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How do food safety regulations influence market price? A theoretical analysis

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1. Introduction

A part of European food safety legislation model is based on imposition of Maximum Residue Limit (MRL)[1]. This regulatory tool specifies the maximum admitted thresholds of contaminants in a product for instance aflatoxin, dioxin, heavy metals etc. The Regulation (EC) n.396/2005 (Council regulation no 396/2005) assigns MRLs for pesticides in every food and feed and the Regulation (EC) n.1881/2006 (Council regulation no 1881/2006) establishes MRLs for mycotoxins in foodstuffs. Beside legislation, official control schemes are designed to verify the compliance with feed and food law (Regulation (EC) n.882/2004). All these regulations have one goal: to reduce the food-related risk of consumption and to preserve the health of consumers. From the economic perspective, an important issue deals with the impact of these food safety constraints imposed on productive systems on various economic index, particularly on the price that emerge in the market.

Indeed, one of the challenges of food safety regulations is the impact they can have on the economic performances, including a price increase of food commodities and their scarcity on the market. The other fear is that if regulations are too demanding, they could threaten the participation of small producers in the country's production system. These threats are even more real because the stringent health regulations require high level of logistics investments, extensive producer training etc.

The Industrial Economics literature most likely to analyses product quality issues is the Minimum Quality Standards (MQS) literature (Crampes and Hollander, 1995; Scarpa, 1998; Garella and Petrakis, 2008). However, this literature is most often focused on situations where product quality is recognized by consumers and becomes a differentiation strategy for firms[2]. As pointed by Hammoudi et al. (2009), this literature commonly focuses on an overall quality without explicitly separating the attributes of food safety and other attributes (taste, quality, appearance etc.). Moreover, these works, which generally based on vertical differentiation models (Mussa and Rosen, 1978; Dixit, 1979; Das and Donnenfeld, 1989), are not appropriate

[1] The Maximum Residue Limit (MRL) is the highest level of a pesticide residue that is legally tolerated in food or feed when pesticides are applied correctly (Good Agricultural Practice).
[2] Some theoretical works try to fill this gap by proposing an alternative to the existing model where the consumers have indirect information about this quality. Rouvière and Soubeyran (2011) consider the imposition of MQS under the effect of reputation: a product of low-quality generates a negative externality of the industry. They show that the imposition of a MQS may reduce the exclusion in the market by inducing firms to enter in the market.

to food safety issues where the consumer don't recognize the sanitary attribute of the product[3]. In fact, few works have focused on ensuring the safety of generic products traded on spot markets (for example, on wholesale markets) where public systems of food safety regulation play a significant role. The exceptions are the work of Giraud Héraud et al. (2012), which targets more specific problems (emergence of private standards), and the work of Grazia et al. (2012) where the context studied is a simple international supply chain (exporter/importer relationships)[4]. There are even less works, which analyse the relationships between food safety constraints imposed on productive systems, the exclusion of producers, and the availability of food in the domestic market.

To fill this literature gap, we propose an original study that identifies the causal relationship that may exist between, on the one hand, i) public food safety regulations (specifically, the maximum authorised levels of chemical or microbiological contaminants, MRL), and on the other hand, ii) the expected price in the spot markets (wholesale markets, for example) and the producers' participation in agricultural activity. The model of industrial economics that we propose allows one to determine what market price will emerge from such an economy subject to public regulation constraints. Based on this, it is possible to evaluate the quantity of supply available on the market, the level of producer exclusion due to regulation and the sanitary and phytosanitary safety level associated with this market.

The assessment of the quality level of available products and exclusion allows us to position our analysis in the context of the question of the link between food safety and food security in the quantitative sense. Even if the compatibility between food supply availability and food safety on markets is currently an important issue in both developing and developed and it is, obviously a bigger challenge for developing countries (DCs). Indeed, in contrast to developed countries, combating malnutrition remains a major challenge for DCs which are highly dependent on imports and whose domestic production cannot meet growing local demand. Food safety has never such a high priority in DCs as in developed countries. The question associated with food safety is largely dominated by the concern linked to food security in terms of quantitative acceptance (Henson and Jaffee, 2007; Henson and Blandon, 2007). Consequently, food production in many DCs often has limited standardization and minimal imposition of food safety requirements, except in export sectors where constraints are set by

[3] However, note that this critic cannot extrapolated to empirical literature where some studies take into account explicitly these specificities of food safety context (see Rouvière and Caswell, 2012; Crivelli and Groschl, 2015). For more details, see a limit and a critical analysis of this literature in Hammoudi et al. (2009).
[4] See section background.

importing countries (Keiichiro et al., 2015)[5]. However, consumers in DCs are increasingly exposed to high levels of various risks with the food they consume such as pesticides (WHO, 2004) or food poisoning (toxins and E-coli)[6]. In fact, this trend is persistent primarily because consumers in DCs are often non-quality-seekers or lack information regarding food-borne risks (Hanak et al. 2002; Kopper, 2002). Thus, the sanitary crisis continues to grow and to be a genuine public health concern. However, the achievement of a satisfactory level of food safety, i.e. better consumer health insurance, must address the capacity of these countries' production systems. On the basis of these observations, the questions that we raise in this work include: Can the development schemes incorporate quality improvement goals without undermining the effectiveness of quantitative objectives? Can we attain a better safety level without sacrificing economic indicator levels which are socially crucial (prices, supply, and stakeholder participation)?

To conduct the analysis, we use a theoretical model of industrial organisation and the conceptual framework of game theory. We adopt the spot market modelling proposed in Giraud-Héraud et al. (2012)[7] and the control system modelling proposed by Grazia et al. (2012). We assume that the production system is composed of homogeneous producers, who have identical product costs and the same managerial capacities to comply with public regulation. We assume that public regulation is a combination of an authorised maximum residue level (of pesticides, for example[8]) and an official control system (sanitary inspections). In response to this regulation, producers determine the appropriate good agricultural practices (GAPs) (investment in resources and know-how) to implement in their production sites. Producers' strategic behaviour (the strategic choice of investment level on a production site) has an indirect impact on the supply available in domestic markets and on the safety associated with these products. Indeed, among the products that are offered to consumers, some are compliant with the regulation and others are not compliant but passed the inspections because they were not detected by the imperfect official control system.

