Identity Preservation, Enforcement of Labelling Rules and the Coexistence of GM and Non-GM Varieties*

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Abstract

As the GM varieties of many agricultural products are increasingly being produced around the world, the consumers who are averse to consumption of GM varieties, are feeling increasingly threatened by the contamination risk. As the society wants to protect the non-GM consumers' right through mandatory labelling of the GM variety, this paper characterizes the possible choices of the testing technology by the enforcement authority when the producer chooses its identity preservation effort strategically. The paper also discusses the coexistence of different varieties of a product on the production side at alternative choices of the testing technology. In particular, it analyzes the effects of common production shock, the effects of adopting higher quality standard and of the possible punishment on the producers for supplying the GM variety to the non-GM consumers on the protection of the non-GM consumers as well as on the coexistence of the varieties.

Keywords: GM Labels, Identity Preservation, Enforcement, Co-existence
JEL Classification: Q15, Q18, K42

1. Introduction

In recent times the GM technology is growing in its popularity with the producers worldwide as more and more agricultural lands are farmed[1] with 'first generation GM seeds'[2]. On the other side of the market, groups of consumers in some countries appear still not out of their initial scepticism about the possible 'health and environmental hazards' associated with the consumption of GM products as foods and feeds[3]. Continued confrontation between this group of consumers and the GM producers are widely reported[4]. In this situation, the efficiency demands the existence of two separate markets for GM and non-GM varieties, which adequately addresses the concern of the non-GM consumers. However, the separation is not easy for several reasons. First, the varieties look identical unless identified by the producers as they are marketed. They taste similar. No distinguishable effect on health follows after the consumption in the short run. Second, the GM variety is cheaper to produce relative to its non-GM counterpart, which is apparent in the popularity of the GM variety among the producers. Third, there are contamination and admixture possibilities between the GM and the non-GM varieties at different stages of production, processing and transportation. The identity preservation (IP) effort provided by the producers can reduce the chance of contamination or admixture but raises the production cost of the non-GM variety further. These factors together open up the scope for strategic behaviour to the producers. As they face strong incentive to sell the GM variety as non-GM and deceive the non-GM consumers, the society plunges into the Akerlof's (1970) 'lemon' type problem with the 'inferior' variety driving out the 'superior' variety from the market. This also explains the concern of the non-GM consumers and the history of their confrontation with the producers.

Given these difficulties, policy-makers in many countries, especially in Europe, face the problem of regulating the food market in a way that favours the coexistence of separate GM and non-GM markets[5]. The policy of 'GM labelling' is thought as an

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[1] More than 1 billion acres are farmed within last 12 years. See Moschini and Lapan (2007).
[2] Input traits like Roundup Ready soybeans and Bt corn.
[3] See Lusk, Jamal, Kurlander, Roucan and Taulman (2005), and Dannenberg (2009).
[4] See Evenson and Santanielli (2004).
[5] See for the European case: EC (2003) and EC (2006).

antidote to the problem. In this policy, the society sets a quality standard about the GM content of a product. If the GM content of the product exceeds this pre-specified level, the product must be labelled as 'GM product'. The standard is enforced by public controls based on random testing of samples declared by the producers as non-GM. If the GM content is above the labelling threshold, then no consignment of it can be sold at the non-GM market. This policy has already come into practice with strict enforcement in countries like European Union, Australia and New Zealand, Japan and South Korea for different agricultural products[6]. It is reported that the developing countries like Brazil, China and India have also come out with similar policy but with lax enforcement[7].

This paper concerns itself with the opportunistic behaviour of the vertically integrated firms at the stage of supplying IP effort and the issue of enforcement of the GM labels. It captures an institutional set up where the quality standard is chosen by the society politically or scientifically and the enforcement is delegated to a separate authority. The enforcement authority chooses the testing technology. The available testing technologies are not accurate. However, a more efficient testing technology ensures the truth is discovered with higher probability. But, the more efficient technology can be chosen only at a higher cost[8]. As the authority commits to the testing technology, which is commonly known as inaccurate, the firm chooses its IP effort strategically keeping in mind the authority can make a mistake in testing: it can pass the GM variety as a non-GM and also a non-GM variety as a GM. The authority anticipates the firm's behaviour and chooses the technology appropriately to protect the non-GM consumers.

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[6] See Carter and Gruere (2003) for details. Some countries like USA depended on the voluntary labeling by the firms without the government involvement. The argument in favor of voluntary labeling was that the government intervention would be costly as it is prone to failure and the firms themselves would separate out the two varieties of a product as a part of their socially responsible behavior. Recent proofs of contamination in Starlink seeds by Aventis (before it was purchased by Bayer in 2002) and in Bt-10 maize seeds by Syngenta show that the voluntary labeling did not work perfectly. See Clapp (2008) for more details.

[7] See Bansal and Ramaswami (2007).

[8] Bansal and Ramaswami (*op cit.*) provide details of two alternative testing technologies: ELISA test and PCR test. Of them the ELISA test is not accurate but expensive. The PCR test is relatively more accurate but has many limitations. As such it is more expensive than the ELISA test. Overcoming the limitations is costly too.

