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Segregation and Testing Strategies for GM/non-GM Coexistence in Supply Chains*

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Abstract: This article proposes a model to determine the conditions under which GM and non-GM products coexist when the final consumer demand is mostly composed of consumers who are hesitant to purchase GM products. The novelty of this model is that it endogenously considers contamination risks between GM and non-GM products and the resulting consequences in terms of product compliance with regulatory labeling thresholds. The results suggest that a public constraint on private sampling strategies may be a relevant regulatory tool, which has not been considered up until now for the regulation of GM/non-GM coexistence in supply chains. Public intervention related to testing strategies may therefore be used as a substitute for penalties, whose purpose is to punish non-compliant products on the final market.

Keywords: TESTING, SEGREGATION, GENETICALLY MODIFIED, GM COEXISTENCE, PRODUCT COMPLIANCE

JEL CODES: L13, L15, Q18

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I. Introduction

To guarantee the freedom of choice for both producers and consumers in using GM products, EU public officials have set up a regulatory framework which focuses primarily on the regulation of GM crops and their resulting dissemination over farmland (Directive 2001/18/EC). It also imposes mandatory labeling of products for animal and human consumption if the GM content is above the regulatory threshold of 0.9% (Directive 1829/2003/EC). Public control measures are related to (1) the relevance of the information listed on commercialized products and (2) GM producer compliance with requirements for documentary traceability (2001/18 directive, 1829/2003/EC, 178/02/EC, 1830/2003/EC). Additionally, biotechnology firms are required to provide methods for the identification and quantification of GM products to the European CRL-GMFF (Directive 1830/2003/EC).

Despite this regulatory framework, there are still numerous conflicts among the various stakeholders, and the conditions of development for products using GM organisms remain uncertain. Aside from environmental issues (e.g., impact on biodiversity, creation of resistant varieties) which fall outside the scope of the present paper, an important issue is contamination and its effect on the ability to continue providing for non-GM demand once GM products have acquired a significant share of the market.

Upstream, the risk of contaminating conventional or organic crops by the dissemination of pollen from neighboring GM crops represents a major concern. Such contamination may lead to the downgrading of conventional or organic products, and may also result in financial losses for non-GM producers and/or manufacturers. The same issue arises further down the product chain and the contamination risk from the shared use of storage, transport, and industrial manufacturing equipment for GM and conventional is becoming a crucial issue. These admixture risks are subject to general regulations and are based on the notion of "accidental" admixture. The presence of a small amount of GM material in a non-GM product may be acceptable without mandatory labeling if the presence of GM material is unintentional and technically inevitable. This means that firms are obligated to take all reasonable measures and put forth all reasonable effort to avoid the presence of GM material in non-labeled products. There is also a traceability requirement whereby documentary public control procedures aim to show the accidental nature of any contaminations which may have been observed.

However, even when unintentional, the "accidental" risks of mixing are necessarily influenced by the segregation measures adopted by firms. These measures are based on economic decisions balancing the cost of this segregation against the level of product purity expected by the market. This, in turn, raises the question of whether it possible to satisfy demand for non-GM products and if so, under what conditions, given that in a situation of coexistence, control of the risks of accidental admixture requires costly segregation measures which may affect the price and quality of non-GM products.

Economic research has been conducted for several years to assess the impact of GM production on agri-food businesses and to evaluate the possible effects of various public and private levers[1] (see Moschini (2008) for a very complete review of the literature). Some empirical studies assessed the costs related to GM / non-GM coexistence and traceability (e.g., Bullock and Desquilbet 2002; Kalaitzandonakes et al., 2001; Lin, 2002). Other research has focused on the labeling of GM products, the effects of this labeling on the supply of

[1] Other papers deal with the impact of GM regulation on international trade (see for instance Lapan and Moschini, 2001; Plastina and Giannakas, 2007; Sheldon 2002 and 2004). This literature is outside the scope of this paper.

products, and stakeholders' profits in the food chain (see Caswell, 1998; Carter and Gruere, 2003; Crespi and Marette, 2003). For instance, Fulton and Giannakas (2004) proposed a vertical relationship model between biotechnology firms (which create GM seeds), producers, and consumers. This model is used to compare stakeholders' profits and surpluses according to various (mandatory or voluntary) labeling schemes. The authors show how the impact of introducing GM products depends on the market power of biotechnology firms, the degree of consumer aversion to GM products, and segregation costs related to labeling. In another paper, Giannakas and Fulton (2006) proposed a vertical relationship that addressed 3 products: a conventional product, a genetically-modified product, and an organic product. They analyzed consumer decisions and the surplus related to the introduction of labeling for genetically-modified products. The effects on the market and the surpluses depend on (1) the segregation costs generated by mandatory labeling, (2) consumer aversion/preferences in relation to GM or organic products, and (3) the structure of the supply chain.

In other articles, authors consider mandatory labeling, but specifically deal with the issue of the optimal threshold of GM material which should require labeling. For example, Lapan and Moschini (2007) studied a supply chain made up of producers, processors, and final consumers, and explicitly considered the accidental mixing of non-GM products in an industrial setting. Public regulations are considered vis-à-vis setting the labeling threshold. In another paper, Lapan and Moschini (2004) consider a regulation based on a penalty imposed when a commercialized non-GM product has GM content above the labeling threshold. On this basis, the authors study whether the production of non-GM products is preserved according to the frequency of tests and the level of penalty costs.

Other works have focused on segregation measures and test strategies aimed at preserving the identity of non-GM products within supply chains. Wilson and Dahl (2005) and Wilson et al. (2007) proposed a stochastic optimization model to calculate optimal testing strategies in chains. Their model is based on the example of the grain chain in the U.S. and considers the costs related to tests and downgrades of products when the non-labeled product is identified as a GM product. On this basis, the authors calculate the best strategy in terms of the location, frequency, and intensity of the tests to be implemented within the supply chains. They also estimate the bonus necessary to enable GM/non-GM coexistence depending on the risks of accidental mixing, test accuracy, and the accuracy of producers' statements concerning the characteristics of the raw material.

These papers consider the risks of contamination between GM and non-GM products throughout the product chain, but they are defined exogenously and do not stem from the stakeholders' decisions. For instance, Lapan and Moschini (2004) consider (1) a distribution function for the impurity level of a given lot and (2) the proportion of non-GM output that has an impurity level less than or equal to the labeling threshold when it reaches the marketing stage. This proportion is used to evaluate the stakeholders' profits under various assumptions, but it is exogenously defined and does not depend on decisions made in the chain. The same comment can be made for the works of Wilson (2005) and (2007). The aim of this paper is to precisely assess the probability of compliance with the regulatory labeling threshold of non-GM products (sold on the final market) by considering this probability as the result of private or public actions in supply chains.

We propose a model to analyze the coexistence of GM and non-GM products within a supply chain made up of a manufacturer capable of producing both types of products and a retailer focused solely on consumer demand for non-GM products. The goal is to determine under what conditions demand for non-GM products can be satisfied given that upstream coexistence generates contamination risks between the two types of products, thereby resulting in (1) additional segregation and control tests and (2) a risk of downgrades to non-GM products due to this potential contamination. The manufacturer must decide on the

quantities of GM/non-GM products to be ordered from agricultural producers with the knowledge that the price differential between GM and non-GM raw materials will increase when there is a high purity requirement for a non-GM product. Further down the chain, the manufacturer sells GM products in a market in which he is simply a price taker, and sells non-GM products to a retailer specializing in non-GM foods. The retailer imposes tests for the non-GM products offered by the manufacturer, and the ensuing negotiations focus on (1) the intermediate sales price for the non-GM product and (2) the testing procedure imposed on the manufacturer. The rigorousness of the testing procedure then defines the level of segregation that must be implemented between GM and non-GM products within the industrial process.

Within this framework, the prices and quantities of commercialized non-GM products are analyzed, along with the level of contamination of non-GM products throughout the supply chain. The quality of non-GM products is defined by the regulatory labeling threshold. However, this level of quality is reached in an uncertain manner due to the contamination risks at the upstream production level (in the fields) or at an intermediate level (e.g., storage and transport). The originality of the proposed model lies precisely in making the contamination risks endogenous, providing that they are considered as the result of the decisions made by the stakeholders regarding the selection of the raw material, the segregation efforts in the chain, and the implementation of controls and tests.