[5] Not that the majority of available works addressing food safety issues in DCs adopt an international trade perspective (Keiichiro et al. 2015). Economists do not neglect the consumer health issue, but the predominance of strategic development plans based on exports have, to a certain extent, oriented the economic literature in this direction, by relaying the DCs' donors' and public authorities' concerns (Unnevehr, 2015).

[6] We can cite several recent crises such as Aflatoxins in Kenya in 2004, food poisoning in a school in Bihar 2013 or the Chinese milk crisis in 2008 (for more details, refer for example to Xiu and Klein (2010), FAO/WHO (2005)).

[7] More precisely, we use modeling of control systems and MRLs proposed by Grazia et al. (2012), which we extrapolate to a context with any number of producers activating a wholesale market and combine it with the modeling of interactions on spot markets proposed by Giraud et al. (2012).

[8] The theoretical nature of the work allows a broad interpretation of a contamination threshold: microbiological contamination (e.g., aflatoxin) or micro chemical contamination (pesticides and heavy metals).

The originality of our model is that it shows how all variables (economic variables and sanitary variables) interact in the formation of agricultural prices and determine the final size of the productive system (number of active producers). The characterisation of the market price as a function of producers' investment efforts and of the level of official control reliability allows us to determine both the total supply and the proportion of this supply that is contaminated (i.e., does not comply with the maximum threshold of contamination). We initially provide the expression of market prices according to private efforts (producer investment on the production site) and public regulation (MRL and control level). The initial results that we obtained show that the toughening of legislation on MRLs does not always improve the consumer health indicator; such improvement depends on the reliability of the control. When the MRL is set, improving the reliability of controls may be in some cases a solution to better reduce food safety risk in the market. However, even if strengthening controls in some cases is likely to reduce the risk, such a measure induces an ambiguous effect on prices. It is shown that this strengthening controls creates inflation in markets where controls are initially relatively unreliable while creating a fall in prices in markets where they were initially relatively reliable. On the other hand, we show that strengthening MRLs is not always synonymous with reduction of risk. It may be in some cases effective to reduce risk if this measure is simultaneously associated with strengthening controls.

Moreover, the impact of reinforcing the MRL policy depends on a country's typology, which is a function of the size of the domestic market's demand. We show that the quantitative objective (food security in quantitative terms), the health objective (the quantity of contaminated food circulated in the market), and the producers' participation objective may not be met simultaneously. The size of the domestic demand of the country and the control reliability play important roles in achieving such a result.

2. Background

European regulations on maximum limits for harmful substances have gradually become more stringent since the '90s. Regulation (EC) No 466/2001 on the fixing of maximum levels for certain contaminants have been amended several times before being repealed by Regulation (EC) No 1881/2006. (Grazia et al., 2014). For example, Regulation (EC) n. 2375/2001 adds the determination of levels of dioxin, Regulation (EC) n. 221/2002 completes the list of products concerned, by fixing maximum levels of heavy metals. As outlined in the introduction, the regulatory framework for official controls at European level is based on

Regulation (EC) n. 882/2004, which lays down the methods for sampling and analyzing samples used in official MRL compliance checks. The effectiveness of official controls depends, among other things, on the procedures (workers training, frequency of controls, number of accredited laboratories, etc.) set up by each country, and the application of sampling procedures (Grazia et al. 2014; Grazia et al., 2012).

Much of descriptive works of the literature and international agencies' reports highlight the limited effectiveness of controls. They often identify products introduced in the market which however exceed MRLs. According to the latest European Food Safety Authority (EFSA) report on pesticide residues in foods (EFSA 2016), 2.9% of the 82,649 samples analysed in 2014 exceeded MRLs. Theoretical or quantitative economic literature has in fact, hardly been studied the question related to the reliability of official controls. A branch of this literature focused on the issue of private controls introduced by downstream operators of supply chain vis-à-vis their suppliers (see for example, Chalfant et al., 1999; Starbird, 2005; Starbird et al. 2007). Another branch focused on the issue of private-public partnership which aim to substitute part of official controls by private controls (Rouvière et Caswell, 2012). For this part, Starbird (2005) characterizes the conditions for the effectiveness of such private control system in detecting noncompliant products delivered by suppliers to downstream agents. The authors show how the inspection policies affect the producer's willingness to exert higher effort to ensure safety. Rouvière and Caswell (2012) evaluate the degree of shift toward co-regulation (private and public partnership) from traditional approaches (public regulation). Based on a case study of experience in France, the Authors show how a co-regulation enforcement regime may induce changes in the enforcement practices of regulatory agencies. These changes in practices result in a shift from economic incentives based on punishment to incentives based on prevention (Rouvière and Caswell, 2012). Finally, Grazia et al. (2012) analyse under the hypothesis of imperfect controls, the impact of the vertical relationship between one producer in a DC and one importer in a developed country. The authors developed an Industrial Organization approach in order to analyse the interaction between the MRL legislation and control system and the impact of these interactions on the food safety risk associated with imports. The main originality of this study is that the food risk is endogenously determined through the supplier strategic response to the regulatory environment (investment in the quality of production practices).

Note that the majority of studies of this branch of literature assume a simple vertical relationship between one producer and one upstream operator. More generally, the industrial organization literature has rarely studied the process of price formation on spot market except some pioneer works (Zhang and Sexton, 2000; Xia and Sexton, 2004) and more recently the work of Géraud-Héraud (2012). Zhang and Sexton (2000) propose a spatial model to show how processors can manipulate the spot market prices through exclusive contracts. Xia and Sexton (2004) analyse the competitive implications of contractual agreements when these contracts are linked to the cash market price. In their model, producers are price-taking and have to trade-off between contract and cash market according to the contractual price. The authors show that with certain type of contracts, the buyers' incentives to compete aggressively on the spot market decrease (Xia and Sexton, 2004).