The goal of this paper is (i) to predict the choice of testing technology by the enforcement authority as a function of efficiency of the non-GM production technology, the rise in cost of production of both the GM and non-GM varieties, the stricter quality standard and possible punishments to the firm for the strategic behaviour; (ii) to discuss its consequences on the co-existence of the varieties at the production stage, and finally (iii) to discuss the effectiveness of the GM labels in protecting the non-GM consumers at the equilibrium.

The results show that *ceteris paribus* if testing technology is not efficient enough, the mandatory labelling rule fails to protect the interest of the non-GM consumers. On the production side, it turns out that the efficiency of the non-GM production technology facilitates the coexistence of the varieties. An inefficient testing technology along with inefficiency of the non-GM production technology may endanger the coexistence of the varieties. The prevalence of similar situations in technology poor developing countries foresee the failure of the authority in protection of the interest of the non-GM consumers as well as the coexistence of the varieties at the advent of GM production. Besides predicting the trends in the composition of GM and non-GM outputs at the different combination of testing and production technology parameters, the paper finds out that the scope of coexistence reduces with the imposition of punishment on the faltering producers. The similar result is found in the presence of an adverse production shock to both the GM and the non-GM variety of the product and for the choice of the stricter quality standard by the society.

1.1. Related literature

The literature dealing with the GM labelling and contamination risks in chains so far mostly overlooked the aspect of strategic behaviour of the firms in relation to their supply of the IP effort and the enforcement. There are two different strands of the existing literature. One of them is concerned with the determination of the optimum quality standard for the non-GM variety like the paper by Moschini and Lapan (2007). The other strand discusses the effect of GM labelling on international trade like the paper by Plastina and Giannakas (2007). The papers that are closer to the scope of the present paper are by Lapan and Moschini (2004), Starbird (2005), Hammoudi et al. (2007) and Desquilbet and Bullock (2009). Of these, in Lapan and

Moschini (2004) and Desquilbet and Bullock (2009) consider the welfare impact of IP cost. But, in these papers there is nothing strategic about the choice of IP effort on the part of the firms. The probability of contamination of the GM and the non-GM varieties is treated as completely random, independent of the choice of the firm. In contrast Starbird (2005) considers the scope of strategic behaviour in the choice of IP effort, but it assumes perfect verifiability of the firm's effort on the part of the enforcement authority. On the other hand, Hammoudi et al. (2007) like Starbird though consider the strategic behaviour of the firms but do not consider the fact that the rejected non-GM product can be sold at the GM market and affect the GM consumers' surplus. They also do not look at the choice of the testing technology. The present paper attempts to address some of the missing aspects of all these papers. We treat the IP effort supplied by the firm as strategic, while we make room for the diagnostic error made by the enforcement authority and also take into account the effect of the outside market. So, this paper addresses a more realistic set of circumstances and attempts to act as a guide to the optimum enforcement strategy adopted by the authority.

Consumers' misperception of the product and the possibility of product failure have earlier been discussed in papers like Spence (1977). These papers assume the product failure is detectable in the short run without any noise associated with the detection process and therefore argues the producer's liability solves the efficiency problem. But, this framework is inapplicable in our context as the effects of the GM products are not distinguishable from that of the non-GM products in the short run. Grieson and Singh (1990) discuss the regulation of externalities through testing. In their framework the enforcement authority chooses the testing probability without commitment. In contrast our paper for its purpose assumes the authority's commitment to the testing probability and produces different set of results. The paper also relates to the literature in law and economics as it supports Posner's (1999) view that " ….greater accuracy in the determination of guilt increases returns to the being innocent" and therefore increases "the law's deterrent effect"[9].

[9] Lando (2006) for a recent critic of Posner's view.

1.2. Plan of the paper

In the next section of the paper we describe the model in which we discuss the firm's strategies, the authority's choice both without punishment and with punishment. In the section following we conclude.

2. The model

We consider a vertically integrated agricultural firm that manufactures as well as retails both the genetically modified (GM) and the non-GM varieties of a product. It is common knowledge that there is a chance of contamination between the two varieties at either of the stages of production. Even storing or processing the two varieties in the same equipments can raise admixture risks which can introduce some GM elements in the non-GM lots. The level of contamination s per unit of the non-GM lots by GM batches depends on the per unit identity preservation (IP) effort e supplied by the firm. We assume in particular $e \in [0, 1]$ and $s = 1 - e$. The effort choice of the firm is its private information. The level at which e is chosen determines s i.e. the level of contamination in different varieties of the product.

There are consumers in the market who regard the varieties with a level of contamination $s \leq \bar{s}$ as 'superior' than both the varieties with a level of contamination $s > \bar{s}$ (referred to as 'inferior') and the GM. They are also ready to pay higher price for the 'superior' variety compared to the rest, while the 'inferior' variety is not paid more than the price of the GM variety. In this model we denote the 'superior' variety by S, the 'inferior' variety by I and the GM variety G. Since the varieties are identical in their look and on consumption, the consumers cannot distinguish between the S, I and the G, unless their true identities are disclosed.

