0$) increase the extent of the exclusion effect.

3.3. Regulatory reinforcement, producer/exporter strategic behaviour and effects on exporting country's compliance capacity

As previously showed, the quality effort decreases in s and increases in the effectiveness of the control system. The effort-decreasing effect of a laxer norm and the effort-increasing effect of a more effective control system show that a lax norm may not lower the incentive for producers/exporters to invest, notably when associated with an improvement of the control system effectiveness. Equivalently, an increase in control system imperfections does not *a priori* weaken the producer/exporter's quality effort if the public norm s is adequately tightened. Producers/exporters strategic behaviour finally affects the probability $f(s, k)$, and thus the domestic long-term compliance capacity, and the contaminated quantity, as illustrated by the following proposition 3. For a given level of quality effort k, a tightening of the regulation (s decreases) lowers the compliance probability $f(s, k)$ and thus the probability $g(s, k)$ to pass the inspection. This may in turn generate losses for producers/exporters (increase of rejections, reduction of profit). As a consequence, a tightening of regulation may incentive producers/exporters to improve the quality of production practices, taking into account the costs of a quality improvement. Nevertheless, the effect of the tightening of regulation on quality investments crucially depends on the effectiveness of the control system. Hence, as previously specified, producers/exporters choose the optimal level of investment by taking into account the probability $g(s, k)$ to pass the inspection.

***Proposition** 3*

There exist $\hat{\beta}(F,r,w,q,s)$ and $\hat{q}(F,r,w,s)$ such that:

(i) $\dfrac{\partial f(s,k^*)}{\partial s} < 0$, $\dfrac{\partial q^R(s,k^*)}{\partial s} > 0$ *and* $\dfrac{\partial q^C(s,k^*)}{\partial s} > 0$ *if and only if* $\beta > \hat{\beta}(F,r,w,q,s)$ *and* $q > \hat{q}(F,r,w,s)$

(ii) if $q < \hat{q}(F,r,w,s)$ *or* $\beta \leq \hat{\beta}(F,r,w,q,s)$ *then* $\dfrac{\partial f(s,k^*)}{\partial s} > 0$, $\dfrac{\partial q^R(s,k^*)}{\partial s} < 0$ *and* $\dfrac{\partial q^C(s,k^*)}{\partial s} < 0$.

Proof in the appendix.

Proposition 3 *(i)* illustrates the conditions whereby a reinforcement of the maximum admitted contamination threshold implies a sufficiently high exporter's investment so that the compliance probability increases, the rejected quantities and the contaminated quantities decrease. Hence, the norm reinforcement implies a positive effect both for the exporting country and its operators ($f(s, k)$ and $q^R(s,k^*)$) and for the importing country ($q^C(s,k^*)$) only when two elements coexist: a sufficiently effective control system ($\beta > \hat{\beta}(F,r,w,q,s)$) and a size that is not too small ($q > \hat{q}(F,r,w,s)$). A small producers' size or an ineffective border control system imply a negative effect on all the indicators (ii). When the norm s is reinforced an ineffective control system implies that producers under-invest in production practices (hence the investment k increases, but not enough to determine a positive effect on f). In other words, the producer increases his level of investment but less than proportionally with respect to the norm reinforcement. This behaviour implies a negative effect on $f(s, k)$. Even if the control procedure is improved, this result still holds when the producer size is relatively small ($q < \hat{q}(F,r,w,s)$). Hence, countries where producers' size is small are penalized by a reinforcement of the norm, with respect to the compliance probability and rejected quantity. Hence, the reinforcement of the norm s (s decreases) does not imply the same effects for small and large producers. Hence small producers are worse off, when the norm is reinforced, whereas large producers are better off (in terms of compliance probability and rejected quantity).

4. Regulatory reinforcement and consumers' health protection

The reinforcement of the maximum admitted contamination threshold is justified by the objective to protect consumers' health, notably by assuring the safety of products imported by third countries. In this section, we analyze the conditions whereby a norm's reinforcement effectively protects consumers' health. A public criterion is thus defined that makes it possible to measure health gains or losses when a norm's reinforcement is set by the public authority of the importing country.

In the previous section, we pointed out the role of $Q^C(s,k)$ as an indicator of the contaminated quantities (with respect to the norm s) that passes the inspection at importing country's border. Nevertheless, this variable is not sufficient to correctly define the health gains or losses associated with a regulatory reinforcement. Given that contamination is always defined with respect to a given contamination threshold, it is necessary to take into account the relation among quantities consumed by a given consumer, their contamination rates and the related effects of consumption on a consumer's (or population's) health. Considering this relation needs to dispose of epidemiological data and goes beyond the scope of this paper. Nevertheless, we raise the question whether a regulatory reinforcement makes it possible (or not) to eliminate from the market products that are contaminated with respect also to the laxer norm, *i.e.* evolving from the norm s_0 to a stricter norm ($s_1 < s_0$) makes it possible or not to reduce the contaminated quantities that are consumed in the importing country and are contaminated with respect to both the norm s_0 and the norm s_1, and we assume that such a reduction of the total contaminated quantities implies a lower risk for consumers' health. Hence, we consider that a threshold's reinforcement from s_0 to s_1 improves consumers' health when it results in a decrease of the total contaminated quantity that passes the inspection (with respect to both the thresholds s_0 and s_1), *i.e.* if and only if the following conditions are both verified:

$$Q^C(s_0,k^*(s_1)) < Q^C(s_0,k^*(s_0)) \tag{C1}$$

$$Q^C(s_1,k^*(s_1)) < Q^C(s_1,k^*(s_0)) \tag{C2}$$

Let us denote by s_i the maximum admitted contamination threshold fixed by the importing country and consider a norm's reinforcement whereby the country initially fixes the level s_0 and then reinforces to the stricter level s_1. We thus compare the total contaminated quantity that passes the inspection and does not comply with the norm s_j $(j=0,1)$ when the norm s_1 is in force $(Q^C(s_j,k^*(s_1)))$ to the total contaminated quantity that passes the inspection and does not comply with the norm s_j $(j=0,1)$ when the norm s_0 is in force $(Q^C(s_j,k^*(s_0)))$. Given conditions (C1) and (C2), the health improvement condition can be expressed as follows:

$$Q^C(s_j,k^*(s_1)) < Q^C(s_j,k^*(s_0)),\ j=0,1 \tag{8}$$

First, we point out that in the absence of a border control $(\beta=0)$, the investment effort in the quality of production practices is null $(k^*(s_i)=0)$. In this extreme case, a norm's reinforcement has no effect on the producer's strategic behavior and thus does not imply any variation in the total contaminated quantity that passes the inspection. In the opposite case, when the control system is perfect $(\beta=1)$, norm reinforcement always implies a decrease in the total contaminated quantity that passes the inspection and thus a consumer health improvement. When the border control system is imperfect $(\beta\in]0,1[)$, the effect of norm reinforcement depends on the extent of control imperfections and on the producer/exporter's size. The following proposition illustrates the conditions whereby the norm reinforcement does achieve an improvement of consumer health protection, i.e. a decrease of the total contaminated quantities $Q^C(sj,k^*(s_i))$, $j = 0,1$.

***Proposition** 4*

A reinforcement of the maximum admitted contamination threshold (from the threshold s_0 to the threshold s_1) implies a reduction of the levels of contamination at s_0 and s_1 $(Q^C(s_j,k^*(s_1)) < Q^C(s_j,k^*(s_0)),\ j=1,2)$ if at least one of the following conditions is verified:

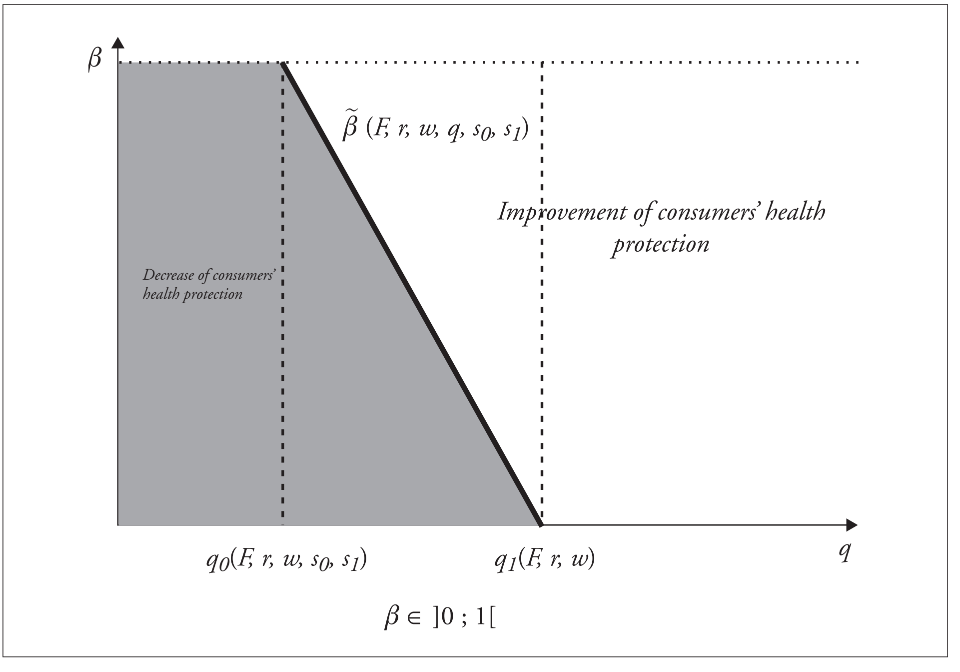
(i) exporters' size is relatively large $(q \geq q_1(F,r,w))$

(ii) exporters' size is moderately large $(q_0(F,r,w,s_0,s_1) < q < q_1(F,r,w))$, but the control system is sufficiently reliable $(\beta > \tilde{\beta}(F,r,w,q,s_0,s_1))$

Proof in the appendix.

A regulatory reinforcement does not achieve the expected decrease of the total contaminated quantity when imports come from a country whose producers are characterized by a too small production capacity ($q < q_0(F,r,w,s_0,s_1)$). Producers belonging to this exporting country's typology (Figure 2) do not sufficiently react to regulatory reinforcements regardless of the border control system effectiveness.