Particular attention is given to the sampling strategies aimed at eliminating non-conforming non-GM products. This issue has been examined by Starbird (2005), who studied the role of an inspection policy defined by a buyer in order to control the safety of products delivered by a supplier. The aim of Starbird's model was to determine how the parameters of a sampling inspection policy influence the willingness to pay for safer food and the supplier's willingness to deliver safer food when the buyer has imperfect information about the supplier's effort. In our approach, we do not explicitly consider the moral hazard problem related to information asymmetry about the supplier's effort between the two agents. Nevertheless, this study also considers the key role of a sampling strategy. Indeed, one of the main points we address is the substitutability between penalty costs imposed by public officials and a regulatory constraint on the sample sizes used by firms for their private controls.

Section II of this article presents the model, and Section III presents the main results. Section IV discusses the results and concludes with suggestions for future research opportunities in this area.

II. The Model

II.1. Raw material supply and segregation effort by the manufacturer

We consider a manufacturer that acquires its raw materials through supply by agricultural producers. Given its production capacity Q, this firm may purchase two types of products: a raw material labeled as GM, for a quantity q_o at price w_o, or a (non-labeled) non-GM raw material for a quantity q_n at price $w_o + \delta$. The firm is free to buy either or both of the products, provided that $Q = q_n + q_o$.

The non-labeled raw material is assumed to comply with the regulatory threshold defined by public officials. As a result, the GM content of the non-GM product should be under the threshold s. However, due to upstream contamination risks of the firm (in the fields or during transport), it is possible that a fraction of the non-labeled raw material may contain a GM quantity X above the regulatory threshold. We denote $\varphi_0 = P(X<s)$ as the probability of

compliance of the non-GM product at this stage of the chain (with $\varphi_0 \in [0,1]$). This compliance probability reflects the level of segregation between GM and non-GM flows before the manufacturing stage.

Price w_0 is assumed to be exogenous. Price difference δ between the labeled GM raw material and the non-labeled raw material depends on the minimum quality threshold s and on the compliance probability φ_0 of the non-GM product: $\delta = \alpha.\varphi_0(1-s)$. Thus, the price differential δ between GM and non-GM raw materials purchased by the manufacturer is positive or nil, rising with φ_0 and decreasing with s. This means that non-GM products are sold at an even higher price if the compliance probability φ_0 is higher, which necessitates greater efforts at the upstream level to comply with the labeling threshold, and if the labeling threshold is more stringent.

The raw material is used by the manufacturer to make a finished product for customers at the end of the chain. When both products are used in the firm, there are contamination risks related to the industrial process. To eliminate or reduce these risks, the manufacturer must segregate GM and non-GM products. The segregation intensity can be variable. For instance, the manufacturer can dedicate different storage silos or production lines to GM and non-GM products. Alternatively, the manufacturer could use the same tools and stop the process to clean the equipment between GM and non-GM flows. He could also decide not to stop the process and simply use a portion of non-GM flow to clean the equipment (in this case, this share of the non-GM product is downgraded). These operations will be referred to here according to segregation effort e ($0 \leq e \leq 1$), which directly affects the contamination rate of the products exiting the process. Thus, non-labeled GM products, which entered the firms with compliance probability φ_0, leave the firm with compliance probability φ_1, which depends on the segregation efforts implemented by the firm. This relationship may be simply expressed as:

$$\varphi_1 = f(\varphi_0, e) = \varphi_0.e \quad (\varphi_1 \in [0,1]).$$

Transformation costs are assumed to be negligible. However, segregation effort e induces a cost $C(e)$, which increases if the effort level e is high, if the regulatory labeling threshold is stringent, and if the quantity of the GM product used in the firms is high. Indeed, the greater the share of production capacity dedicated to the GM product, the greater the risk of mixing with the non-GM product, and the larger the segregation costs needed to protect the non-GM product[2]. The function $C(e)$ used here is:

$$C(e) = e.(1-s).q_0 / Q = e.(1-s).(Q - q_n) / Q. \quad (1)$$

[2] Moschini (2008) considers that the negative impact of GM crop adoption depend on the fact that some GM crops are grown at all, and less on the extent of GM crop cultivation. If this assumption is acceptable to a first approximation at the field level, empirical studies lead us to consider that it is not always right at the processing firms' level. In many cases, the investment costs make very difficult to move from one to two production lines. The GM and the non GM must be processed on the same production line which leads to higher costs for the cleaning of the equipments when the share of GM products increases.

Once the two products have been processed, the manufacturer sells them on two distinct markets. It is assumed that there is no change in the quantities between the firm's input and output (no losses, no storage). The quantity q_o of the GM product is sold on the GM market with unit distribution cost d. The model assumes the exogeneity of the GM product market price p_o and the price-taking nature of the firm.

The quantity q_n of non-GM finished products is sold at price w_n to a retailer. We assume that the latter faces a majority of consumers opposed to GM products. Therefore, the retailer only sells the non-GM product at a final price p_n. This assumption is justified by the current situation in Europe, in which retailers decided against selling labeled GM products following the widespread opposition of European consumers to these products[3].

II.2. The manufacturer-retailer relationship

To reduce the contamination rate of products, stakeholders can decide to set up tests and reject products not complying with targeted purity levels. Several types of tests are available on the market and are used by public officials and firms. The reliability of the test depends on the technology used and on the sampling procedures, which have an especially critical effect when testing large and heterogeneous volumes.

The model considers that the retailer may test non-GM products offered by the manufacturer, measuring the GM content of the non-GM product. Based on the test results, the retailer may refuse quantities supplied by the manufacturer. In this case, the product is downgraded and sold on the GM market by the manufacturer.

However, these tests are imperfect. Depending on the performance of the test, a large proportion of non-GM product could be accepted by the retailer even though it should have been eliminated. Conversely, a large proportion of product could be refused by the retailer even though it should have been accepted. The performance of the tests depends on the technology used (summarized here by the parameter β) and on the sample size n used to perform the analysis. The higher n is, the higher the statistical reliability of the test, and the lower the probability of a test error. Therefore, we assume that the test is correct with probability βn and that it is false with probability $(1-\beta n)$. We assume that $0<\beta<1$ and $0<n<1$ (n represents the tested proportion of the total quantity of the analyzed product).

Given (1) the probability of compliance for non-GM products upon output from the industrial process and (2) the probability of test errors, four cases may be distinguished:

- *Case A*: the product is truly non-GM (in compliance with regulatory labeling requirements) and the test result is correct. The product is therefore correctly identified as being non-GM.

- *Case B*: the product is truly non-GM (in compliance with regulatory labeling requirements) and the test result is wrong. The product is identified as a GM product even though it is non-GM.

- *Case C*: the product is GM (in compliance with regulatory labeling requirements) and the test result is correct. The product is therefore correctly identified as being a GM product.

[3] Conso et OGM, pourquoi se concentrer sur oposants

- *Case D*: the product is GM (in compliance with regulatory labeling requirements) and the test result is wrong. The product is identified as a non-GM product even though it is GM.

The probability of occurrence for each of these cases is listed in Table 1 below:

	The test is correct with probability β.n	The test is wrong with probability 1-β.n
The "non-GM" product is non-GM with probability φ_1	$\varphi_1 . \beta$.n (Case A)	φ_1.(1-β.n) (Case B)
The "non-GM" product is GM with probability 1-φ_1	(1-φ_1) β.n (Case C)	(1-φ_1)(1-β.n) (Case D)

Table 1

Probability of occurrence of the different cases

Therefore, the quantity refused by the retailer is:

$$q_{n1} = q_n \left[\varphi_1 . (1 - \beta . n) + (1 - \varphi_1) \beta . n \right] . \qquad (2)$$

This quantity is sold by the manufacturer at the price p_0 on the GM market. The quantity q_{n2} accepted by the retailer and sold on the final non-GM market is:

$$q_{n2} = q_n \left[\varphi_1 . \beta n + (1 - \varphi_1)(1 - \beta . n) \right] . \qquad (3)$$

Provided that the sampling strategy is known to both the manufacturer and the retailer, q_{n2} is the quantity ordered by the retailer. This quantity, which is ordered and accepted by the retailer, has a probability φ_2 of being compliant with the labeling threshold *s*:

$$\varphi_2 = 1 - (1 - \varphi_1)(1 - \beta . n) / \left[\varphi_1 . \beta n + (1 - \varphi_1)(1 - \beta . n) \right] . \qquad (4)$$

The strategic decision to investigate a product has two aspects. First, it must be determined whether it is beneficial for agents to impose testing, and second, if so, what sample size *n* is required for the analysis. The influence of this decision on the characteristics and price of commercialized products must be considered.

The tests performed are assumed to have a cost $C(n) = c.n.q_n$, with *c* being the unit test cost, *n* the proportion of lots sampled for the tests, and q_{n1} the quantity of the non-GM product subjected to the tests. This cost is borne by the manufacturer, but as shown later, it is considered by the two agents during the negotiation at an intermediate price w_n.