The work of Giraud-Héraud et al. (2012) is devoted to the analysis of the specific issue of private standards through the conceptual framework of endogenous formation of coalitions. The authors analyse the effects of the creation of collective private standards (standards established by a coalition of retailers) on both: i) the prices of the spot markets in which private standards set and ii) the market price of generic products. The authors determine the conditions under which the collective standard can emerge and what size coalition will form (complex trade-off between individual rationality and collective rationality regarding the stability concepts of coalitional games, see for more details Giraud-Héraud (2012)). In our Knowledge, this work is the only one that has formally studied the price formation issue in relation to spot markets. However, the spot markets in their model are subject to *private* food safety standards and not to *public* regulations.

3. Model

We consider a domestic market for a food product from which emanates demand D given by:

$$D = a - \omega. \tag{1}$$

Where $a, (a \geq 0)$ is the market size, and ω is the market price, which is determined by equalising supply and demand.

To ensure a healthy food supply, public authorities set regulation on the basis of two instruments:

- The threshold $s, (s \in [0,1])$, which represents the maximum level of contamination permitted in each unit product (sanitary standard).

- The level of sanitary control $\beta, (\beta \in [0,1])$, which is the probability that a unit of product is detected as contaminated (e.g., contamination threshold exceeding s)[9]. If the product is identified as contaminated, it is immediately rejected.

We further assume that the concerned product's domestic production system E is composed of $N, (N > 0)$, identical producers of size 1, which is the size corresponding to their production capacity.

In response to the regulation (s, β), each producer $i \in E$ invests a level k, $(k \in [0,1])$ of good agricultural practices (GAPs) and sells his production level x, $(x \in [0,1])$ on the domestic market.

The producer $i, (i \in E)$, who chooses the level k of GAPs, supports the investment cost $C(F, k)$[10].

The producer $i, (i \in E)$, who chooses the level k of GAPs, anticipates the following proportions of his production x:

- The compliance probability $f(s, k)$[11], which is the probability that the unit of goods produced with practice k complies with food safety standard s.
- The proportion offered $g(s, \beta, k)$, which is the probability that the unit of goods produced with practice k is detected by the control system β and complies with food safety standards.

Therefore, each producer $i \in E$ can anticipate their individual quantities $q^O(s, \beta, k, x)$ which are effectively sold on the domestic market and those $q^f(s, \beta, k, x)$ that effectively comply with the sanitary standard:

$$q^O(s, \beta, k, x) = x\, g(s, \beta, k); \quad (2)$$

$$q^f(s, \beta, k, x) = x\, f(s, k). \quad (3)$$

The profit $\pi\,(s, \beta, F, \omega, k, x)$ of the producer i, $(i \in E)$ who chooses the levels x of production and investment k is given by:

[9] The errors related to compliance tests can also generate false positive results (probability that an uncontaminated sample will be identified as contaminated, see Starbird (2007)). For simplicity, in this model, we assume that this probability is zero.

[10] Empirical studies have generally identified several types of costs which certain are fix and other are variables (see for example Crivelli and Gröschl, 2015; Henson and Jaffee, 2007; Aloui and Kenny, 2005).

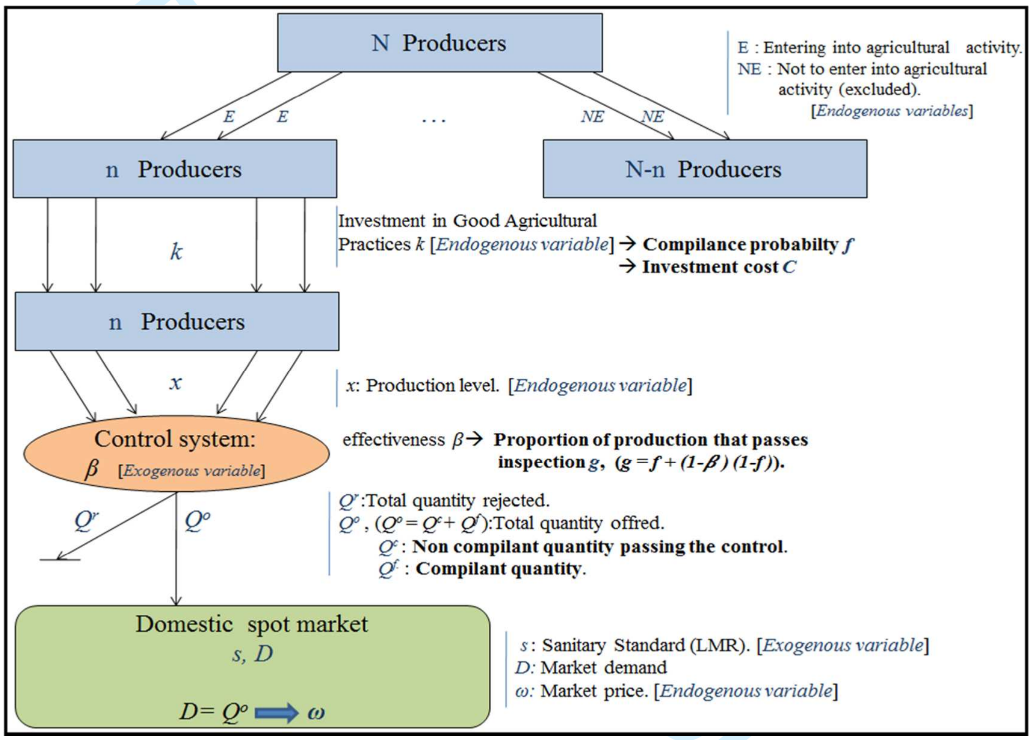
[11] The function f must be increasing in s and k; an increase in the effort of GAPs increases the probability of compliance for each product unit and a norm reinforcement (s decreases), decreases the compliance probability.

$$\pi\,(s, \beta, F, \omega, k, x) = \omega\, q^{O}(s, \beta, k, x) - C(F, k). \tag{4}$$

The producer's profit is the difference between the outcome associated with the quantity that they offer (and is not rejected) at market price ω and the cost associated with their investment in GAPs.