As it is, the firm with its objective of profit maximization has very little incentive for disclosure of true identities of the varieties because of the reasons specified below. First, technologically it is cheaper to produce the GM variety; per unit cost of production of the Non-GM ($w + \delta$) is greater than per unit cost of production w of the GM. Second, the supply of IP effort is costly to the firm; $g(e)$ being the disutility of supplying the effort with $g(0) = 0$, $g'(e) > 0$ and $g''(e) \geq 0$ for all possible values of $e > 0$. So, as the S variety cannot be produced without $e \geq \bar{e} = 1 -$

$\bar{s}$ that ensures $s \leq \bar{s}$, its effective per unit cost of production ($w + \delta + g(e)$) stands above the per unit cost of production of either of the two other varieties. Third, the output declared as S variety sells at price p_s higher than the price p_g either of the I or the G variety. The price difference not only reflects the difference in unit cost of production but also the quality premium.

Since due to the lower cost of production most of the firms adopt the GM variety, we assume the market for GM variety is competitive. In contrast the non-GM market with captive consumers that is served by few producers incurring the higher unit cost of production in return of a price greater than the cost of production, has non-competitive characters and for convenience we model it as a monopoly[10]. Under symmetric information the S variety sells at a price $p_s = a - q_s > w + \delta + g(e)$ where the G variety sells at $p_g = w < p_s$. However since the varieties cannot be distinguished by the consumers by their look, under asymmetric information all the three varieties can be sold at price p_s. Each firm has the strongest incentive to deceive the consumers in the S market by selling the G variety of the product to them, which is produced at the lowest cost, presenting it as an S variety.

The S consumers as well can anticipate such behaviour of the firm and may refrain from demanding the S product at the market. So following the 'lemons' example given by Akerlof (1970), here too we have a case where a market disappears due to asymmetry of information. As the society thinks that the market for the S should exist, it steps in to preserve the market through policy intervention. First, it makes it mandatory for the firm to declare the varieties before the product is being retailed. In this framework, if the GM content of the non-GM product is below the threshold $\bar{s}$, the firm is allowed to claim that it is an S product. If not, the product must be considered of type I and must be labelled and sold in the GM market. Second, the public authority appoints an enforcement body to test randomly some samples of the variety, claimed as S. If it discovers $s > \bar{s}$ in the test, the consignment is rejected

[10] Let us consider the European example. Producers would like to produce both GM and non-GM foods. As a large part of European consumers rejects GM products, the non-GM production would be delivered to the domestic market (which is supposed to be only supplied by the European producers), whereas the GM production would be sold on the international markets (which are supposed to be perfectly competitive). In this paper, we want to analyse the impacts of such setting, considering that the admixture risks at the production level between GM and non-GM can raise costs and reduce the ability to provide compliant non-GM foods to the domestic consumers.

to be sold at the S market. If it finds $s \leq \bar{s}$, the consignment passes through in the S market. However, the common knowledge is that the authority itself is prone to making mistakes. It commits to a testing technology which is not full-proof. The testing technology finds out the truth with probability α and makes a mistake with probability (1 - α). The value of α is determined as $\alpha = \beta n$, where β represents the technique used as indexed between 0 and 1; n represents the proportion of the entire consignment drawn as sample. The increase in either of β or n increases α. But α can be increased only with a cost $c(\alpha)$; $c'(\alpha) > 0$, $c'(\alpha) \to \propto$ as $\alpha \to 1$. The consumers and the firm take their decisions given the knowledge of α. The enforcement authority on the other hand chooses α anticipating the reactions of the firm and the consumers to the change in α and its own knowledge of $c(\alpha)$[11].

In the S market the consumers demand $q_s = a - p_s$ if the authority declares the variety as $s \leq \bar{s}$ and make no demand if the government puts a 'GM' label on it. Now, we look at the firm's decision. In spite of the higher cost of production, serving the S market appears to be lucrative to the firm because of its monopoly power in that market, in contrast to the GM market where it is forced to behave competitively. But, due to imperfection of the testing technology a certain amount of gambling is involved in its decision to serve the S market. On the other hand, production of the G variety appears as a default option to the firm involving zero risk and normal profit. Even the rejected S market products are sold at the G market. Now, in the given situation the firm can adopt two different strategies to serve the S market: (i) *Honest* strategy: the firm puts an IP effort level $e \geq \bar{e}$ producing a combination of the S variety and the G variety; (ii) *Opportunistic* strategy: the firm puts an IP effort level $e < \bar{e}$ producing a combination of the I variety and the G variety. In the case of *Opportunistic* strategy, the firm waits for the authority to make mistakes in the labelling, which is routine, for entering the S market and if it is successful, the S consumers are deceived.

In the following subsections we describe the firm's behaviour under these two strategies. We discuss the firm's as well as the authority's choices subsequently.

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[11] Note that the choice of $\bar{s}$ is made by the society at the political/scientific level. It is beyond control of the enforcement agency.