II.3. Consumer demand and liability costs

Consumer behavior relating to GM products has been widely studied (see Lusk et al., 2005; Gaskell et al, 2003; Huffman et al., 2003; Noussair et al., 2004). Most of these works attempted to assess consumers' willingness to pay for or to accept GM products based on the information provided about them or based on the labeling threshold. To the best of our knowledge, no research has been conducted aiming to evaluate the impact of uncertainty about the "true" quality of non-GM products offered to consumers. In our model, given a labeling threshold s, the product purchased by the consumers as non-GM is truly non-GM with a probability φ_2, but it may be a GM product (i.e., with a GM content above the regulatory threshold) with probability $(1-\varphi_2)$. In practice, of course, the compliance probability cannot be directly assessed by each consumer. Nevertheless, this can be assumed to be public knowledge due to outside forces such as advocacy groups or anti-GM product NGOs, which also perform independent analyses to detect flaws in the control systems designed to manage the coexistence of these products. It would also be interesting to consider the possibility of mandatory disclosure and to examine what might occur if the retailer and manufacturer were obligated to inform consumers about test results.

However, this paper supposes that the consumer's utility is not influenced by this uncertainty, and that it only depends on prices and quality characteristics defined by the labeling threshold. This means that we do not consider the commercial impact of non-conforming non-GM products on consumers and their possible effect on quality regulation.

We consider a framework of vertical product differentiation[4] developed by Mussa and Rosen (1978), which has already been used in several papers dealing with GM/non-GM coexistence. Given the issues we would like to address in this article, we will focus solely on consumer demand which refuses products with GM content. Let $\theta \in [0,1]$ be the consumer aversion to GM content in a non-labeled GM product. It is assumed that for all consumers, this characteristic θ is distributed uniformly over the interval $\theta \in [0,1]$. As the regulatory threshold *s* defines the maximum GM level contained in a non-GM product, then the utility of a consumer for characteristic θ is:

$$U_\theta = u - p_n - \theta s ,$$

with *u* being the basic unit utility level (it is assumed that *u* is sufficiently high for utility U_θ to be positive). Given this, consumers will purchase non-GM products when:

$$U_\theta > 0, \qquad \text{i.e.,} \qquad \theta < \frac{u - p_n}{s} .$$

In this setting, it is clear that consumers will not penalize the supply chain if non-conforming products are marketed on the final market. However, this issue would also be considered by public officials. Since labeling is mandatory, public officials control the conformity of the marketed products and verify whether the characteristics of the products comply with the label. On this basis, if the product does not comply with the label, the firm will have to pay financial penalties.

[4] See Moschini (2008) for a discussion on the assumption of vertical product differentiation.

The impact of financial penalties has already been analyzed by Lapan and Moschini (2004). Their model considers government testing and analyzes the trade-off between frequency of testing and the amount of the fine. They show that an equilibrium which includes production of the non-GM product may only be tolerable with a sufficiently high testing frequency. Based on this result, we suppose that the final stage of the chain (i.e., the retailer) should pay penalties if the GM content of the non-GM product is higher than the labeling threshold s. We assume that the control performed by public officials is certain (*i.e.,* high frequency) and that the unit penalty cost is γ. The total penalty cost decreases in φ_2 so that:

$$C(\gamma) = (1-\varphi_2)\gamma q_{n2} \ . \quad (5)$$

This penalty cost is paid by the retailer, but as shown below, it will be part of the intermediate price negotiation between the retailer and the manufacturer.

II.4. The Game

To identify the interactions between stakeholder decisions and the impact on the final market, we consider the following three-stage game:

Stage 1. The manufacturer orders the quantities of GM and non-GM raw material it wants to get from its suppliers in the upstream market.

Stage 2. The retailer orders the non-GM processed products from the manufacturer and the contractual price is negotiated by the manufacturer and the retailer.

Stage 3. The retailer chooses the quantity and price of the non-GM products it wants to sell on the final market.

The game is solved by backward induction so as to achieve perfect Nash equilibriums in sub-games.

At Stage 3, the manufacturer chooses the quantities ordered in the upstream market by anticipating demand in the non-GM market. The retailer chooses the quantity q_{n2} of non-GM products sold in the final market and orders this quantity from the manufacturer. This quantity must maximize his profit, and is therefore obtained by:

$$q_{n2}(s, e, \varphi_0, w_n, n) = \arg\max_{q_{n2}} \pi_R \ , \quad (6)$$

with:

$$\Pi_R = (p_n - w_n - \gamma(1-\varphi_2))q_{n2} \ . \quad (7)$$

The resolution of the conditions of the first-order system represents the sole sub-game equilibrium.

At Stage 2, the intermediary price w_n is negotiated between the manufacturer and the retailer. The retailer purchases non-GM products at this price from the manufacturer. Given that this involves a contractual relationship (which is assumed to be long-term), negotiation of w_n is conducted on the basis of joint profit maximization, and takes into account the relative

bargaining power of each player. Let *k* be the manufacturer's bargaining power and *(1-k)* the retailer's bargaining power. Maximal joint profit is given by:

$$\pi_J = k\pi_M + (1-k)\pi_R \ ,$$

with Π_R given by (6) and

$$\Pi_M = q_{n2}.w_n + (q_o + q_{n1}).p_o - w_o.q_o - (w_o + \delta).q_n - e.(1-s).q_o / Q - c.n.q_n \ . \quad (8)$$

The intermediate price w_n is obtained by:

$$w_n(s, e, \varphi_0, n) = \arg\max_{w_n} \pi_J = k\pi_M + (1-k)\pi_R \ . \quad (9)$$

The sections below will study the impacts of the test and the sampling size on the characteristics of the non-GM product. We will consider the case where the sampling size is exogenously defined (for instance, by public officials), and the case where it is chosen by the supply chain. In this case, we will suppose that the optimal value of the sampling size is obtained simultaneously with the intermediate price and is given by the maximization of the joint profit.

At Stage 1, the retailer chooses the quantity and price for non-GM products sold in the final market. The manufacturer selects the quantity q_o of GM raw materials and the quantity q_n of non-GM materials to be ordered from upstream agricultural producers. At this stage, w_n and q_{n2} are known. The relationship between q_{n2} and the quantity q_n of non-GM raw materials ordered by the manufacturer is given by (2). Therefore, q_n is given by:

$$q_n = \frac{q_{n2}}{\left[\varphi_1.\beta n + (1-\varphi_1)(1-\beta.n)\right]} \ , \quad (10)$$

and q_o is given by $q_0 = Q - q_n$.

Note that we assume that $q_0 > 0$. This excludes the case ($q_0 = 0$) in which non-GM final demand is greater than the manufacturer's capacity *Q*. Indeed, if this was the case, the result would be obvious. The manufacturer would never produce GM product because he would always be able to get a larger profit when producing only non-GM product (double marginalization effect) without having to pay the extra costs associated with segregation.

Finally, at equilibrium, the non-GM price is $p_n = u - s.q_{n2}$ and the quantity of non-GM product marketed is:

$$q_{n2} = \left[\frac{(u - p_0 + d)}{2s(-1+3k)} - T\right], \qquad (11)$$

with

$$T = \frac{(Q \propto \varphi_0 - e)(1-s) + Q(\gamma(1-n\beta)(1-e\varphi_0) + cn)}{2Qs(-1+3k)(1-e\varphi_0 - n\beta + 2n\beta e\varphi_0)}.$$

The profits of the manufacturer and retailer are given by:

$$\Pi_M = (p_o - d - w_o)Q - e(1-s) + q_{n2}\left[u - \gamma - p_o + d + \frac{\left[(e - \alpha\varphi_0 Q)(1-s) + Q\left[-cn + \gamma e\varphi_0 n\beta\right]\right]}{Q\left[1 - e\varphi_0 - n\beta + 2e\varphi_0 n\beta)\right]}\right] - 2sq_{n2}^2 \quad (12)$$

$$\pi_R = sk^2\left[\frac{(-p_0 + u + d)}{s(-1+3k)} - T\right]^2. \qquad (13)$$

Thus, we obtain the intermediate price $w_n = w_n(e,k,n,s,\gamma)$ (14), which is a function of the different parameters and variables of the models (see the mathematical characterization in the appendix).

On this basis, it is now possible to examine the ability of the product chain to guarantee the conformity of the non-GM product to consumers and to study the impacts of several regulatory tools.