The main hypothesis of the model are summarized on the following figure:

Figure 1– Strategic Interaction and price formation under MLR Constraints.



The interactions between producers and public authorities through the strategic decision k and the decision (s, β) can be represented by the following the three-stage dynamic game:

Stage 1: The producers observe (s, β) and simultaneously decide to enter or not in the production activity

Stage 2: A producer i that has decided to enter in the activity determines his level k_i of investment in good practices taking account (s, β).

Stage 3: Each producer determines his level x_i of production to sell in the domestic market.

At the end of the stage 2, the total supply intersects the total demand and the intersection induces the level of the market price.

One solves the game by *Backward Induction*. Note that producers make their decisions at different stages of the game as price takers. Since the producers have identical costs, the model is symmetric and the investment decided by each one at the equilibrium is $k_i \equiv k$. At the game's equilibrium, the market price ω^* is determined by the intersection of the total supply offered by producers and the total market demand. Because the public authorities control the quantities decided by the producers, a certain proportion is rejected because it does not comply with sanitary standards. Following these controls, the quantities offered are those that pass inspection and those that are those that meet the demand and contribute to determining the market price ω^*. Regarding the rationality of individual decisions, it is assumed each operator will to maximise their profit. The contamination rate is defined simply by the ratio of the contaminated total quantity and the total quantity offered (see more details in section 4.2).

4. Resolution of the game

To solve the game and give some original and counter-intuitive results, we will specify the cost function $C(F,k)$ and the compliance probability $f(s,k)$. Thus, we may be able to determine the explicit expression of the market price as a function of the maximum threshold of contamination and the level of official control. Such expression may allow us to determine both the total supply and the proportion of the total supply that is contaminated (i.e., does not comply with the maximum threshold of contamination). We propose the following general specifications of these functions $f(s,k)$[12] and $C(F,k)$[13].

$$f(s,k) = 1 - (1-s)(1-k); \tag{5}$$

$$C(F,k) = F\,k^2. \tag{6}$$

Thus, $g(s,\beta,k)$ is deduced from $f(s,k)$ as follows:

$$g(s,\beta,k) = f(s,k) + (1-\beta)\big(1 - f(s,k)\big). \tag{7}$$

[12] More precisely, i) at a given threshold s, and in the absence of investment effort ($k = 0$), the probability that a unit of good complies with s depends solely on the level of the standard($f(s,k) = s$), and ii) at a given level k and in the presence of the most exacting standard ($s = 0$), the probability that a unit of good complies with s depends solely on the level of investment ($f(s,k) = k$). The proportion complies and attains its maximum level ($f(s,k) = 1$) if the investment effort is maximal ($k = 1$) and/or the sanitary standard is lax ($s = 1$).

[13] The parameter $F, (F \geq 0)$ represents the fixed cost of compliance, and for simplicity, we assume that the variable costs are zero.

We define the *Economy* studied here (noted *E*) by the size of the domestic market and the number of producers participating in the production activity. In the following sections, we assume that this Economy is such that $a \leq 2\,F$[14]. Then we can solve the game defined in the previous section and determine the investment in GAPs, the number of producers entering in the market, and the market price at equilibrium. The following proposition presents these main results.

Proposition 1.

The number $N^*(s,\beta)$ of producers, investment level $k^*(s,\beta)$, and market price $\omega^*(s,\beta)$ at equilibrium are given by[15]*:*

$$N^*(s,\beta) = min\left(N, \left\lfloor\frac{a}{1-\beta(1-s)}\right\rfloor\right);$$

$$k^*(s,\beta) = \frac{\beta(1-s)\left(a-\big(1-\beta(1-s)\big)N^*(s,\beta)\right)}{2\,F+\beta^2(1-s)^2N^*(s,\beta)};$$

$$\omega^*(s,\beta) = \frac{2\,F\,\left(a-\big(1-\beta(1-s)\big)N^*(s,\beta)\right)}{2\,F+\beta^2(1-s)^2N^*(s,\beta)}.$$

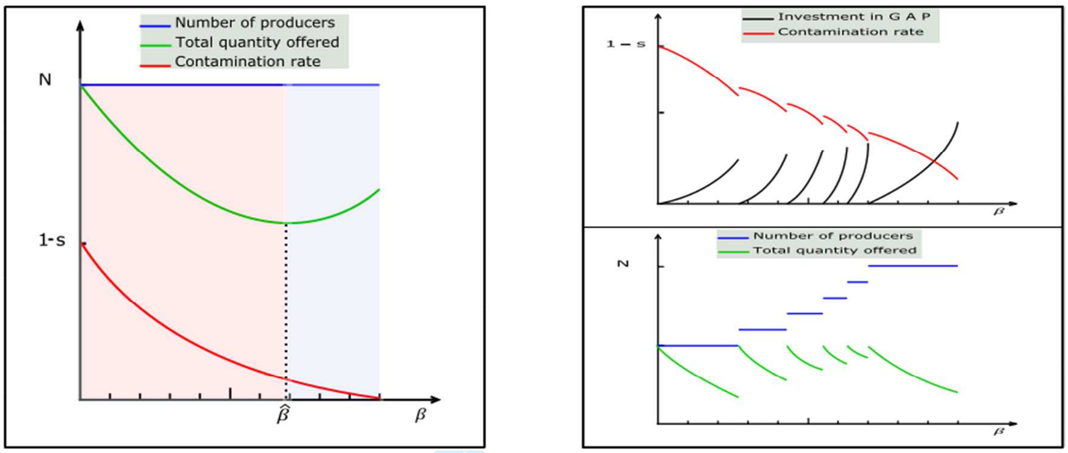
First, from this proposition, we can deduce a first counter-intuitive result. Indeed, the control improvements may encourage excluded producers to enter the domestic market$\left(\frac{\partial\, N^*(s,\beta)}{\partial\,\beta} \geq 0\right)$. This result can be explained by the fact that the reinforcement of controls involves the increase of rejected quantities and mechanically creates the possibility of viable outlets for potential new entrants. The result remains valid for the reinforcement of the admitted contaminant threshold$\left(\frac{\partial\, N^*(s,\beta)}{\partial\, s} \leq 0\right)$. From this proposition 1, and to give an idea of some key results, let us distinguish two polar cases representative of the typology of countries: *large* countries (Type1) with relatively *high potential* demand $(a < N)$, which ensures the viability of all producers and *small* countries (Type 2) with relatively *low potential* demand $\left(a < \big(1-\beta(1-s)\big)N\right)$ in which only a subset of producers enter the market at the equilibrium (partial producer access). Considering these two types of countries (Type 1 and Type2), we can analyse quite simply some of the consequences of proposition 1 in terms of the health and economic impacts of i) regulations based on the variation of the quality of control (section 4.1) or ii) regulations based on the reinforcing of the MRL threshold (section 4.2). The results are given in the following sections.