2.1 The firm behaving *honestly*

Under this strategy the firm produces $q_s \geq 0$ amount of the S variety and $q_g > 0$ amount of the GM variety such that $q_s + q_g = Q$. In order to produce the S variety *honestly* it supplies an IP effort $e_s \geq \bar{e}$ and incurs a per unit cost of $(w + \delta + g(e_s))$ in the production of the S variety. Per unit cost of production of the GM variety remains at w. The firm's expected profit from adopting this strategy is given by:

$$\pi_h = [\alpha(a - q_s) + (1-\alpha)w - (w + \delta + g(e_s))]\, q_s. \tag{1}$$

Since being competitive in the GM market, the firm earns zero profit from its GM operation, the profit from the production of the G variety does not show up in (1). The firm maximizes π_h as in equation (1) by choosing q_s and e_s appropriately subject to the constraint $q_s < Q$. Suppose (q_s^*, e_s^*) represents the solution. It is clear from the expression of π_h that the firm is never going to choose $e_s^* > \bar{e}$. This is because $g'(e)$ being positive any higher choice of e_s^* above $\bar{e}$ is costly and reduces the profit of the firm as although it improves the quality of the S variety on the offer, but fails to bring in any premium in terms of price. This happens as no separate gradation about the quality of the S product is declared by the authority and all such qualities are valued equally by the S consumers. So after plugging $e_s^* = \bar{e}$ in equation (1), we redefine the objective of the firm as: maximization of

$$\pi_h = [\alpha(a - q_s) + (1-\alpha)w - (w + \delta + g(\bar{e}))]\, q_s \tag{2}$$

by choice of $q_s \in [0, Q)$. It turns out that $q_s^* > 0$ if and only if $\alpha > \alpha_1$ where $\alpha_1 = \dfrac{\delta + g(\bar{e})}{a - w}$ and solves the first order condition of the profit maximization as:

$$q_s^* = \frac{\alpha(a-w) - (\delta + g(\bar{e}))}{2\alpha}. \tag{3}$$

Observe, if $\alpha \leq \alpha_1$, $q_s^* = 0$. If $\alpha > \alpha_1$ by plugging back the value of q_s^* from (3) in equation (2), we calculate the equilibrium profit of the firm as:

$$\pi_h^* = \frac{[\alpha(a-w) - (\delta + g(\bar{e}))]^2}{4\alpha}. \tag{4}$$

However, if $\alpha \leq \alpha_1$, it turns out that: $\pi_h^* = 0$.

Lemma 1: $\frac{\partial \pi_h *}{\partial \alpha}$ *> 0 if* $\alpha > \alpha_1$*;* $\frac{\partial \pi_h *}{\partial \alpha}$ *= 0 otherwise.*

Proof: Suppose $\alpha > \alpha_1$. Then, from equation (4) it can be derived:

$$\frac{\partial \pi_h *}{\partial \alpha} = \frac{1}{4\alpha^2}[\alpha(a-w)-(\delta+g(\bar{e}))][\alpha(a-w)+(\delta+g(\bar{e}))]$$

which is positive if and only if $[\alpha(a-w)-(\delta+g(\bar{e}))] > 0$. However, this is true since $\alpha > \alpha_1$.

Now, suppose $\alpha \le \alpha_1$. Then, we know $\pi_h * = 0$ for all possible values of α. So, it must be: $\frac{\partial \pi_h *}{\partial \alpha} = 0$. □

2.2 The firm behaving *opportunistically*

Under this strategy the firm produces $q_i \ge 0$ amount of the I variety and $q_g > 0$ amount of the G variety such that $q_i + q_g = Q$. In order to produce the I variety it supplies an IP effort $e_i < \bar{e}$ and therefore incurs a per unit cost of $(w + \delta + g(e_i))$ in the production the I variety. Per unit cost of production of the G variety remains at w. The firm's expected profit from adopting this strategy is given by:

$$\pi_o = [\alpha w + (1-\alpha)(a-q_i) - (w+\delta+g(e_i))]\, q_i. \qquad (5)$$

As in the case of (1) here also the profit from the production of the G variety does not show up in (5) as the firm being competitive in the GM market earns zero profit from its GM operation. The firm maximizes π_o as in equation (5) by choosing q_i and e_i appropriately subject to the constraint $q_i < Q$. Suppose (q_i*, e_i*) represents the solution. It is clear from the expression of π_o that the firm is never going to choose e_i* > 0. This is because $g'(e)$ being positive, any higher choice of e_i* above 0 is costly and reduces the profit of the firm. Although it improves the quality of the I variety on the offer, but fails to bring in any premium in terms of price of the variety as all $s^* > \bar{s}$ that gets rejected in the enforcement test are sold at the GM market with $p_g = w$. So after plugging $e_i^* = 0$ in equation (5), since $g(0) = 0$ we redefine the objective of the firm as: maximization of

$$\pi_o = [\alpha w + (1-\alpha)(a-q_i) - (w+\delta)]\, q_i \qquad (6)$$

by choice of $q_i \in [0, Q)$. It turns out that $q_i^* > 0$ if and only if $\alpha < \alpha_2$ where $\alpha_2 = 1 - \frac{\delta}{a-w}$ and solves the first order condition of the profit maximization as:

$$q_i^* = \frac{(1-\alpha)(a-w)-\delta}{2(1-\alpha)}. \tag{7}$$

Observe, if $\alpha \geq \alpha_2$, $q_i^* = 0$. If $\alpha < \alpha_2$ by plugging back the value of q_i^* from (7) in equation (6), we calculate the equilibrium profit of the firm as:

$$\pi_o^* = \frac{[(1-\alpha)(a-w)-\delta]^2}{4(1-\alpha)}. \tag{8}$$

However, if $\alpha \geq \alpha_2$, it turns out that: $\pi_o^* = 0$.