Figure 2. **Tightening the norm and effects on consumers' health protection: the role of producers/exporters' size and on the effectiveness of the border inspection system**



Nevertheless, we verify that the critical size $q_0(F,r,w,s_0,s_1)$ increases in F. This means that an exporting country that improves infrastructures and services may incentive small producers to meet importing country's requirements. Hence, a positive change in the economic environment of the exporting country may prompt small producers to renounce undertaking "risky" behaviors.

With respect to the importing country, a regulatory reinforcement achieves the health improvement objective without having to improve border control effectiveness, if producers are sufficiently large ($q \geq q_1(F,r,w)$). The critical size $q_1(F,r,w)$ increases in F. Hence, the lower the infrastructures and services in exporting country (F increases), the higher is the critical size whereby a regulation reinforcement implies an improvement of consumers' health in the importing country. In other words, a positive evolution in exporting country's infrastructures (F decreases) benefits importing country in the sense that it implies a higher effectiveness of the regulation reinforcement strategy. Finally, as illustrated by figure 2, a regulation's reinforcement is effective with respect to the health criterion if it is associated with an improvement of border control system effectiveness.

5. Consumers' health protection and exclusion effect

The negative effect of a tightening of the regulation on producers/exporters' exclusion from the export market may be justified by the objective to protect consumers' health by assuring the safety of food imported from third countries. In this section, we raise the question whether producers/exporters' exclusion is always justified by the objective of consumers' health protection. The following proposition 5 shows the conditions whereby a strengthening of the regulation generates producers' exclusion without improving consumers' health.

Proposition 5

There exist $q'(F,r,w,\beta,s_0,s_1)$ and $r'(F,w,\beta,s_0,s_1)$ whereby reinforcing the norm from the level s_0 to s_1 increases the exclusion without reducing the total contaminated quantities if and only if $s_1 < \overline{s}(r,w,\beta)$, $\beta > \underline{\beta}(r,w)$, $r < r'(F,w,\beta,s_0,s_1)$ and $q < q'(F,r,w,\beta,s_0,s_1)$.

Proof in the appendix.

Proposition 5 shows the conditions whereby the norm reinforcement increases the exclusion effect and *at the same time*, increases the total contaminated quantities thus reducing consumers' health protection.

Let us consider that the norm is reinforced from the level s_0 to the more stringent level s_1. As showed by proposition 2, tightening the norm implies a negative exclusion effect *if and only if* the norm is sufficiently strict ($s_1 < \overline{s}(r,w,\beta)$) and the control system relatively effective ($\beta > \underline{\beta}(r,w)$); this exclusion effect notably concerns exporters, whose size belongs to the interval $[Max\{0,\overline{q}(F,r,w,\beta,s_0)\};\overline{q}(F,r,w,\beta,s_1)[$ [13]. The $N(s_0)$ exporters with production capacity lower than $\overline{q}(F,r,w,\beta,s_1)$ are excluded from the market if the norm is reinforced from s_0 to s_1 and, given the assumption of free entry and exit, other $N(s_1)$ exporters with production capacity higher than $\overline{q}(F,r,w,\beta,s_1)$ will get the lost market share. We also verify that tightening the norm from the level s_0 to the more stringent level s_1 reduces the total contaminated quantity (and thus improves consumers' health protection) if and only if producers/exporters' size is relatively high, notably higher than the threshold $q'(F,r,w,\beta,s_0,s_1)$. Hence, sourcing from exporters with size relatively lower than this threshold implies an increase of the total contaminated quantities.

We verify that $\overline{q}(F,r,w,\beta,s_1) < q'(F,r,w,\beta,s_0,s_1)$ *if and only if* the rejection costs are relatively low ($r < r'(F,w,\beta,s_0,s_1)$). Hence, tightening the norm implies a negative exclusion effect of sufficiently small producers/exporters and at the same time reduces consumers' health protection by increasing the contaminated quantities *if* imports are sourced from exporters, whose size is not sufficiently high (notably, with size

[13] Hence, if $s_0 < \overline{s}(r, w, \beta)$, exporters whose size is lower than the threshold $\overline{q}(F, r, w, \beta, s_0)$ are excluded when the norm s_0 is in force. The reinforcement from s_0 to s_1 implies the exclusion from exporters whose size belongs to $[\overline{q}(F, r, w, \beta, s_0)$; $\overline{q}(F, r, w, \beta, s_1)[$. If instead $s_0 > \overline{s}(r, w, \beta)$, the norm s_0 does not imply exclusion and the norm reinforcement from s_0 to s_1 implies the exclusion of exporters whose size belongs to $[0$; $\overline{q}(F, r, w, \beta, s_1)[$.

belonging to $[\overline{q}(F,r,w,\beta,s_1);q'(F,r,w,\beta,s_0,s_1)[$. Looking in more details into this result, the norm reinforcement implies the exclusion of the $N(s_0)$ exporters, whose size is lower than $\overline{q}(F,r,w,\beta,s_1)$; the $N(s_1)$ exporters with size higher than $\overline{q}(F,r,w,\beta,s_1)$ that get the lost market share won't be able to ensure a better consumers' health protection if their size is not sufficiently high (higher than $q'(F,r,w,\beta,s_0,s_1)$). Hence, in this case, the norm reinforcement that implies the exclusion of small-sized exporters to the benefit of larger-sized ones worsens consumers' health protection. On the contrary, for the same context of parameters (s_1,β,r), sourcing from exporters, whose size is relatively high (*i.e.* higher than the threshold $q'(\beta,w,r,F,s_0,s_1)$) implies that the norm reinforcement generates exclusion of relatively small exporters, while improving consumers' health protection.