[14] This hypothesis imply that all variables at equilibrium are prior solutions (particularly, $k^*(s,\beta) \in\ [0,1[$).
[15] The notation $\left\lfloor\frac{a}{1-\beta(1-s)}\right\rfloor$ is used in this expression to indicate the integer portion of $\frac{a}{1-\beta(1-s)}$.

4.1. Impact of food controls evolution

At a given threshold s, the economic and health indicators vary according to the level of official control. These variations are given in Figure 2[16] below:

Figure 2– Producer participation, total quantity available in the market, and contamination rate as a function of the intensity of the controls.



a) Type1countries **b)** Type2 countries

i) Impact on countries of type 1

When a country is type1, we can easily verify that the improvement of controls and/or switch to more stringent standards encourage producers to improve their investments in GAPs. The market price in these countries can attain a maximum intermediary value $\hat{\beta}, \left(\hat{\beta} = \frac{(N-a)+\sqrt{(N-a)^2+2\,F\,N}}{(1-s)\,N}\right)$ of $\beta \in \,]0,1[$ (see Figure 2.a). This concavity of the function $\omega^*(s,\beta)$ compared with β can be explained by the fact that improved controls in the zone with low levels of efficiency $[0,\hat{\beta}]$ encourage producers to improve their level of investment; however, their practices remain too few to generate a positive variation in total supply. This is due to the increase in rejected quantities and the negative variation of the gap between compliant supply and contaminated supply. In this zone, the market price increases and the contamination rate decreases. In the zone associated with high levels of efficiency$[\hat{\beta},1]$, the control improvements encourage producers to make sufficiently high investments to generate a positive variation in the gap between the compliant supply and the contaminated quantity. In

[16]The shape of figure 2 can be obtained with the following parameter values:
I) Type 1 countries: $a = 40; F = 20; N = 5; s = 0.3$.
II) Type 2 countries: $a = 03; F = 20; N = 5; s = 0.3$.

this case, the total supply increases, the market price decreases, and the contamination rate decreases.

i) Impact on type 2 countries

The control reinforcement can positively or negatively impact the investment in GAPs in type2 countries (see Figure 2.b). This is because of the negative relationship between investment in GAPs and the number of producers engaging in the activity; producers' investment decreases relative to the number of producers present. This ambiguous result (the positive or negative impact of control reinforcement on investment in GAPs) leads to two possible effects on the price. First, in the situation in which the strengthening of control does not impact the number of producers, the producers improve their investment to increase their offers and reduce their rejected quantities. In this case, if the gap between their compliant quantities and their contaminated quantities varies positively, the total supply increases and, mechanically, the market price decreases. If not, supply decreases and the market price increases. Second, in the situation in which the strengthening of control induces an increase in the number of producers, producers' investments are negatively impacted by the greater number of producers and positively impacted by incentives to improve the investment (because of the increase in β). When the (improving) "investment effect" outweighs the "participation effect", then the offered quantities increase and the market price decreases. Conversely, when producers' "participation effect" outweighs the "investment effect", supply decreases because the insufficient investment is not compensated by the increase in the producers' participation. As shown in Figure 1.b, one can also deduce that strengthening the control can have a negative or positive impact on the contamination rate in the domestic market depending on whether the investment in goods sufficiently increases (with a positive effect on compliant quantities or a reduction in the compliant quantities).

4.2. Impact of strengthening MRL threshold

In this section, we consider the context in which public authorities envisage a move toward more stringent standards. The question is whether a reinforcement of the sanitary standards is legitimate with respect to health objectives. We consider that the transition from a sanitary standard $s_0$to a more stringent sanitary standard $s_1, (s_1 \leq s_0)$ is legitimate with respect to health objectives if it at least results in a decrease in the contamination rate$t_c$compared with s_0 and s_1. In other words:

$$t_c\left(s_j, k(s_1)\right) \leq t_c\left(s_j, k(s_0)\right), \quad \forall\, j \in \{0,1\}. \tag{8}$$

The notation $t_c(s_j, k(s_i))$ indicates the contamination rate for any level s_j when the current standard (in force) in the domestic market is s_i. This rate is calculated based on the quantity contaminated relative to the level of contaminant s_j when the producers respond to the required standard s_i (see Grazia et al., 2012). Thus, reinforcing the standard policy is considered legitimate if at least every contamination rate (compared with s_i, and with s_j) obtained after strengthening decreases with respect to the initial situation[17]. The expression of the different variables given in proposition 1 enables us to solve the inequality (8); therefore, we obtain the following result:

Proposition 2.