III. Supplying the non-GM market

Several papers have focused on the impacts of the labeling threshold choice. For instance, Moschini and Lapan (2006) show that the reducing of regulatory constraints for GM labeling (an increase in *s*) may facilitate coexistence between GM and non GM products. If this threshold is very stringent, then segregation costs are high. Conversely, when the threshold is less stringent, the decrease in costs related to this slack may lead to a drop in the price of non-GM products and may also increase their market share.

However, it is possible to describe a situation in which a less stringent labeling threshold leads to a decrease in non-GM market share. If (as in the present paper) the increase in segregation costs is considered when GM market share increases (as a result of higher contamination risks of non-GM products by GM products), a less stringent labeling threshold does not necessarily imply higher non-GM product quantities. Indeed, it is interesting to note that when *s* increases, the price of non-GM products in the final market decreases, but the quantity of the non-GM products does not necessarily decrease. On one hand, the increase in *s* decreases the price of the raw material. On the other hand, the loosening of the threshold for accidental GM presence tends to push down the demand for the non-GM product. This effect leads to a decrease in the final price, but as the share of the industrial capacity allocated to the GM product increases, the costs linked to segregation efforts also increase, because it is more expensive to avoid non-GM product contamination. For this reason, the decrease in price is

not sufficient to compensate for the decrease in quality. The quantity of non-GM products sold also decreases.

The non-GM market is also influenced by the manner in which negotiating power is shared between the retailer and manufacturer. As a result, it is possible to compare the manufacturer's profit in the case of GM/non-GM coexistence, as indicated by (12), with the profit obtained when only producing GM products. In this case, the manufacturer's profit is given by $\Pi_{M-GM} = (p_o - d - w_o)Q$. We can then see that there exists $\bar{k}(e,n,s,\gamma)$ for which $\Pi_M < \Pi_{M-GM}$, if and only if $k < \bar{k}(e,n,s,\gamma)$. The expression for $\bar{k}(e,n,s,\gamma)$ is given in the annex.

Consequently, if $k < \bar{k}(e,n,s,\gamma)$, the manufacturer produces only GM products and non-GM demand is not met. If $k > \bar{k}(e,n,s,\gamma)$, the manufacturer will meet the demand for non-GM products, but the intermediate price (w_n) it negotiates with the retailer is such that the manufacturer captures a higher share of the value than the retailer. Thus, when the negotiating power (k) of the manufacturer increases, there is a classic effect of double marginalization, which leads to both a decrease in product quantity on the market and an increase in non-GM product prices.

Note that the penalties for non-compliance of non-GM products accentuate this effect. It may be observed that $\bar{k}(e,n,s,\gamma)$ rises as the penalty γ increases. For this reason, when γ increases, the decrease in the quantities made available on the market penalize the manufacturer less (despite a decline in w_n) than the retailer (despite an increase in final price p_n). As a result, as penalties for product non-compliance increase, joint profit decreases, but the manufacturer's share of the total value will increase.

IV. Segregation efforts and sampling size

Compliance of the non-GM product on the final market depends on three decisions made in the product chain: (1) the choice of the characteristic φ_0 of the raw material, (2) the segregation effort e by the manufacturer, and (3) the sampling strategy n which determines the rate of downgraded non-conforming products. An increase in segregation effort or raw material compliance will necessarily increase the compliance of the non-GM final product. However, the impact of these factors on the price and quantity of the final product will depend on the testing strategy, as shown in Results 1 and 2:

Result 1.

If $n > \tilde{n}_e$, an increase in the manufacturer's segregation effort will increase the quantity of the non-GM product placed on the final market and will reduce its price. If $n < \tilde{n}_e$, an increase in the segregation effort will have the opposite effect.

Proof. *See Appendix.*

Segregation effort *e* implemented by the manufacturer has a dual effect. When *e* increases, the compliance probability of the non-GM product increases. The penalty paid by the retailer decreases, thereby tending to lower the price of the non-GM product. At the same time, however, costs related to the segregation effort increase, thereby leading to an increase in the intermediate price and encouraging an increase in the final price of the non-GM product. When the test is sufficiently successful ($n > \tilde{n}_e$), the proportion of the products wrongly rejected is low. Each additional level of effort has a higher value due to the increased reliability of the test. In this case, the positive effect resulting from the decline in penalties is dominant. The final price decreases and the quantity of non-GM product increases. In contrast, when the test is not sufficiently successful ($n < \tilde{n}_e$), the negative effort resulting from the increase in segregation costs is dominant. The price increases and the quantity of non-GM product declines.

The effect of φ_0 on the price and quantity of non-GM products depends on the testing strategy in the same way.[5] The characteristics of the non-GM raw material φ_0 purchased by the manufacturer have a dual effect. On the one hand, an increase in φ_0 tends to favor a decrease in the price of non-GM products due to a rise in the final product compliance rate (and therefore a drop in penalty costs). On the other hand, an increase in φ_0 induces a rise in the intermediate price, which tends to favor an increase in the price of non-GM products (due to an increase in the manufacturer's supply costs). When the test is successful, the positive effect related to the reduction in the risk of contamination of non-GM products (and therefore the risk of a penalty) is dominant. As a result, the final price decreases and the quantity of non-GM products sold increases. In contrast, when the test is not successful, the effect related to the increase in supply costs is dominant. As a result, the final price increases and the quantity of non-GM products sold decreases.

Result 2.

There exists $\tilde{\tilde{n}}_e(.)$ *such that the manufacturer's profit increases with segregation effort if and only if* $n > \tilde{\tilde{n}}_e$, *and there exists* $\tilde{n}_e(.)$ *such that the retailer's profit increases with segregation effort if only if* $n > \tilde{n}_e$. *We have:* $\tilde{n} < \tilde{\tilde{n}}_e$.

Proof. *See Appendix.*

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[5] In an identical manner, it is possible to demonstrate that if $n > \tilde{n}_{\varphi_0}$, an increase in the compliance level of non-GM raw material (φ_0) increases the quantity of non-GM product placed on the final market and decreases its price. If $n < \tilde{n}_{\varphi_0}$, an increase in the compliance level of non-GM raw material has the opposite effect. This is given by $\tilde{n}_{\varphi_0} = \dfrac{A' - \sqrt{4e\beta Q(1-s)(\alpha Q - e^2)(\beta\gamma - 2c) + A'^2}}{2e\beta Q(\beta\gamma - 2c)}$.

Generally, it is not in the interest of either the manufacturer or the retailer to make significant segregation efforts if the test is not successful (i.e., if the sampling size is too small). In this case, as mentioned above, when effort increases, the penalty cost diminishes (due to the decrease in φ_2). However, significant losses resulting from the wrongful rejection of a portion of non-GM products do not provide extra value for each additional effort. However, the motivation to implement significant segregation efforts is not necessarily identical for the manufacturer and the retailer. Thus:

- If $n < \tilde{n}_e$, it is not in the interest of either the retailer or the manufacturer to make a significant segregation effort. In this case, the probability of compliance of the non-GM product placed on the market is low.

- If $\tilde{n}_e < n < \tilde{\tilde{n}}_e$, it is in the interest of the retailer to make a significant segregation effort, but not in the manufacturer's interest. This means that the higher retailer profit resulting from an increase in *e* is not sufficient to compensate the manufacturer's losses (via the intermediate price).

- If $n > \tilde{\tilde{n}}_e$, it is in the interest of both the manufacturer and the retailer to make a significant segregation effort. In this case, the probability of compliance of the non-GM product placed on the final market is high.

Therefore, a higher level of testing success is required to provide a sufficient incentive for the manufacturer to increase its level of segregation efforts. This can again be explained by the above-mentioned double marginalization effect.

V. Impacts of regulatory tools

The previous section considered that *n* was exogenous. If we now assume that the sampling size is determined by a negotiation process between the manufacturer and the retailer, the optimal value chosen by the chain is:

$$n^* = \frac{Q(1-e\varphi_0)(u-p_o+d-\gamma)+(e-Q\alpha\varphi_0)(1-s)}{Q\left[c+\beta(u-p_o+d-\gamma)(1-2e\varphi_0)-\gamma e\varphi_0\right]} \quad . \quad (17)$$

The value of n^* increases with *e* and decreases with γ. Additionally, in the absence of any public regulation (if $\gamma = 0$), it may be observed that $n^* < \tilde{\tilde{\tilde{n}}}_e$. In this case, segregation effort and compliance of the raw material are low. It thus follows that the probability that non-GM product will comply with the labeling threshold is low.