6. Conclusion

European food safety regulation is nowadays source of controversy. First, several European consumers' associations regularly point out the existence of high contaminated quantities on the market. Second, developing countries consider that the reinforcement of European regulation at a more exigent level than the standards set by the *Codex Alimentarius* reduces the access of their exports to international markets.

This debate pertains to the wider question of economic and sanitary legitimacy of European regulation. The literature often analyzes this question by assessing the negative impact of European legislation on trade flows with third countries. European public authorities reply by pointing out health objectives and notably the necessity to assure the safety of agri-food products.

The Industrial Economics model proposed in this paper shows the reason why it is crucial to take into account the role of the control system at importing country's borders as well as the strategic dimension that characterize the relation between a regulation that is based on "obligations of results" (*i.e.* norm pertaining to the final product characteristics) and the investment on "means" (notably production practices) undertaken by producers/exporters. We have shown that depending on the characteristic of exporters (size), a regulatory reinforcement may reduce consumers' health protection if not accompanied by an adequate improvement of the control system effectiveness, notably when exporters' size is relatively low. In addition, we have shown that a regulatory reinforcement may imply the exclusion of relatively small exporters and, at same time, reduce consumers' health protection.

Hence, more and more exigent sanitary measures may prompt relatively small-sized producers to under-invest in the quality of production practices. In a context of an imperfect control system, the gap between the investment suitable for the importing country and the one that is undertaken by producers may strongly increase the risk related to imports. Hence, the existence of large contaminated quantities on the market, characterized by contamination rates that largely exceed the maximum admitted level of contamination, may be partially explained by such strategic behaviors. This phenomenon of under-investment may also concern larger producers when norms are reinforced and the border inspections are imperfect.

The existence of these producers, who may undertake risky behaviors, constitutes a problem for the importing country (in terms of sanitary risk), but also for the exporting country, which risks a decrease in the reputation of its products in the long term as well as a reduction in its compliance capacity. Hence, in the context of a "co-governance" of sanitary risk between the North and the South, the subsidies addressed by importing countries to exporting countries' producers have to take into account these considerations and have to be addressed not only to producers that risk to be excluded from market transactions, but also to small producers that cannot bear the necessary investments and thus may under-invest by taking advantage of control imperfections. Moreover, large size increasing the incentive for producers to comply with importing countries' requirement and also reducing the exclusion effect of a regulatory reinforcement, policies favoring the horizontal coordination among producers' exporters may be envisaged.

Finally, it is worthy to notice that our results rely on two hypotheses that could be released in the context of a further development of this research. The first hypothesis specifies that the market price is not affected by variations of the contamination threshold and the second one specifies that the demand addressed to exporters is constant. The direct effect of evolutions of contamination thresholds on the market price remains an open question from an empirical point of view, which is worth being addressed by quantitative studies. However, we can assume that if this framework of hypotheses is released, the strengthening of the regulation (*i.e.* the reduction of the maximum admitted contamination threshold) would logically lead to an increase of price and a decrease of demand. From a normative perspective, the contamination threshold elasticity of price and the price elasticity of demand could thus play a crucial role in the level of investment chosen by producers [14]. The various indicators (notably the critical size and the critical threshold of control effectiveness, as illustrated in proposition 3) would evolve under the combined effect of two factors: the increase of the level of a producer's investment due to the price increase and the reduction of the quantities ordered from producers (decrease of demand). By intuition, when the decrease of demand is not offset by the competitive advantage due to a regulatory reinforcement, the main results of our model should remain qualitatively unchanged, even if the level of the various indicators could vary: level of investment, supply passing the inspection, and various critical thresholds illustrated in our model results (critical size, control effectiveness and contamination critical thresholds, etc.). However, taking into account the correlation between the contamination threshold and the price and releasing the hypothesis of a constant demand could constitute an interesting extension of the theoretical analysis proposed in this paper by drawing attention to more complex trade-offs pertaining, for example, to the issue of producers' exclusion.

[14] For example, in the case of a regulatory reinforcement, the critical size below which the producer undertakes an underinvestment behaviour (implying an increase of the contaminated quantities) would depend on the extent of the consequent increase of the price. Notably, this critical size would be relatively lower if producers obtain a higher price. Furthermore, the exclusion critical size (see proposition 2) would also be lower. Hence, smaller-sized producers would not be systematically excluded from the export activity.

Indeed, this question could be addressed not only by considering the characteristics of excluded producers (minimal size needed for participation) but also by taking into account the evolution of the number of producers that satisfy the demand [15].

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[15] In our model, the number of participating producers is inversely proportional to the individual quantity passing the inspection (see footnote 12). If a variable demand is taken into account in the analysis, a regulatory reinforcement would have an ambiguous effect on the number of participating producers.