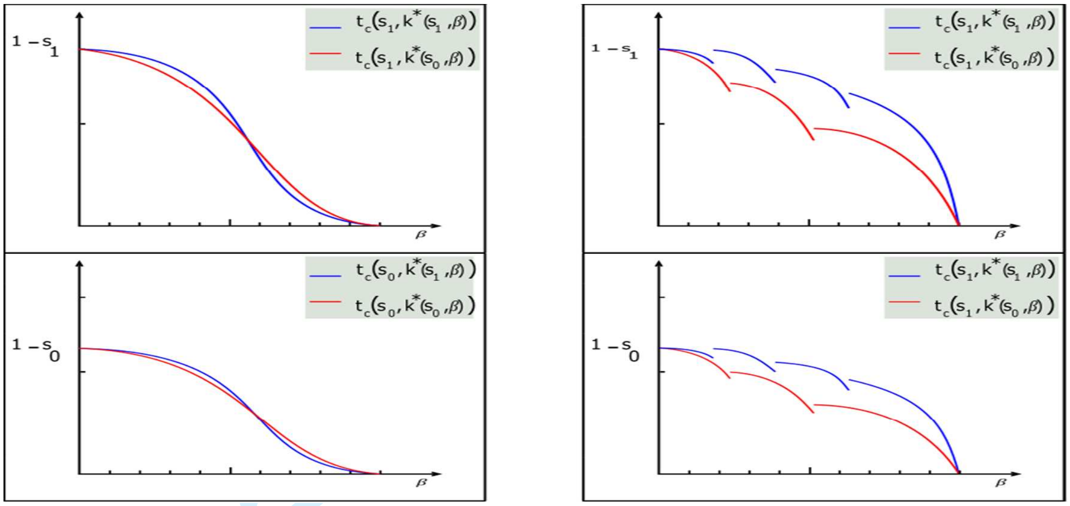
The shift from sanitary standard s_0 to more stringent food standards s_1, $(s_1 \leq s_0)$ does not necessarily induce an improvement in the health criterion.

The food safety criterion used in proposition 2 is given by the relation (8). We rely on Figure 3 to draw conclusions concerning the effect of the shift to standard s_1 on the consumers' health, which depends on the level of the control system[18]:

[17] The choice of a health criterion is particularly complex, and the existing literature in this area has suggested very few solutions to this problem. To the best of our knowledge, the exception is the work of Otsuki et al. (2001) that in an empirical study associates at each level of MLR (aflatoxins) an expected number of cancers within the population

[18] The graph lines of Figure 3 are obtained from the following parameter values:
(a) Type 1 countries: $a = 20; F = 10;\ N = 15;\ s_0 = 0.5; s_1 = 0.35;$
(b) Type 2 countries: $a = 10; F = 10;\ N = 15;\ s_0 = 0.5; s_1 = 0.35;$

Figure 3- Impact of the shift to higher standards in consumer health.



a) Type 1 countries **b)** Type 2 countries

When the country is type1, e.g., in which all producers entered at equilibrium, Figure 3.a shows how the shift from $s_0$to $s_1$does not always induce an improvement in food safety. Food safety is improved solely through high levels of control. Indeed, it is only from a certain level of control that producers get the incentive to sufficiently invest and may promote a reduction in the contamination rate compared with both s_0 and s_1. *In other words, the shift to a more stringent standard may not be legitimate if its accompanying control remains unreliable.* When the country is type 2 the shift from s_0 to $s_1$can induce an increase in the number of producers (proposition 1). The reinforcement of controls can cause the same effect. The shift of the regulation from $s_0$to s_1 has a dual effect on the level of investment; it can provide an incentive for the producers to enter the market. However, this shift can also lead to a reduction in investments precisely because of the large number of producers engaged in the market (Figure 2.b). The evolution of the rate of contamination when we reinforce the thresholds depends on the relationship between the level of individual investment and the number of active producers. When investment decreases (as a consequence of the increase in the number of entrants, the level of contamination increases.

5. Conclusion

In this study, we use an industrial economic model to show how a spot market price can be influenced by the food safety regulation levels (MRL and official control level). Moreover, we show that the size of the targeted market and compliance costs have an important role in determining the level of this price. A main economic teaching of the paper is that we show

how the establishment of an effective MRL regulation to control the sanitary and phytosanitary risk can be complex and may in some cases lead to results contrary to the objectives desired by the public authorities. If some parameters of the economic environment are not taken into account in setting the MRL thresholds (quality of controls, market size, compliance costs), a demanding level of the MRL can effectively reassure the consumer but not protect its health against food risk. In addition, regulation can not only be inefficient in terms of reducing food risk, but also has negative economic effects (less supply on the market, more exclusion from producers).

Otherwise, the characterization of the market price allows us to provide results concerning the compatibility of food safety objectives and food security (in the quantitative sense). As pointed in the introduction, despite the fact that the proposed model is general and applicable to all type of countries, regardless of their level of development, our analysis rely a major issue for DCs (food security *versus* food safety). It is also an originality of the article that to deal with this classical issue of development economics using the tools of game theory and industrial economics, relying on the strategic behaviours of the Stakeholders. The results obtained allow us to question some established ideas, associated for example with the effects of strengthening or weakening of MRL regulations (thresholds, health inspections), on prices, quantities, exclusion and consumer health[19]. For instance, a large number of development experts emphasise the opposition that may exist between constraints on production systems, particularly regarding food safety quality standards and the capacity of these systems to generate a satisfactory food supply in domestic markets. Indeed, they argue that the imposition of food safety constraints represents costs to producers (see, for example, Shafaeddin (2009), Caswell and Kleinschmit (1997)) and such costs can generate both a contraction in supply and an exclusion of domestic producers. We show that the classical thesis of opposition between quality and quantity considerations can be contradicted. The compatibility of food safety and food security objectives depends, among other things, on the control system established by the public authorities and the characteristics of the demand in the studied country. However, our results suggest that the quantitative criterion (food security in quantitative terms), the health criterion (the quantity of contaminated food consumed in the market) and the criterion of producers' participation may not be ensured simultaneously.