Lemma 2: $\frac{\partial \pi_o^*}{\partial \alpha}$ *< 0 if* $\alpha < \alpha_2$*;* $\frac{\partial \pi_o^*}{\partial \alpha}$ *= 0 otherwise.*

Proof: Suppose $\alpha < \alpha_2$. Then, from equation (8) it can be derived:

$$\frac{\partial \pi_o^*}{\partial \alpha} = - \frac{1}{4(1-\alpha)^2}[(1-\alpha)(a-w)-\delta][(1-\alpha)(a-w)+\delta]$$

which is positive if and only if $[(1-\alpha)(a-w)-\delta] > 0$. However, this is true since $\alpha < \alpha_2$.

Now, suppose $\alpha \geq \alpha_2$. Then, we know $\pi_o^* = 0$ for all possible values of α. So, it must be: $\frac{\partial \pi_o^*}{\partial \alpha} = 0$. □

2.3 The firm's choice

Since the firm is profit maximizer in its objective it chooses the *honest* strategy over the *opportunistic* strategy if and only if $\pi_h^* \geq \pi_o^*$. The choice turns opposite if and only if $\pi_h^* < \pi_o^*$. However, the firm's choice depends on the values of the variables beyond its own control.

Lemma 3: $\alpha_1 > = < \alpha_2$ if and only if $\frac{(a-w)-g(\overline{e})}{2} < = > \delta$.

Proof: It follows from the above discussion that,

$\alpha_1 - \alpha_2 = -\dfrac{[(a-w)-g(\overline{e})-2\delta]}{a-w}$.

Hence the statement of the lemma follows. □

Proposition 1: (i) *If* $\delta < \dfrac{(a-w)-g(\overline{e})}{2}$, *there exists a value of* $\alpha = \alpha^* \in (\alpha_1, \alpha_2)$ *such that for all values of* $\alpha < \alpha^*$, *the firm chooses the 'opportunistic' strategy and for all values of* $\alpha \geq \alpha^*$, *the firm chooses the 'honest' strategy.*

(ii) *If* $\delta = \dfrac{(a-w)-g(\overline{e})}{2}$, *there exists a value of* $\alpha = \alpha_0 = \alpha_1 = \alpha_2$ *such that for all values of* $\alpha < \alpha_0$, *the firm chooses the 'opportunistic' strategy and for all values of* $\alpha > \alpha_0$, *the firm chooses the 'honest' strategy. If* $\alpha = \alpha_0$ *the firm chooses to produce only the GM variety.*

(iii) *If* $\delta > \dfrac{(a-w)-g(\overline{e})}{2}$, *for all values of* $\alpha < \alpha_2$ *the firm chooses the 'opportunistic' strategy. However, for all values of* $\alpha > \alpha_1$ *the firm chooses the 'honest' strategy. The firm chooses to produce only the GM variety for all values of* $\alpha \in [\alpha_2, \alpha_1]$.

Proof: See the appendix.

Proposition 1 shows us how depending on the values of α and δ the firm chooses its strategy. Typically the *opportunistic* strategy is chosen for low values of α and the *honest* strategy is chosen for high values of α. The intuition suggests if the enforcement authority employs a good testing technology such that the truth is discovered with high probability, the firm knows that the *honest* strategy is going to be rewarded with higher probability, so it responds by choosing the *honest* strategy. On the other hand, the inefficient testing technology encourages the *opportunistic* behaviour as the firm knows that now with higher probability the honesty would not be rewarded, but there is a chance that the opportunistic behaviour is rewarded. For higher values of δ, the cost of production of the non-GM variety is greater. So, for very high values of δ, unless α is very high, the expected reward does not cover the escalated cost of the non-GM variety and the firm refrains from choosing the *honest* strategy. However, the firm can choose *opportunistic* strategy in this situation if α is very low such that the expected reward from the opportunistic behaviour covers the escalated cost of non-GM production. In the middle, as it is too costly the firm stops producing the non-GM variety. Couple of interesting observations about the co-existence of GM and non-GM varieties and the nature of the variety supplied in the S market follow:

Observation 1: (i) *If* $\delta < \dfrac{(a-w)-g(\bar{e})}{2}$, *independent of the type of the testing technology both the GM and non-GM varieties co-exist.*

(ii) *If* $\delta = \dfrac{(a-w)-g(\bar{e})}{2}$, *for the most types of testing technology the GM and non-GM varieties co-exist except* $\alpha = \alpha_0$, *for which only the GM variety exists.*

(iii) *If* $\delta > \dfrac{(a-w)-g(\bar{e})}{2}$, *for* $\alpha < \alpha_2$ *and* $\alpha > \alpha_1$ *the GM and non-GM varieties co-exist; for* $\alpha \in [\alpha_2, \alpha_1]$ *only the GM variety exists.*