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MATHEMATICAL APPENDIX

Proof of Proposition 1

By using (7), the producer/exporter's maximization program is given by $\underset{x}{Max}\,\pi(F,r,w,x,\beta,s)$. We determine $\dfrac{\partial\pi(F,r,w,x,\beta,s)}{\partial x} = wg(s,k) - r(1-g(s,k))$. We easily verify that $\dfrac{\partial\pi(F,r,w,x,\beta,s)}{\partial x} > 0$ for $\pi(F,r,w,x,\beta,s) \geq 0$. The function $\pi(F,r,w,x,\beta,s)$ decreases in x. We thus obtain the optimal quantity produced x^*:

$$x^* = q \tag{A0}$$

By using (7) and (A0), the producer/exporter's maximization program is given by $\underset{k}{Max}\,\pi(F,r,w,q,\beta,s)$. We thus obtain the optimal investment effort $k^*(F,r,w,q,\beta,s)$ that is given by:

$$k^*(F,r,w,q,\beta,s) = Min\left\{\frac{\beta(1-s)\,(w+r)q}{2F},\ 1\right\} \tag{A1}$$

By using (A1), we easily verify that the function $k^*(F,r,w,q,\beta,s)$ decreases in s and increases in β, decreases in q, and decreases in F. By substituting (A1) into (7), the profit $\pi(F,r,w,q,\beta,s)$ is given by:

$$\pi(F,r,w,q,\beta,s) = \frac{q}{4F}\{\beta^2(1-s)^2(w+r)^2 q + 4F[w - \beta(1-s)(w+r)]\} \tag{A2}$$

By using (A2) we easily verify that $\partial\pi(F,r,w,q,\beta,s)/\partial s > 0$ and $\partial\pi(F,r,w,q,\beta,s)/\partial\beta < 0$.

Proof of Proposition 2

By using (A2), we easily verify that $\pi(F,r,w,q,\beta,s) \geq 0$ if and only if the following condition is verified: $\beta^2(1-s)^2(w+r)^2 q + 4F[w-\beta(1-s)\,(w+r)] \geq 0$. Let us denote by $\bar{s}(r,w,\beta) = 1 - \dfrac{w}{(r+w)\beta}$, $\bar{\beta}(r,w) = \dfrac{w}{(w+r)}$, and $\bar{q}(F,r,w,\beta,s) = \dfrac{4F[\beta(1-s)\,(w+r)-w]}{\beta^2(1-s)^2(w+r)^2}$.

If $\beta \leq \bar{\beta}(r,w)$ then $\pi(F,r,w,q,\beta,s) \geq 0$ $\forall q$ and $\forall s$.

If $\beta > \bar{\beta}(r,w)$ we distinguish the following cases.

If $s \geq \bar{s}(r,w,\beta)$ then $\pi(F,r,w,q,\beta,s) \geq 0$ $\forall q$.

If $s < \bar{s}(r,w,\beta)$ then $\pi(F,r,w,q,\beta,s) \geq 0$ if and only if $q \geq \bar{q}(F,r,w,\beta,s)$.

Proof of Proposition 3

By substituting (A1) in (2), we determine the probability $f(s,k^*)$ of compliance with the norm s:

$$f(s,k^*) = 1-(1-s)(1-k^*) = 1-(1-s)\left[1-\frac{\beta(1-s)(w+r)q}{2F}\right] \tag{A3}$$

By using (2), the probability to pass the inspection given by (3) can be written as follows:

$$g(s,k) = 1-\beta(1-s)(1-k) \tag{A4}$$

By substituting (A1) in (A4) we determine the probability to pass the inspection when the norm s is in force $g(s,k^*)$:

$$g(s,k^*) = 1-\beta(1-s)(1-k^*) = 1-\beta(1-s)\left[1-\frac{\beta(1-s)(w+r)q}{2F}\right] \tag{A5}$$

By substituting (A5) in (4) we determine the rejected quantity when the norm s is in force $q^R(s,k^*)$ given by:

$$q^R(s,k^*) = q\{\beta(1-s)\left[1-\frac{\beta(1-s)(w+r)q}{2F}\right]\} \tag{A6}$$

By substituting (A5) in (5) we determine the quantity that passes the inspection (or imported quantity) when the norm s is in force $q^I(s,k^*)$:

$$q^I(s,k^*) = q\{\beta(1-s)\left[1-\frac{\beta(1-s)(w+r)q}{2F}\right]\} = q\{1-\beta(1-s)\left[1-\frac{\beta(1-s)(w+r)q}{2F}\right]\} \tag{A7}$$

By substituting (A5) in (6) we determine the contaminated quantity (non compliant with the norm s) that passes the inspection when the norm s is in force $q^C(s,k^*)$:

$$q^C(s,k^*) = q(1-\beta)(1-s)\left[1-\frac{\beta(1-s)(w+r)q}{2F}\right] \tag{A8}$$

By using (A1), (A3), (A6) we determine:

$$\frac{\partial f(s,k^*)}{\partial s} = \frac{F-q\beta(1-s)(r+w)}{F} \tag{A9}$$

$$\frac{\partial q^R(s,k^*)}{\partial s} = -\beta q\{\frac{F-q\beta(1-s)(r+w)}{F}\} \tag{A10}$$

$$\frac{\partial q^C(s,k^*)}{\partial s} = -(1-\beta)q\{\frac{F-q\beta(1-s)(r+w)}{F}\} \tag{A11}$$