[19] It should be noted that even if the results obtained relate to an application (associated with a specification of certain functions of the model), this does not detract from the generality of the model which can be used to support questions other than those we have studied in this article.

Il is important to note that by proposing a comparative analysis of on the one hand, the level of economic indicators after the implementation of regulation (compliance costs, exclusion level, available supply and price) and on the other hand, health benefit, the work falls within the general framework of cost/benefit analysis and cost/effectiveness (Antle, 1999; Otsuki et al., 2001; Rau and Tongeren, 2010). From a methodological point of view, the approach can be seen as a contribution to classical cost / benefit and cost-effectiveness analyses. As we have shown, difficulties in compliance with norms do not only and systematically depend on the level of compliance costs but also on the opportunistic behaviours of the operators and their interactions with the economic environment and the characteristics of the regulation (MRL, deficiencies in control system, level of the demand,…). Our results highlight the importance of considering competition and strategic interactions, which are not generally taken into account in the traditional cost/benefit and cost/effectiveness analyses. In this line, an interesting development of this work consist to slightly adapt the model in order to take into consideration an important issue in this field: the public-private partnerships issue (delegation of the control to private sector for example), in accordance with the works of Martinez et al. (2007), Narrod et al. (2009), and other authors cited in the introduction. This development could complement existing empirical studies (Rouvière and Caswell, 2012) through theoretical elucidation.

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Mathematical appendix

A. Resolution of the game

A.1 Production

At a given (s,β,ω,F,k), the rational behaviour of a producer $i,(i\in E)$ consists in seeking the level of production $x^*,(x^*\in[0,1])$ which maximizes his profit $\pi(s,\beta,\omega,F,k,x)$:

$$x^* = \underset{x}{argmax}\ \pi(s,\beta,\omega,F,k,x). \qquad (A.1)$$

The first order condition is:

$$\frac{\partial\,\pi(s,\beta,\omega,F,k,x)}{\partial\,x} = \omega\left(1-\beta(1-s)(1-k)\right)\geq 0. \qquad (A.2)$$

From $(A.2)$ and knowing that $x,(x\in[0,1])$, the optimal production level $x^*(s,\beta,\omega,F,k)$ of the producer i is so given by:

$$x^*(s,\beta,\omega,F,k)=1, \qquad i\in E. \qquad (A.3)$$

A.2 Investment in GAPs

At a given (s,β,ω,F,k), the rational behavior of a producer $i,(i\in E)$ consists in seeking the level of investment $k^*,(k^*\in[0,1])$ which maximizes his profit $\pi(s,\beta,\omega,F,k,x^*)$:

$$k^* = \underset{k}{argmax}\ \pi(s,\beta,\omega,F,k,x^*). \qquad (A.4)$$

The conditions of first and second orders give:

$$\frac{\partial\,\pi(s,\beta,\omega,F,k,x^*)}{\partial\,k}=0 \Leftrightarrow k=\frac{\beta\,(1-s)\,\omega}{2\,F}; \qquad (A.5)$$

$$\frac{\partial^2\,\pi(s,\beta,\omega,F,k,x^*)}{\partial^2\,k}=-2\,F\leq 0. \qquad (A.6)$$

From $(A.5)$ and $(A.6)$, the optimal level of investment $k^*(s,\beta,\omega,F)$, of producer $i\in E$ is given by:

$$k^*(s,\beta,\omega,F)=\min\left(1,\frac{\beta\,(1-s)\,\omega}{2\,F}\right). \qquad (A.7)$$

A.3 Price, Investment and profits at equilibrium

Given (s,β), and $n,(n\leq N)$, producers activate on domestic market, the total quantity offered $Q^o(s,\beta,n)$ in domestic market is given by:

$$Q^o(s,\beta,n)=n\ q^0(s,\beta,k,x). \qquad (A.8)$$

If $a\leq 2\,F$, then

By using (A.7), the optimal Investment $k^*(s,\beta,\omega,F)$, of a producer i is:

$$k^*(s,\beta,\omega,F)=\frac{\beta\,(1-s)\,\omega}{2\,F}. \qquad (A.9)$$

By substituting $(A.9)$ in$(A.3)$, the optimal level of production $x^*(s,\beta,\omega,F,k^*)$, of a producer i is given by:

$$x^*(s,\beta,\omega,F,k) = 1. \qquad (A.10)$$

By substituting $(A.9)$ and $(A.10)$ in$(A.8)$, the total quantity offered $Q^o(s,\beta,\omega,F,n)$, in domestic market is:

$$Q^o(s,\beta,\omega,F,n) = \left(1-\beta\,(1-s)\right)n + \frac{\beta^2(1-s)^2\omega}{2\,F+\beta^2(1-s)^2\,n}. \qquad (A.11)$$

The sale price $\omega^*(s,\beta,F,n)$ at equilibrium, is determined by the equalization of supply $(A.11)$ and demand D:

$$Q^o(s,\beta,\omega^*,F,n) = D \Leftrightarrow \omega^*(s,\beta,F,n) = \frac{2\,F\left(a-\left(1-\beta\,(1-s)\right)n\right)}{2\,F+\ \beta^2(1-s)^2\,n}. \qquad (A.12)$$

By substituting $(A.12)$ in $(A.9)$, the optimal investment $k^*(s,\beta,F,n)$, of producer i at market equilibrium is given by:

$$k^*(s,\beta,F,n) = \frac{\beta\,(1-s)\left(a-\left(1-\beta\,(1-s)\right)n\right)}{2\,F+\ \beta^2(1-s)^2\,n}. \qquad (A.13)$$

By substituting $(A.10)$, $(A.12)$and $(A.13)$ in $\pi(s,\beta,\omega,F,k,x)$, the profit of a producer i at the market equilibrium is given by:

$$\pi^*(s,\beta,F,n) = \frac{F\,(a-(1-\alpha)\,n)\left(2\,(1-\alpha)(2\,F+\alpha^2\,n)\right)+\alpha^2(a-(1-\alpha)\,n)}{(2\,F+\ \alpha^2\,n)^2}. \quad (A.14)$$

where: $\alpha = \beta\,(1-s)$.