Several actions can be taken to encourage higher levels of segregation effort and to guarantee consumers that they will have products which comply with the labeling threshold. First, public officials may impose controls on the final market and may impose penalties in the event of non-compliant products (which this paper considers through the level of γ). The implementation of rules aimed at minimizing cross contamination in the field (which in our model induces costs to increase φ_0) may be considered as a second possible type of action. A third possible action is related to the assessment of segregation efforts *e* and the verification

that all "reasonable" action has been undertaken in the event of documented accidental contamination.

Up until now, the testing strategies implemented by stakeholders have not been considered from a regulatory perspective. The EC has made some recommendations to homogenize the control and testing practices of public officials, and Codes of Best Practices have been proposed. However, to the best of our knowledge, no constraints have been implemented to influence private testing strategies.

Result 3.

If the penalty cost is sufficiently high ($\gamma > \tilde{\gamma}_e$), an increase in segregation effort by the manufacturer increases the quantity of non-GM product placed on the final market (q_{n2}) and reduces its price (p_n). Otherwise, if ($\gamma < \tilde{\gamma}_e$), an increase in the segregation effort has the opposite effect.

The retailer's profit increases in accordance with segregation effort if $\gamma > \tilde{\gamma}_e$, otherwise it decreases. The manufacturer's profit increases in accordance with segregation effort if $\gamma > \tilde{\tilde{\gamma}}_e$, otherwise it decreases. We have: $\tilde{\gamma}_e < \tilde{\tilde{\gamma}}_e$.

***Proof**: See Appendix.*

As expected, the amount of the fine influences the stakeholder's decision, and the penalty cost must be greater than a certain value to induce segregation efforts in the chain. However, once again, we can note some differences between the retailer and the manufacturer:

- If $\gamma < \tilde{\gamma}_e$, it is in the interest of neither the retailer nor the manufacturer to make a significant segregation effort. In this case, the probability that the non-GM product placed on the market will be compliant is low.

- If $\tilde{\gamma}_e < \gamma < \tilde{\tilde{\gamma}}_e$, it is in the interest of the retailer to make a significant segregation effort, but not in the interest of the manufacturer. This means that it will not be able to pass the penalty cost on to the manufacturer - *via* the intermediate price negotiation - to induce it to implement greater segregation efforts. As mentioned earlier, this is a consequence of the double marginalization effect.

- If $\gamma > \tilde{\tilde{\gamma}}_e$, it is in the interest of both the manufacturer and retailer to make a significant segregation effort. In this case, the probability of compliance of the non-GM product placed on the final market is high.

Result 4

In the absence of penalties, public intervention related to the compliance of non-GM raw material or the segregation effort is not sufficient to guarantee the compliance of the final product. However, regulatory intervention which imposes a testing strategy, such as $n > \tilde{\tilde{n}}_e$, is sufficient to induce correct decisions by the manufacturer regarding segregation efforts and the control of non-GM raw materials. Public intervention related to testing strategies may

therefore be used as a substitute for penalties whose purpose is to punish non-compliant products on the final market.

Proof. *See Appendix*

When $\gamma < \tilde{\tilde{\gamma}}_e$, even if public officials mandate a high level of segregation efforts or a high conformity of the raw material, a high level of compliance for the final non-GM product is not necessarily guaranteed. This is because if γ is not too high, it will always be more profitable to pay the penalty cost rather than to increase the sampling size.

In contrast, if the sampling size is mandatory and equal to $\tilde{\tilde{n}}_e$, even if the penalty cost is nil or below $\tilde{\tilde{\gamma}}_e$, the chain will choose a high level of segregation effort and a high conformity of raw material, thereby leading to a high level of compliance for the final non-GM product.

A numerical illustration in Table 2 summarizes these results. It presents non-GM product characteristics and the shareholders' profits (for a null penalty cost) relative to the levels of segregation effort, compliance probability of the raw material, and sampling size of the test imposed by the retailer. Without regulatory constraints, it is clear that the best solution for stakeholders is the case in which segregation effort, compliance probability of raw material, and sampling size are low (column (h)). If public officials mandate a high segregation effort (see columns (a), (b), (c) and (d)), the best response for the product chain is to choose a low compliance probability for raw material and a small sampling size (column (d)). In this case, the compliance probability of the non-GM final product is low. If public officials mandate a high compliance probability for raw material (see columns (a), (b), (e) and (f)), the best response for the product chain is to choose a low segregation effort and a small sampling size (column (e)). In this case, once again, the compliance probability of the non-GM final product is low. If public officials mandate a high sampling size (see columns (a), (c), (f) and (g)), however, the best response for the product chain is to choose a high segregation effort and a high compliance probability for the raw material (column (a)). In this case, the compliance probability of the non-GM final product is high.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Segregation effort	0.95	0.95	0.95	0.95	0.05	0.05	0.05	0.05
Compliance probability of raw material	0.95	0.95	0.05	0.05	0.95	0.95	0.05	0.05
Sampling size	0.95	0.05	0.95	0.05	0.05	0.95	0.95	0.05
Non-GM quantity sold	61.5	28.1	37.1	78.0	71.3	3.0	27.0	78.0
Non-GM retail price	33.8	37.2	36.3	32.2	32.9	39.7	37.2	32.2
Compliance probability of final product	0.98	0.30	0.23	0.00	0.00	0.23	0.02	0.00
Retailer's profit	379	79	138	608	508	1	78	608
Manufacturer's profit	2051	1852	1891	2205	2139	1801	1851	2206

Table 2

Non-GM product characteristics and profits relative to the segregation effort, the compliance of raw material, and the sampling size (for a null penalty cost) (Other parameters: s=0.1, u=40, p0=20).

Thus, it is possible to guarantee a high level of conformity of the non-GM product, even without a penalty cost, by *ex ante* regulation focusing on the sample size used for tests and controls. *Ex ante* regulations on the minimum sampling size and *ex post* regulations based on liability rules and penalty costs may even be considered as substitutes. As shown in Figure 1,

public officials can impose a penalty cost, a constraint on the sampling size, or a combination of both.

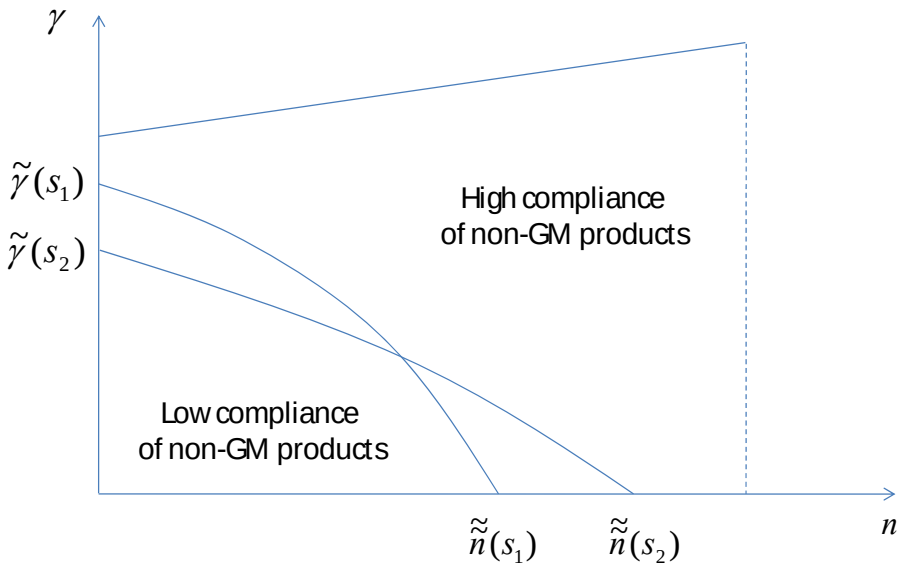

Figure 1
Compliance of non-GM products according to the penalty cost and the sampling size

Note that the values of the penalty cost and sampling size that must be imposed to guarantee a high compliance probability of the final product depend on the labeling threshold. Without any public constraint on the sampling size, a greater labeling threshold and a lower penalty cost are required. In contrast, without any penalty cost, a greater labeling threshold and greater sampling size are required. This would suggest that if only one tool were used, it would be easier to use an *ex ante* regulation on a public sampling size constraint if the labeling threshold is small, or an *ex post* regulation on a penalty cost if the labeling threshold is high.

VI. Conclusion

The aim of the model proposed in this article was to determine the conditions under which GM and non-GM products coexist when the final demand is mostly composed of consumers who are hesitant to purchase GM products, but producers want to produce GM products to supply outside markets. In this model, contamination risks may induce a downgrade of non-GM products. These risks are considered to be even greater if the proportion of GM products is high, and their occurrence depends on decisions made by the stakeholders in the product chain based on concerns over segregation and testing.