By using (A9)-(A11), we easily verify that $\frac{\partial f(s,k^*)}{\partial s} > 0$, $\frac{\partial q^R(s,k^*)}{\partial s} < 0$ and $\frac{\partial q^C(s,k^*)}{\partial s} < 0$ if and only if $F - q\beta(1-s)(w+r) > 0$. Let us denote $\hat{\beta}(F,r,w,q,s) = \frac{F}{q(1-s)(w+r)}$ and $\hat{q}(F,r,w,s) = \frac{F}{(1-s)(w+r)}$.

If $q < \hat{q}(F,r,w,s)$ then $\frac{\partial f(s,k^*)}{\partial s} > 0$, $\frac{\partial q^R(s,k^*)}{\partial s} < 0$ and $\frac{\partial q^C(s,k^*)}{\partial s} < 0$ $\forall \beta$.

If $q > \hat{q}(F,r,w,s)$ we distinguish the following cases:

If $\beta < \hat{\beta}(F,r,w,q,s)$ then $\frac{\partial f(s,k^*)}{\partial s} > 0$, $\frac{\partial q^R(s,k^*)}{\partial s} < 0$ and $\frac{\partial q^C(s,k^*)}{\partial s} < 0$.

If $\beta > \hat{\beta}(F,r,w,q,s)$ then $\frac{\partial f(s,k^*)}{\partial s} < 0$, $\frac{\partial q^R(s,k^*)}{\partial s} > 0$ and $\frac{\partial q^C(s,k^*)}{\partial s} > 0$.

We easily verify that $\frac{\partial f(s,k^*)}{\partial s} > 0$, $\frac{\partial q^R(s,k^*)}{\partial s} < 0$ and $\frac{\partial q^C(s,k^*)}{\partial s} < 0$ if and only if $\beta < \hat{\beta}(F,r,w,q,s)$ or $q < \hat{q}(F,r,w,s)$.

We easily verify that $\frac{\partial f(s,k^*)}{\partial s} < 0$, $\frac{\partial q^R(s,k^*)}{\partial s} > 0$ and $\frac{\partial q^C(s,k^*)}{\partial s} > 0$ if and only if $\beta > \hat{\beta}(F,r,w,q,s)$ and $q > \hat{q}(F,r,w,s)$.

Proof of Proposition 4

Let us denote by $f(s_j, k^*(s_i))$ the probability of compliance with the norm s_j when the norm s_i is in force, where $k^*(s_i)$ is given by (A1):

$$f(s_j, k^*(s_i)) = 1 - (1-s_j)(1-k^*(s_i)) \tag{A12}$$

Let us denote by $q^C(s_j, k^*(s_i))$ the contaminated quantity non compliant with the norm s_j that passes the inspection when the norm s_i is in force, given by:

$$q^C(s_j, k^*(s_i)) = \frac{q(1-\beta)(1-s_j)[2F - \beta q(1-s_i)(w+r)]}{2F} \tag{A13}$$

Let us denote by $Q^C(s_j, k^*(s_i)) = Nq^C(s_j, k^*(s_i))$ the total contaminated quantity non compliant with the norm s_j that passes the inspection when the norm s_i is in force.

By using (A6), the quantity that passes the inspection (or imported quantity) when the norm s_i is in force $q^I(s_i, k^*(s_i))$ is given by:

$$q^I(s_i, k^*(s_i)) = \frac{q\{2F[1-\beta(1-s_i)] + \beta^2 q(1-s_i)^2(w+r)]\}}{2F} \tag{A14}$$

The contamination rate to the norm s_j when the norm s_i is in force $t(s_j, k^*(s_i))$ is given by:

$$t(s_j, k^*(s_i)) = \frac{q^C(s_j, k^*(s_i))}{q^I(s_i, k^*(s_i))} \quad \text{(A15)}$$

By using (A13)-(A15) the contamination rate to the norm s_j when the norm s_i is in force $t(s_j, k^*(s_i))$ is given by:

$$t(s_j, k^*(s_i)) = \frac{(1-\beta)(1-s_j)[2F - \beta q(1-s_i)(w+r)]}{2F[1-\beta(1-s_i)] + \beta^2 q(1-s_i)^2 (w+r)]} \quad \text{(A16)}$$

Given that $N = \dfrac{Q}{q^I(s_i, k^*(s_i))}$ we easily verify that $Q^C(s_j, k^*(s_i)) = Qt(s_j, k^*(s_i))$ and thus we have $Q^C(s_j, k^*(s_1)) < Q(s_j, k^*(s_0)) \Leftrightarrow t(s_j, k^*(s_1)) < t(s_j, k^*(s_0))$, with $j=0,1$.