Observation 2: (i) *If* $\delta < \dfrac{(a-w)-g(\bar{e})}{2}$, *for all values of* $\alpha < \alpha^*$ *the consumers in the non-GM market are supplied with the I variety (completely contaminated non-GM variety of the product); for all values of* $\alpha \geq \alpha^*$, *however, they are supplied with the S variety (non-GM variety of the desired quality).*

(ii) *If* $\delta = \dfrac{(a-w)-g(\bar{e})}{2}$, *for all values of* $\alpha < \alpha_0$ *the consumers in the non-GM market are supplied with the I variety; for all values of* $\alpha > \alpha_0$, *however, they are supplied with the S variety.*

(iii) *If* $\delta > \dfrac{(a-w)-g(\bar{e})}{2}$, *for all values of* $\alpha < \alpha_2$ *the consumers in the non-GM market are supplied with the I variety; for all values of* $\alpha > \alpha_1$, *however, they are supplied with the S variety.*

So, it turns out that the efficiencies of both the testing technology and the non-GM production technology are extremely important both for the co-existence of different varieties at the production level and for the quality of the product supplied at the non-GM market. If both the testing technology and the non-GM production technology are inefficient, the labelling system fails to protect the consumers at the non-GM market. They end up being deceived with low quality products which are supplied without labels on them. So, the question we arrive at: how should the enforcement authority behave at this juncture? The answer we discuss in the next subsection.

3 The enforcement authority's choice

We recall that the enforcement authority adopted the policy of testing the varieties supplied by the manufacturer at the S market with its objective of prevention of flooding the S market with G and I variety products and thereby supporting the existence of the S market. From Observation 2 above we have seen that the choice of an inefficient technology fails this purpose. So, we observe in order to fulfil its objective of protecting the non-GM consumers the authority should restrict its choice of α in certain zone.

Observation 3: (i) *If* $\delta < \frac{(a-w)-g(\bar{e})}{2}$*, to protect the consumers in the S market the enforcement authority should choose* $\alpha \geq \alpha^*$.

(ii) *If* $\delta = \frac{(a-w)-g(\bar{e})}{2}$*, to protect the consumers in the S market the authority should choose* $\alpha > \alpha_0$.

(iii) *If* $\delta > \frac{(a-w)-g(\bar{e})}{2}$*, to protect the consumers in the S market the authority should choose* $\alpha > \alpha_1$.

Observation 3 specifies the zone in which α must be chosen by the enforcement authority depending on different possible values of δ, to fulfil its objective of protecting the S consumers. The zone is represented in the following figure. The figure also shows the zones of co-existence of the GM and non-GM varieties on the production side.

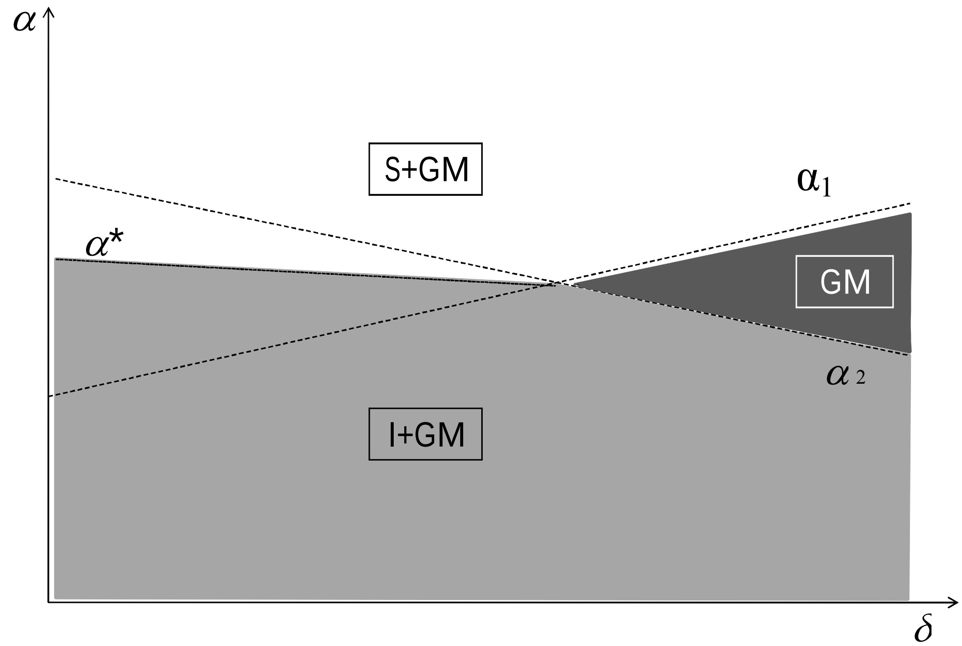

Figure 1. The choice of α for the protection of non-GM consumers and the coexistence of GM and non-GM varieties

Figure 1 has been simulated from the model for the following values of the parameters: Q = 9, a = 20, w = 2 and $g(e)$ = 5. Here, the positions of the α_1 and α_2 curves are explained by lemma 3 above. The α^* curve is derived by implication of Proposition 1. The S + GM zone represents the combinations of α and δ for which the firm adopts the *honest* strategy; the I + GM zone represents the combinations of α and δ for which the firm adopts the *opportunistic* strategy. From observation 1 it follows that for the combinations of α and δ representing the GM zone the firm produces only GM variety and the coexistence of the varieties is not possible.