The novelty of this model is that it endogenously considers contamination risks between GM and non-GM products and the resulting consequences in terms of product compliance with regulatory labeling thresholds. The possibility of trade-offs is considered at each level of the chain regarding price/costs and quality/product compliance. This analysis produced some interesting results concerning the management of coexistence in product chains.

Previous research has focused on the optimal labeling threshold from the perspective of social welfare. These studies tend to highlight the impact of a very stringent labeling threshold by advancing segregation costs in the case of GM/non-GM coexistence. Given the assumptions of the model in the present article, it is possible to describe a situation in which a less stringent labeling threshold may lead to a reduction in the quantity of non-GM products. Due to the risks of cross contamination, which increase when the share allocated to GM products rises, the price reduction cannot be sufficient to compensate for the decrease in quality resulting from a higher labeling threshold. For this reason, slackening of the labeling threshold does not necessarily make it any easier to preserve the non-GM market.

Given this situation, we have observed that GM/non-GM coexistence is possible, but it is not always systematic. Above all, it depends on the manner in which negotiating power is shared among players in the product chain. In the present case, it depends on the manufacturer's capacity to have sufficient leverage in negotiations concerning optimal test levels and the intermediate price. Otherwise, the manufacturer will only favor the GM market.

Among the results obtained in this paper, the impact of testing and sampling size on the decisions made by the stakeholders should be highlighted. The role of sampling strategy has already been investigated in previous papers (see Johnson and Lin, 2005; Wilson et al., 2007). Following Starbird (2005), who studied the role of an inspection policy in controlling product food safety in a buyer-supplier relationship. Our results suggest that a public constraint on private sampling strategies may be a relevant regulatory tool. In the setting studied in this paper, public intervention related to testing strategies may therefore be used as a substitute for penalties, whose purpose is to punish non-compliant products on the final market. This instrument has not been considered up until now for the regulation of GM/non-GM coexistence in chains. While the attention of public officials is focused on controlling contamination at an upstream level and segregation efforts within the product chain, our results demonstrate that effective control of testing and sampling size strategies implemented by private operators may play a significant role in guaranteeing a satisfactory level of compliance for non-GM products. Moreover, we show that this effective control of testing and sampling strategies at the downstream level could allow reducing the regulatory constraints at the upstream level. Additionally, regulatory intervention in sampling size strategies (a European directive already exists for public controls) may be easier to implement than public testing of products placed on the market (the cost of which would be even higher as the frequency of testing increases).

Of course, it is important to consider the limits of the model proposed in the present paper, given the key assumptions. First, it is clear that if consumers were hypothesized to have information about the compliance probability of non-GM products, requirements related to penalties or sampling size could be lowered by public officials. Furthermore, we have assumed linear pricing between the manufacturer and the retailer. If another type of pricing was defined (e.g., binomial), it is likely that contractual commitments between different parties would change. We have also not explicitly included the transmission of the retailer's penalty to the manufacturer in the supply agreement. Finally, we have chosen to consider testing at only a single stage in the process (on the final product), whereas in practice, these tests may be performed at each step in the chain. However, these limits to the present model provide further avenues for future research.

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Annex

Equilibriums

1. At equilibrium, the function of the intermediary price w_n is given by:

$$w_n^* = \frac{\left[F_1 + F_2\right]}{Q(-1+3k)(1-e\varphi_0 - n\beta + 2en\beta\varphi_0)} \qquad (14)$$

with $F_1 = ek(-1+s) + eQ\varphi_0\left[(-1+2n\beta)\left[k(-d+2u+p_o)-u\right] + (1-k)(1-n\beta)\right]$

and $F_2 = Q\left[ckn + (1-n\beta)\left[-dk + \alpha\varphi_0 k(1-s) + \left[-u+\gamma+k(2u+p_o-2\gamma)\right]\right]\right]$

2. The expression of $\bar{k}(e,n,s,\gamma)$ for which $\Pi_M < \Pi_{M-GM}$ if and only if $k < \bar{k}(e,n,s,\gamma)$ is given by:

$$k < \bar{k} = \frac{Q\varphi_0^2(1-\beta)\left[Q^2(d-cn)^2 + 2eQ(d+2n\alpha s\beta Q\varphi_0^2) + e^2\left[1+2Q^2\varphi_0^2(1+n^2\beta^2 A_1)\right]\right]}{4Q^2(u-d+cn-p_o)^2 - 2eQ(cn+p_o)(1-s) + eQ\left[2d(1-s)+9sQ\right] + 2e^2\left[(1-s)+d\varphi_0^2Q^2\right]}$$

with $A_1 = \sqrt{\left[e\left[e(1+2s)+2Q\left[(d+cn)(1+s)+p_o(1-s)+6sQ\right]\right]\right] + 4\gamma(d+u-p_o)}$

3. The expression of $\tilde{n}_e(.)$ is given by:

$$\tilde{n}_e = \frac{A - \sqrt{4\varphi_0 Q\beta(1-s)(Q\alpha\varphi_0^2 - 1)(\beta\gamma - 2c) + A^2}}{2\varphi_0\beta Q(\beta\gamma - 2c)} \qquad (15)$$

$$\text{with } A = \beta(1-s)(2\alpha\varphi_0^2 Q - 1) + \varphi_0 Q(\beta\gamma - c)$$

4. The expression of $\tilde{\tilde{n}}_e(.)$ is given by:

$$\tilde{\tilde{n}}_e = \tilde{n}_e + \frac{A'' + A'''}{kQ^2\left[c + \beta(u - p_O + d + \gamma)(1-\varphi_0) + d\varphi_0\right]} \qquad (16)$$

with

$$A'' = \sqrt{ck + (1-\varphi_0\beta)\left[(u + p_o - \gamma + d) + k\alpha\varphi_0(1-s)\right]}$$

$$A''' = sQ\left[(u - p_O + d + \gamma)(1-\varphi_0) + (1-s)(1+Q\alpha\varphi_0^2)\right] + \left[(1+s)(1+Q\alpha\varphi_0) + c + Q\beta\varphi_0(1-\varphi_0\beta)\right]$$

5. The expression of $\tilde{\gamma}_e(.)$ is given by:

$$\tilde{\gamma}_e = \frac{(1-2n\beta)\left[cn + \alpha\varphi_0(1-s)\right]}{n\beta(1-n\beta)} + \frac{(1-s)}{n\beta\varphi_0 Q} \qquad (18)$$

6. The expression of $\tilde{\tilde{\gamma}}_e(.)$ is given by:

$$\tilde{\tilde{\gamma}}_e = \tilde{\gamma}_e + Q(1-n\beta)\left[(1-k)(1-s)(1+Q\alpha\varphi_0^2) + nc + nQ\beta\varphi_0(u - p_o + d)\right] \qquad (19)$$

Result 1

1. At equilibrium, the quantity of non-GM products sold on the final market q_{n2} is given by (11). The first order condition of q_{n2} with respect to e is as follows:

$$\frac{\partial q_{n2}}{\partial e} = k.f(n) = k.f_1(n).f_2(n)$$

where

$$f_1(n) = \left[n + \frac{\sqrt{4\varphi_0 Q\beta(1-s)(Q\alpha\varphi_0^2 - 1)(\beta\gamma - 2c) + A^2}}{2\varphi_0\beta Q(1-n\beta)} \right]$$

$$f_2(n) = \left[n - \frac{A - \sqrt{4\varphi_0 Q\beta(1-s)(Q\alpha\varphi_0^2 - 1)(\beta\gamma - 2c) + A^2}}{2\varphi_0\beta Q(\beta\gamma - 2c)} \right]$$

$$\text{with } A = \beta(1-s)(2\alpha\varphi_0^2 Q - 1) + \varphi_0 Q(\beta\gamma - c)$$

By assumption e, n, β, $\varphi_0 \in [0,1]$ and Q > 0. Hence we can verify that $\forall$ e $\in [0,1], f_1(n) > 0$.

Moreover,

$$f_2(n) = 0 \text{ when } n = \tilde{n}_e \text{ given by (15)}$$

Thus $\forall\ e \in [0,1],\ f_2(n) < 0$ if and only if $n < \tilde{n}_e$.

In addition, $k \in [0,1]$. Therefore, the first order condition of q_{n2} with respect to e is negative ($\forall$ e$\in[0,1]$, $\frac{\partial q_{n2}}{\partial e} < 0$) when $n < \tilde{n}_e$ and positive ($\forall$ e$\in[0,1]$, $\frac{\partial q_{n2}}{\partial e} > 0$) when $n > \tilde{n}_e$. Then, the quantity of non-GM products is decreasing in e when $n < \tilde{n}_e$ and increasing in e when $n > \tilde{n}_e$.