Absence of border control ($\beta = 0$). By using (A1), (A12)-(A13) we easily verify that if $\beta = 0$ then we have $k^*(s_i) = 0, i = 0,1,$ $f(s_j, 0) = s_j,$ $q^C(s_j, 0) = q(1-s_j)$ and $Q^C(s_j, 0) = Nq(1-s_j)$. Hence, we verify that $Q^C(s_j, k^*(s_1)) = Q(s_j, k^*(s_0)) = Nq(1-s_j),\ j = 0,1.$

Perfect border control system ($\beta = 1$). If the norm s_0 is in force, only the quantity that complies with the norm s_0 passes the inspection. By using (A12) we have $f(s_j, k^*(s_0)) = 1-(1-s_j)(1-k^*(s_0))$. We easily verify that the total contaminated quantity non compliant with the norm s_j that passes the inspection when the norm s_0 is in force $Q(s_j, k^*(s_0))$ is given by:

$$Q^C(s_j, k^*(s_0)) = \begin{vmatrix} 0 & si \quad s_j = s_0 \\ Nq[f(s_0, k^*(s_0)) - f(s_1, k^*(s_0))] & si \quad s_j = s_1 \end{vmatrix} \quad \text{(A17)}$$

By using (A12), (A17) can be written as follows:

$$Q^C(s_j, k^*(s_0)) = \begin{vmatrix} 0 & si \quad s_j = s_0 \\ Nq(s_0 - s_1)(1-k^*(s_0)) & si \quad s_j = s_1 \end{vmatrix} \quad \text{(A18)}$$

If the norm s_1 is in force and the control system is perfect, only the quantity compliant with s_1 passes the inspection. This quantity is also compliant with s_0. We verify that the total contaminated quantity non compliant with s_j that passes the inspection when s_1 is in force is given by $Q^C(s_j, k^*(s_1)) = 0$. We verify that $Q^C(s_0, k^*(s_1)) = Q^C(s_0, k^*(s_0)) = 0$ and $Q^C(s_1, k^*(s_1)) < Q^C(s_1, k^*(s_0))$. Thus we have $Q^C(s_j, k(s_1)^*) \le Q^C(s_j, k(s_0)^*)$.

We now analyze the case $0 < \beta < 1$. We verify that $t(s_j, k^*(s_1)) < t(s_j, k^*(s_0))$ if and only if $\tilde{\beta} < \beta < \overline{\beta}$ with $\tilde{\beta}$ and $\overline{\beta}$ respectively given by:

$$\begin{cases} \tilde{\beta}(F,r,w,q,s_0,s_1) = \dfrac{F(2-s_0-s_1) - \sqrt{F^2(s_0-s_1)^2 + 2Fq(w+r)(1-s_0)(1-s_1)}}{q(w+r)(1-s_0)(1-s_1)} \\ \tilde{\beta}(F,r,w,q,s_0,s_1) = \dfrac{F(2-s_0-s_1) + \sqrt{F^2(s_0-s_1)^2 + 2Fq(w+r)(1-s_0)(1-s_1)}}{q(w+r)(1-s_0)(1-s_1)} \end{cases} \tag{A19}$$

By using (A1) and (A19) we verify that $k^*(s_i) \le 1 \Leftrightarrow \beta \le \beta'$, with $\beta' = \dfrac{2F}{q(1-s_i)(w+r)}$. We verify that $\overline{\beta} > \beta'$ and thus $\forall k^*(s_i) \le 1$ we have $\beta < \overline{\beta}$. Hence we have $t(s_j, k^*(s_1)) < t(s_j, k^*(s_0))$ if and only if $\beta > \tilde{\beta}$.

By using (A19) we verify that $\tilde{\beta} > 0$ if and only if $2F - q(w+r) > 0$. Let us denote $q_1(F,r,w) = \dfrac{2F}{w+r}$. Then, $\tilde{\beta} > 0$ if and only if $q < q_1(F,r,w)$.

By using (A19) we verify that $\tilde{\beta} < 1$ if and only if $q_0 < q < q''$ with q_0 and q'' respectively given by:

$$\begin{cases} q_0(F,r,w,s_0,s_1) = \dfrac{F[3-s_0-s_1-\sqrt{5+s_0^2-(2-s_1)s_1-2s_0(1+s_1)}}{(1-s_0)(1-s_1)(r+w)} \\ q''(F,r,w,s_0,s_1) = \dfrac{F[3-s_0-s_1+\sqrt{5+s_0^2-(2-s_1)s_1-2s_0(1+s_1)}}{(1-s_0)(1-s_1)(r+w)} \end{cases} \tag{A20}$$

with $0 < q_0(F,r,w,s_0,s_1) < q''(F,r,w,s_0,s_1)$.

We also verify that $\forall k^*(s_i) \le 1$ we have $q < q''(F,r,w,s_0,s_1)$. Hence, $\tilde{\beta} < 1$ if and only if $q > q_0(F,r,w,s_0,s_1)$.

We easily verify that $q_0(F,r,w,s_0,s_1) < q_1(F,r,w)$.

By using (A19) we thus distinguish the following cases:

If $q \le q_0(F,r,w,s_0,s_1)$ then $\tilde{\beta} \ge 1$. Hence, $t(s_j, k^*(s_1)) > t(s_j, k^*(s_0)), \forall \beta \in]0,1[$ and $Q^C(s_j, k^*(s_1)) > Q^C(s_j, k^*(s_0)), \forall \beta \in]0,1[$.