Observation 3 suggests that for the protection of the S consumers α must be chosen at the S + GM zone in the figure. The figure also shows the implication of the choice of other values of α at the prevailing values of δ. If the choice of α is costly for the enforcing authority, it may happen that the authority fails to choose a sufficiently high value of α and thereby fails to protect the non-GM consumers. This may be the case especially for the enforcing authorities at the developing countries. For higher values of δ, the failure to choose a sufficiently high value of α may also mean at the authority's choice of α, the coexistence between the varieties is not possible.

4 Effect of a rise in *w* and a fall in $\bar{s}$

A rise in *w* in our model implies a rise in the cost of production of either of the S, I and G varieties. Consequently price of all of them rises and from equations (4) and (8) we know the profit from both the *honest* and *opportunistic* behaviour falls. However, it also follows from the definitions of α_1 and α_2, as *w* rises at each possible value of δ, α_1 rises and α_2 falls. In figure 1 above this means an increase in the area where only the GM variety is produced. The result is interesting because it shows although the rise in *w* has apparently similar effects on the firms' behaviour; the coexistence pattern between the varieties may change. This happens in our model since the increase in the price of GM variety actually reduces the deterrent effect of a given testing technology. Now, for commanding *honest* behaviour from the firm given δ the authority must choose a better testing technology. At the old testing technology the firm which was earlier indifferent between S + GM variety and GM variety shifts to production of only GM variety. Similarly, since now return to the GM production increases, the firm which was indifferent between I + GM variety shifts to production of only GM variety.

Observation 4: *As w rises, the combinations of α and δ for which coexistence and the non-GM consumers' protection possible falls.*

Proof: Follows from the discussion above. □

Observation 4 shows the common external shock to all the varieties on the cost side *ceteris paribus* reduces the possibility of coexistence between the varieties. The contingencies under which the protection of the non-GM consumers is possible also falls (see Table 1).

		δ=4.5	δ=5.5	δ=6.5	δ=7.5
w=2	α_1	0.53	0.58	0.64	0.69
	α_2	0.75	0.69	0.64	0.58
	α^*	0.65	0.647	0.64	
w=4	α_1	0.59	0.65	0.71	0.78
	α_2	0.72	0.65	0.59	0.53
	α^*	0.67	0.65		

Table 1

A fall in $\bar{s}$ in our model implies the society adopts a stricter standard for the non-GM variety to be supplied at the market. The stricter standard demands the higher effort supply from the firm in maintenance its *honest* behaviour. But since supplying higher effort is costly, the firms that have incentive to produce S and GM at the initial equilibrium, *ceteris paribus*, now will be inclined to produce only the GM variety or in the extreme situation will be induced to adopt the *opportunistic* behaviour. The intuition is reflected in the rise in the value of α_1 at each possible level of δ with the rise in $\bar{e}$ and therefore $g(\bar{e})$. The testing technology chosen at the initial equilibrium is no longer sufficient to command the *honest* behaviour from the firm. Interestingly, however as $\bar{s}$ rises the incentive for adopting the opportunistic behaviour does not change. So, α_2 remains the same at each possible level of δ. The preference for the higher standard of the non-GM variety therefore must also be supported by the better testing technology. Note also as at each value of δ, α_1 rises and α_2 remains unchanged, the stricter quality standard for non-GM foods reduces the chance of coexistence.

Observation 5: *As $\bar{s}$ falls, the combinations of α and δ for which coexistence and the non-GM consumers' protection possible falls.*

Proof: Follows from the discussion above. □

Observation 5 is supported by the simulated values in table 2.

		δ=4.5	δ=5.5	δ=6.5	δ=7.5
$g(\bar{e})=5$	α_1	0.53	0.58	0.64	0.69
	α_2	0.75	0.69	0.64	0.58
	α^*	0.65	0.647	0.64	
$g(\bar{e})=3$	α_1	0.41	0.47	0.52	0.58
	α_2	0.75	0.69	0.64	0.58
	α^*	0.61	0.60	0.59	0.58

Table 2

For illustration this observation points out that if Japan adopts a stricter quality standard for non-GM foods compared to Europe, it should also adopt better testing technology than the Europeans to ensure the protection of its non-GM consumers and the coexistence of the varieties.