2. At equilibrium, the price of non-GM products sold on the final market p_n is given by: $p_n = u - sq_{n2}$

The first order condition of p_n with respect to e is as follows*:*

$$\frac{\partial p_n}{\partial e} = -ksf(n) = -ks.f_1(n).f_2(n)$$

By assumption s,$k \in [0,1]$, therefore we can verify that the first order condition of p_n with respect to e is positive ($\forall\ e \in [0,1]$, $\frac{\partial p_n}{\partial e} > 0$) when $n < \tilde{n}_e$ and negative ($\forall\ e \in [0,1]$, $\frac{\partial p_n}{\partial e} < 0$) when $n > \tilde{n}_e$. Thus, the price of non-GM products sold on the final market is increasing in e when $n < \tilde{n}_e$ and decreasing in e when $n > \tilde{n}_e$.

Result 2.

1. The retailer's profit Π_R is given by (13). The first order condition of Π_R with respect to e is as follows:

$$\frac{\partial \Pi_R}{\partial e} = sk^2.f_1(n).f_2(n).f_5(n) / f(e)$$

where

$$f_5(n) = n + \frac{Q\left[(u - p_o + \gamma + d)(1 - e\varphi_0)\right] + \alpha\varphi_0 Q(1-s)}{Q\left[c + (1 - \beta e\varphi_0)(u - p_o + \gamma + d)\right]}$$

and $$f(e) = 2sQ^2\left[(-1+3k)\left[1 - e\varphi_0 + n\beta(-1+2e\varphi_0)\right]\right]^2$$

By assumption,

e, φ_0, β and $s \in [0,1]$

$Q > 0$
$\alpha > 0$
c, d and $\gamma \geq 0$
$u > p_o$

Thus, we can verify that $\forall\ e \in [0,1]$, $f_5(n) > 0$ and $f(e) > 0$.

Moreover, by assumption s, $k \in [0,1]$. Therefore, the first order condition of Π_R with respect to e is negative ($\forall\ e \in [0,1]$, $\frac{\partial \Pi_R}{\partial e} < 0$) when $n < \tilde{n}_e$ and positive ($\forall\ e \in [0,1]$, $\frac{\partial \Pi_R}{\partial e} > 0$) when $n > \tilde{n}_e$. The retailer's profit is decreasing in e when $n < \tilde{n}_e$ and increasing in e when $n > \tilde{n}_e$.

2. The first order condition of manufacturer's profit Π_M with respect to e is given by:

$$\frac{\partial \Pi_M}{\partial e} = f(n) = k(1+k).f_6(n).f_7(n).f_8(n).f_9(n) / f(e)$$

where

$$f_6(n) = n + \frac{\sqrt{4e\beta Q(1-s)(\alpha Q - e^2)(\beta\gamma - 2c) + A^2}}{2e\beta Q(1-n\beta)} + (1-s)\left[(1-n\beta)(Q\alpha\varphi_0^2 + 1 + eQ\alpha\varphi_0^2) + e\varphi_0\right]$$

$$f_7(n) = n + \frac{Q\left[(u - po + \gamma + d)(1-\alpha e)\right] + (e + \varphi_0 Q)(1-s)}{Q\left[c + (1-n\beta)(u - p_o + \gamma + d)\right]}$$

$$f_8(n) = \tilde{n}_e + \left[\varphi_0 Q(1-n\beta)\left[(\alpha + e\alpha\varphi_0 + en\varphi_0 c\beta)(u - p_o + d) - (\alpha\varphi_0 + e\alpha\varphi_0)(1-s)\right] + (1-s)(n\beta + e\varphi_0) + \varphi_0 Qcn\right]$$

$$f_9(n) = n - \left[\tilde{n}_e + \frac{A" + A'''}{kQ^2\left[c + \beta(u - p_O + d + \gamma)(1-\varphi_0) + d\varphi_0\right]}\right]$$

With

$$A" = \sqrt{ck + (1-\varphi_0\beta)\left[(u + p_o - \gamma + d) + k\alpha\varphi_0(1-s)\right]}$$

$$A''' = sQ\left[(u - p_O + d + \gamma)(1-\varphi_0) + (1-s)(1 + Q\alpha\varphi_0^2)\right] + \left[(1+s)(1 + Q\alpha\varphi_0) + c + Q\beta\varphi_0(1-\varphi_0\beta)\right]$$

By assumption,

e, β, φ_0, and $s \in [0,1]$

$Q > 0$
$\alpha > 0$
c, d and $\gamma \geq 0$
$u > p_o$

Besides, $\tilde{n}_e > 0$

Thus, we can verify that $\forall\ e \in [0,1]$, $f_6(n), f_7(n)$ et $f_8(n) > 0$.

Furthermore, $f_9(n) = 0$ when $n = \tilde{\tilde{n}}_e$ given by (16). Therefore, $f_9(n)$ is negative ($\forall\ e \in [0,1]$, $f_9(n) < 0$) when $n < \tilde{\tilde{n}}_e$ and positive ($\forall\ e \in [0,1]$, $f_9(n) > 0$) when $n > \tilde{\tilde{n}}_e$.

In addition, $k \in [0,1]$. Therefore, the first order condition of manufacturer's profit Π_M with respect to e is negative ($\forall\ e \in [0,1]$, $\frac{\partial \Pi_M}{\partial e} < 0$) when $n < \tilde{\tilde{n}}_e$ and positive ($\forall\ e \in [0,1]$, $\frac{\partial \Pi_M}{\partial e} > 0$) when $n > \tilde{\tilde{n}}_e$ The manufacturer's profit is decreasing in e when $n < \tilde{n}_e$ and increasing in e when $n > \tilde{n}_e$.

Result 3

1. The first order condition of q_{n2} with respect to e is given by:

$$\frac{\partial q_{n2}}{\partial e} = f(\gamma) = k \frac{\gamma - \left[\frac{(1-2n\beta)\left[cn + \alpha\varphi_0(1-s)\right]}{n\beta(1-n\beta)} + \frac{(1-s)}{n\beta\varphi_0 Q} \right]}{2sQ\left[(-1+3k)\left[1 - e\varphi_0 + n\beta(-1+2e\varphi_0)\right]\right]^2}$$

By assumption, $k,\ s \in [0,1]$ and $Q > 0$

Thus, we can verify that the first order condition of q_{n2} with respect to e is negative ($\forall\ e \in [0,1]$, $\frac{\partial q_{n2}}{\partial e} < 0$) when $\gamma < \tilde{\gamma}_e$ given by (19), and positive ($\forall\ e \in [0,1]$, $\frac{\partial q_{n2}}{\partial e} > 0$) when $\gamma > \tilde{\gamma}_e$. The quantity of non-GM products sold on the final market is decreasing in e when $\gamma < \tilde{\gamma}_e$ and increasing in e when $\gamma > \tilde{\gamma}_e$.

2. The first order condition of p_n with respect to e is given by*:*

$$\frac{\partial p_n}{\partial e} = f(\gamma) = -k \frac{\gamma - \left[\frac{(1-2n\beta)\left[cn + \alpha\varphi_0(1-s)\right]}{n\beta(1-n\beta)} + \frac{(1-s)}{n\beta\varphi_0 Q} \right]}{2Q\left[(-1+3k)\left[1 - e\varphi_0 + n\beta(-1+2e\varphi_0)\right]\right]^2}$$

By assumption $k \in [0,1]$ and Q > 0

Thus, we can verify that the first order condition of p_n with respect to e is positive ($\forall$ e $\in [0,1]$, $\frac{\partial p_n}{\partial e} > 0$) when $\gamma < \tilde{\gamma}_e$, and negative ($\forall$ e $\in [0,1]$, $\frac{\partial p_n}{\partial e} < 0$) when $\gamma > \tilde{\gamma}_e$. In other words, the price of non-GM products sold on the final market is increasing in e when $\gamma < \tilde{\gamma}_e$ and decreasing in e when $\gamma > \tilde{\gamma}_e$.

Result 4

1. *Let us assume that* $\gamma = 0$.