If $q \ge q_1(F,r,w)$ then $\tilde{\beta} \le 0$. Hence, $t(s_j, k^*(s_1)) < t(s_j, k^*(s_0)), \forall \beta \in]0,1[$ and $Q^C(s_j, k^*(s_1)) < Q^C(s_j, k^*(s_0)), \forall \beta \in]0,1[$.

If $q_0(F,r,w,s_0,s_1) < q < q_1(F,r,w)$ then $0 < \tilde{\beta} < 1$. Hence $t(s_j, k^*(s_1)) < t(s_j, k^*(s_0)) \Leftrightarrow \beta > \tilde{\beta}$ and $Q^C(s_j, k^*(s_1)) < Q^C(s_j, k^*(s_0)) \Leftrightarrow \beta > \tilde{\beta}$.

Proof of Proposition 5

Following proposition 2 we verify that:

Case 1: when the norm s_0 is in force, $\pi(F,r,w,q,\beta,s_0)<0$ *if and only if* $s_0<\bar{s}(r,w,\beta)$, $\beta>\bar{\beta}(r,w)$ and $q<\bar{q}(F,r,w,\beta,s_0)$.

Case 2: if $s_0\geq\bar{s}(r,w,\beta)$ or $\beta\leq\bar{\beta}(r,w)$ or $q\geq\bar{q}(F,r,w,\beta,s_0)$ then $\pi(F,r,w,q,\beta,s_0)\geq 0$.

When the norm s_1 is in force: $\pi(F,r,w,q,\beta,s_1)<0$ *if and only if* $s_1<\bar{s}(r,w,\beta)$, $\beta>\bar{\beta}(r,w)$ and $q<\bar{q}(F,r,w,\beta,s_1)$.

We verify that $\dfrac{\partial\bar{q}(F,r,w,\beta,s)}{\partial s}<0$ and thus we have $\bar{q}(F,r,w\beta,s_0)<\bar{q}(F,r,w\beta,s_1)$.

We thus distinguish the following two cases.

In **Case** 1, the reinforcement from s_0 to the stricter level s_1 generates the exclusion *if and only if* $s_1<\bar{s}(r,w,\beta))$, $\beta>\bar{\beta}(r,w)$, and $q\in[\bar{q}(F,r,w,\beta,s_0);\bar{q}(F,r,w,\beta,s_1)[$.

In **Case** 2, the reinforcement from s_0 to the stricter level s_1 generates the exclusion *if and only if* $s_1<\bar{s}(r,w,\beta)$, $\beta>\bar{\beta}(r,w)$ and $q\in[0;\bar{q}(F,r,w,\beta,s_1)[$.

Finally, the reinforcement from s_0 to the stricter level s_1 generates the exclusion if and only if $s_1<\bar{s}(r,w,\beta)$, $\beta>\bar{\beta}(r,w)$ and $q\in[Max\{0,\bar{q}(F,r,w,\beta,s_0)\};\bar{q}(F,r,w,\beta,s_1)[$.

We also verify that $Q^C(s_j,k^*(s_1))<Q^C(s_j,k^*(s_0))\Leftrightarrow q'(F,r,w,\beta,s_0,s_1)<q<q'''(F,r,w,\beta,s_0,s_1)$, with $q'(F,r,w,\beta,s_0,s_1)$ and $q'''(F,r,w,\beta,s_0,s_1)$ respectively given by:

$$\left|\begin{array}{l} q'(F,r,w,\beta,s_0,s_1)=\dfrac{F[1+(2-s_0-s_1)\beta-\sqrt{1+2(2-s_0-s_1)\beta+(s_0-s_1)^2\beta^2}]}{(1-s_0)(1-s_1)(r+w)\beta^2} \\ q'''(F,r,w,\beta,s_0,s_1)=\dfrac{F[1+(2-s_0-s_1)\beta+\sqrt{1+2(2-s_0-s_1)\beta+(s_0-s_1)^2\beta^2}]}{(1-s_0)(1-s_1)(r+w)\beta^2} \end{array}\right. \tag{A21}$$

with $0<q'(F,r,w,\beta,s_0,s_1)<q'''(F,r,w,\beta,s_0,s_1)$.

We also verify that $\forall k^*(s_i)\leq 1$ we have $q<q'''(F,r,w,\beta,s_0,s_1)$. Hence $Q^C(s_j,k^*(s_1))<Q^C(s_j,k^*(s_0))$ if and only if $q>q'(F,r,w,\beta,s_0,s_1)$. We then verify that $\bar{q}(F,r,w,\beta,s_1)<q'(F,r,w,\beta,s_0,s_1)$ if and only if $r<r'(F,r,w,\beta,s_0,s_1)$, with

$$r'(F,r,w,\beta,s_0,s_1)=\frac{w(5-4s_0-s_1-(1-s_1)(2-3s_0+s_1)\beta-(1-s_1)\sqrt{1+2(2-s_0-s_1)\beta+(s_0-s_1)^2\beta^2}}{(1-s_1)(-1+(2-3s_0+s_1)\beta+\sqrt{1+2(2-s_0-s_1)\beta+(s_0-s_1)^2\beta^2}}.$$