We can easily verify that:

$$\pi^*(s,\beta,F,n) \geq 0 \Leftrightarrow n \leq \frac{a}{1-\beta\,(1-s)}. \qquad (A.15)$$

A.4 Proof of proposition 1

By using $(A.15)$, we can deduce the expression of the number of producers $N^*(s,\beta)$ at the equilibrium:

$$N^*(s,\beta) = \min\left(N, \left\lfloor\frac{a}{1-\beta\,(1-s)}\right\rfloor\right). \qquad (A.16)$$

By substituting $(A.16)$ in $(A.12)$ and $(A.13)$, the investment level $k^*(s,\beta)$ and the market price $\omega^*(s,\beta)$at the equilibrium are given by:

$$k^*(s,\beta) = \frac{\beta\,(1-s)\left(a-\left(1-\beta\,(1-s)\right)N^*(s,\beta)\right)}{2\,F+\ \beta^2(1-s)^2N^*(s,\beta)}. \qquad (A.17)$$

$$\omega^*(s,\beta) = \frac{2\,F\ \left(a-\left(1-\beta\,(1-s)\right)N^*(s,\beta)\right)}{2\,F+\ \beta^2(1-s)^2N^*(s,\beta)}. \qquad (A.18)$$

A.5 Types of countries

By using $(A.16)$, and in function of the market size a we can distinguish three countries types:

Type 1 countries with $(a \geq N)$*, so:*

$$N^*(s,\beta) = N. \tag{A.19}$$

Type 2 countries with $a \leq \left(1 - \beta\,(1-s)\right) N$ *so:*

$$N^*(s,\beta) = \left\lfloor \frac{a}{1 - \beta\,(1-s)} \right\rfloor. \tag{A.20}$$

Type 3 countries with $\left(1 - \beta\,(1-s)\right) \leq a \leq N$*, so:*

$$N^*(s,\beta) = N. \tag{A.21}$$

Given the complexities of the third case (type 3 countries), we will restraint the analysis just on the two polar cases (case 1 and case 2).

B. Type 1 countries: Impact of the evolution of food controls

By substituting $(A.19)$ in $(A.17)$ and $(A.18)$, the investment level $k^*(s,\beta)$ and the price $\omega^*(s,\beta)$ at equilibrium are given respectively by:

$$k^*(s,\beta) = \frac{\beta\,(1-s)\left(a - \left(1 - \beta\,(1-s)\right) N\right)}{2\,F + \beta^2(1-s)^2 N}. \tag{B.1}$$

$$\omega^*(s,\beta) = \frac{2\,F\,\left(a - \left(1 - \beta\,(1-s)\right) N\right)}{2\,F + \beta^2(1-s)^2\,N}. \tag{B.2}$$

B.1 Variation of $k^*(s,\beta)$ over β :

$$\frac{\partial\,k^*(s,\beta)}{\partial\,\beta} = \frac{(1-s)\left(-\beta^{\,2}(1-s)^2\,N\,(a-N) + 4\,F\,\,\beta\,(1-s)\,N + 2\,F\,(a-N)\right)}{(2\,F + \beta^2(1-s)^2\,N)^2}; \tag{B.3}$$

$$\frac{\partial\,k^*(s,\beta)}{\partial\,\beta} = 0 \Leftrightarrow \beta = \overline{\beta} = \frac{2\,F\,N + \sqrt{(2\,F\,N)^2 + 2\,F\,N\,(a-N)^2}}{(1-s)\,N\,(a-N)} \geq 1. \tag{B.4}$$

From $(B.3)$ and $(B.4)$, we can deduce that:

$$\frac{\partial\,k^*(s,\beta)}{\partial\,\beta} \geq 0. \tag{B.5}$$

B.2 Variation of $\omega^*(s,\beta)$ over β :

$$\frac{\partial\,\omega^*(s,\beta)}{\partial\,\beta} = \frac{-2\,F\,(1-s)\,N\,(\beta^{\,2}(1-s)^2\,N + 2\,\beta\,(1-s)(a-N) - 2\,F\,)}{(2\,F + \beta^2(1-s)^2\,N)^2}; \tag{B.6}$$

$$\frac{\partial\,\omega^*(s,\beta)}{\partial\,\beta} = 0 \Leftrightarrow \beta = \hat{\beta} = \frac{(N-a) + \sqrt{(N-a)^2 + 2\,F\,N}}{(1-s)\,N}. \tag{B.7}$$

From $(B.6)$ and $(B.7)$, we can deduce that:

$$\frac{\partial\ \omega^*(s,\beta)}{\partial\ \beta}\begin{cases}\geq 0, & if\ \ \beta\in[0,\hat{\beta}];\\ \leq 0, & if\ \ \beta\in[\hat{\beta},1].\end{cases} \qquad (B.8)$$

B.3 Variation of $t_c(s,\beta)$ over β :

$$t_c(s,\beta)=\frac{N\ (1-\beta)(1-s)\big(1-k^*(s,\beta)\big)}{N\ \Big(1-\beta(1-s)\big(1-k^*(s,\beta)\big)\Big)}. \qquad (B.9)$$

$$\frac{\partial\ t_c(s,\beta)}{\partial\ \beta}=0\Leftrightarrow\beta=1\quad\vee\quad\beta=\frac{2\ F}{(1-s)(a-N)}\geq 1. \qquad (B.10)$$

From $(B.9)$ and $(B.10)$, we can deduce that:

$$\frac{\partial\ t_c(s,\beta)}{\partial\ \beta}\leq 0. \qquad (B.11)$$