The retailer's profit is given by (13). Its limit when n tends towards 0 is given by:

$$Lim_{n\to 0}\Pi_R = \frac{sk^2}{4(1-3k)^2}\left[(u - p_o + d) + \frac{(e - \alpha\varphi_0 Q)(1-s)}{Q(1-e\varphi_0)}\right]^2$$

The double limit of retailer's profit when n tends towards 0 and e and φ_0 tend towards 0 is given by:

$$Lim_{e,\varphi_0\to 0}Lim_{n\to 0}\Pi_R = \frac{sk^2}{4(1-3k)^2}\left[(u - p_o + d)\right]^2$$

The double limit of retailer's profit when n tends towards 0 and e and φ_0 tend towards 1 is given by:

$$Lim_{e,\varphi_0\to 1}Lim_{n\to 0}\Pi_R = +\infty$$

The limit of retailer's profit when n tends towards 1 is given by:

$$Lim_{n\to 1}\Pi_R = \frac{sk^2}{4(1-3k)^2}\left[(u - p_o + d) + \frac{(e - \alpha\varphi_0 Q)(1-s) - Qc}{Q(1-e\varphi_0 - \beta + 2e\varphi_0\beta)}\right]^2$$

The double limit of retailer's profit when n tends towards 1 and e & φ_0 tend towards 0 is given by:

$$Lim_{e,\varphi_0\to 0}Lim_{n\to 1}\Pi_R = \frac{sk^2}{4(1-3k)^2}\left[(u - p_o + d) - \frac{c}{(1-\beta)}\right]^2$$

The double limit of retailer's profit when n tends towards 1 and e & φ_0 tend towards 1 is given by:

$$Lim_{e,\varphi_0\to 1}Lim_{n\to 1}\Pi_R = \frac{sk^2}{4(1-3k)^2}\left[(u - p_o + d) + \frac{(1-\alpha Q)(1-s) - Qc}{Q\beta}\right]^2$$

By assumption,

$e, \beta, \varphi_0, k \text{ and } s \in [0,1]$

$Q > 0$

$\alpha, c, d \geq 0$

$u > p_o$

Thus, we can verify that $Lim_{e,\varphi_0 \to 0} Lim_{n \to 0} \Pi_R \geq Lim_{e,\varphi_0 \to 0} Lim_{n \to 1} \Pi_R$

and $Lim_{e,\varphi_0 \to 1} Lim_{n \to 0} \Pi_R \geq Lim_{e,\varphi_0 \to 1} Lim_{n \to 1} \Pi_R$

Moreover, the result 2 shows that the retailer's profit is monotone in e (and φ_0) with whatever $n \in [0,1]$. We can therefore emphasize that without penalty, whatever the level of e and φ_0, the retailer's profit is maximized only when n is small ($n < \tilde{n}_e$). In other words, if the testing strategy is chosen by the retailer, he would prefer a very low n ($n < \tilde{n}_e$).

2. *Always with* $\gamma = 0$, the double limit of manufacturer's profit (see (12)) when n tends towards 0 and e & φ_0 tend towards 0 is given by:

$$Lim_{e,\varphi_0 \to 0} Lim_{n \to 0} \Pi_M = B_1 + B_2$$

with $$B_1 = \frac{2k\left[3sQ(5p_o - d) + (3p_o - d)(-u + \gamma)\right] + k(1+2k)\left[p_o^2 - 12sw_oQ + (u-\gamma)^2\right]}{2s(1-3k)^2}$$

and $$B_2 = \frac{dk(-1+2k)(d-2p_o) + 2sQ(p_o - w_o - d + 3k^2 w_o)}{2s(1-3k)^2}$$

The double limit of manufacturer's profit when n tends towards 0 and e & φ_0 tend towards 1 is given by:

$$Lim_{e,\varphi_0 \to 1} Lim_{n \to 0} \Pi_M = +\infty$$

The double limit of manufacturer's profit when n tends towards 1 and e & φ_0 tend towards 0 is given by: $$Lim_{e,\varphi_0 \to 1} Lim_{n \to 0} \Pi_M = B_1 + B_2 - \frac{2ck(1-k)(u - p_o + d + \gamma)}{(1-\beta)}$$

The double limit of manufacturer's profit when n tends towards 1 and e & φ_0 tend towards 1 is given by:

$$Lim_{e,\varphi_0 \to 1} Lim_{n \to 1} \Pi_M = \frac{\left[B_3 + B_4 - 3kp_o sQ + 3(-1 + s - Qw_o)\right]}{2s\beta^2 Q^2 (1-3k)^2}$$

with $$B_1 = 2d\left[sQ + kp_o(1-k) + u(1-2k) + 2s\left[-1 + s + Q(p_o - w_o)\right]\right]$$

And $B_2 = \left[p_o^2 + p_o(9sQ - 2u) + u^2 + 9s(-1 + s - Qw_o) \right](2k^2 + k)$

By assumption,

e, β, φ_0, k and $s \in [0,1]$
$p_o, w_o, Q > 0$
$\alpha, c, d \geq 0$
$u > p_o$

Therefore, we can verify that $Lim_{e,\varphi_0 \to 0} Lim_{n \to 0} \Pi_M \geq Lim_{e,\varphi_0 \to 0} Lim_{n \to 1} \Pi_M$
and $Lim_{e,\varphi_0 \to 1} Lim_{n \to 0} \Pi_M \geq Lim_{e,\varphi_0 \to 1} Lim_{n \to 1} \Pi_M$

Moreover, the result 2 shows that the manufacturer's profit is monotone in e (and φ_0) with whatever $n \in [0,1]$. We can therefore emphasize that without penalty, whatever the level of *e* and φ_0, the manufacturer's profit is maximized only when n is small ($n < \tilde{\tilde{\tilde{n}}}_e$). In other words, if the testing strategy is chosen by the manufacturer, he would prefer a very low n ($n < \tilde{\tilde{\tilde{n}}}_e$).

3. $\tilde{\tilde{n}}_e \geq \tilde{n}_e$

As we know, $\tilde{\tilde{n}}_e$ is given by:

$$\tilde{\tilde{n}}_e = \tilde{n}_e + \frac{A'' + A'''}{kQ^2 \left[c + \beta(u - p_O + d + \gamma)(1 - \varphi_0) + d\varphi_0 \right]}$$

where

$$A'' = \sqrt{ck + (1 - \varphi_0\beta)\left[(u + p_o - \gamma + d) + k\alpha\varphi_0(1 - s) \right]}$$

$$A''' = sQ\left[(u - p_O + d + \gamma)(1 - \varphi_0) + (1 - s)(1 + Q\alpha\varphi_0^2) \right] + \left[(1 + s)(1 + Q\alpha\varphi_0) + c + Q\beta\varphi_0(1 - \varphi_0\beta) \right]$$

By assumption,

e, φ_0 and $s \in [0,1]$
Q > 0
c, d and $\gamma \geq 0$
u > p_o

Hence, we can verify that: A'' and $A''' > 0 \ \forall$ e

So, $\tilde{\tilde{n}}_e \geq \tilde{n}_e$

When $n \geq \tilde{\tilde{n}}_e$, both first order conditions of manufacturer's profit and retailer's profit with respect to *e* are positive ($\frac{\partial \Pi_M}{\partial e} > 0$ & $\frac{\partial \Pi_R}{\partial e} > 0$), which means that it is beneficial for the firms to set up a high effort.

The probability of being compliant with the non-GM threshold *s* of non-GM products sold on the final market is given by:

$$\varphi_2 = 1 - (1 - \varphi_0 e)(1 - \beta.n) / \left[\varphi_0 e.\beta n + (1 - \varphi_0 e)(1 - \beta.n)\right]$$

The first order condition of φ_2 with respect to *e* is as follows*:*

$$\frac{\partial \varphi_2}{\partial e} = \frac{\varphi_0(1 - \beta.n) + \left[\varphi_0 \beta n + \varphi_0(1 - \beta.n)\right]\left[1 - (1 - \varphi_0 e)(1 - \beta.n)\right]}{\left[\varphi_0 e.\beta n + (1 - \varphi_0 e)(1 - \beta.n)\right]^2}$$

$$\text{i.e. } \frac{\partial \varphi_2}{\partial e} = \frac{\varphi_0\left[e\varphi_0(1 - \beta.n) + 1\right]}{\left[\varphi_0 e.\beta n + (1 - \varphi_0 e)(1 - \beta.n)\right]^2}$$

By assumption, e, n, β, $\varphi_0 \in [0,1]$, thus, we can verify that :

$$\frac{\partial \varphi_2}{\partial e} = \frac{\varphi_0\left[e\varphi_0(1 - \beta.n) + 1\right]}{\left[\varphi_0 e.\beta n + (1 - \varphi_0 e)(1 - \beta.n)\right]^2} \geq 0 \ \ \forall \ \text{e}$$

Therefore, a higher e when $n \geq \tilde{\tilde{n}}_e$ induces a higher φ_2. When $n \geq \tilde{\tilde{n}}_e$, the probability of being compliant with the non-GM threshold of non-GM products sold on the final market is high.

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