5 Imposition of fine on a faltering firm

Now we consider a situation where the authority imposes a fine at the rate of $f>0$ if it concludes through the testing that the firm has made a false claim about the variety of the product. So, the expected profit of the firm by adopting the *honest* and the *opportunistic* strategy in this situation are given by:

$$(\pi_h)_f = [\alpha(a-q_s) + (1-\alpha)(w-f) - (w+\delta+g(\bar{e}))]\, q_s \tag{10}$$

and

$$(\pi_o)_f = [\alpha(w-f) + (1-\alpha)(a-q_i) - (w+\delta)]\, q_i \tag{11}$$

respectively. We assume, the enforcement authority sets its fine at the maximum such that $f = w$ i.e. if the consignment is rejected as GM variety the firm receives no profit per unit of the output sold in the GM market. So, the expected profits are rewritten from equations (10) and (11) as:

$$(\pi_h)_f = [\alpha(a-q_s) - (w+\delta+g(\bar{e}))]\, q_s \tag{12}$$

and

$$(\pi_o)_f = [(1-\alpha)(a-q_i) - (w+\delta)]\, q_i \tag{13}$$

respectively. Now, as described in the model above, the firm chooses $(q_s*)_f$ under the honest strategy by maximizing (12) and $(q_i*)_f$ under the opportunistic strategy by maximizing (13). The values of $(q_s*)_f$ and $(q_i*)_f$ turn out as:

$$(q_s*)_f = \frac{\alpha a - w - (\delta + g(\bar{e}))}{2\alpha} \tag{14}$$

and

$$(q_i*)_f = \frac{(1-\alpha)a - w - \delta}{2(1-\alpha)}. \tag{15}$$

Observe now, the value of α_1 for which $(q_s*)_f > 0$ is $(\alpha_1)_f = \dfrac{w + \delta + g(\bar{e})}{a} > \alpha_1$ for all possible value of δ. Similarly, the value of α_2 for which $(q_i*)_f > 0$ is $(\alpha_2)_f = 1 - \dfrac{w+\delta}{a} < \alpha_2$ for all possible value of δ. So, figure 1 now changes to:

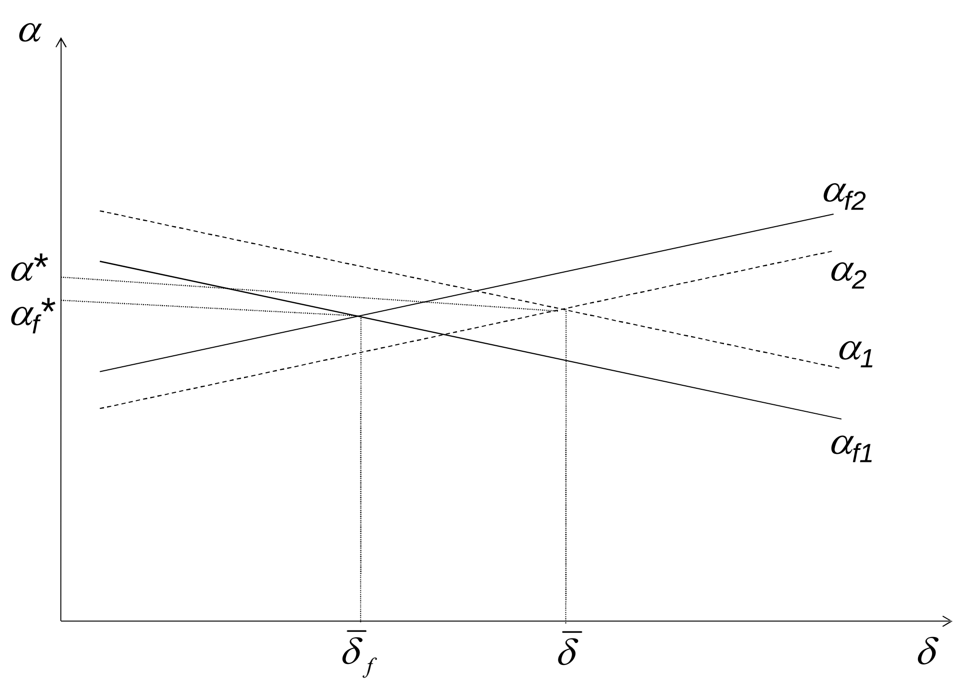

Figure 2. Values of testing efficiency thresholds according to the non-GM extra cost with and without a fine on a faltering firm

If figure 2 is compared with figure 1, it is easy to identify two opposing effects of the punishment.

On the one hand, if δ is not too high, the level of the testing technology efficiency required to supply the non-GM market with the S variety decreases when the fine is implemented. Indeed, $\alpha^* > \alpha^*_f$.

On the other hand, because of the fine the combinations of α and δ for which the firm produces only GM variety expands. So, the scope for the coexistence between the GM and non-GM varieties on the production side falls. The reason for this is outlined below. If we compare the values of $(q_s^*)_f$ and $(q_i^*)_f$ as in equations (14) and (15) with the values of q_s^* and q_i^* as in equations (3) and (7) respectively, we observe $(q_s^*)_f < q_s^*$ and $(q_i^*)_f < q_i^*$ for all possible values of δ. This happens because the fine lowers the downside return of the firm under both the strategies. So, if δ is sufficiently high the firm does not find the production of the non-GM variety profitable anymore.

Observation 6: *At low values of δ the fine introduced on the faltering producers lowers the value of α required to ensure protection of the non-GM consumers at each possible value of δ. The S consumers may not like the introduction of the fine as given* α and δ *as it reduces their welfare. The scope of coexistence between different variety also falls due to introduction of the fine.*

6 Conclusions

The paper develops a theoretical model where the producers of GM and non-GM varieties of the product behave strategically to take advantage of the diagnostic error in the testing technology used by the authority to enforce the labelling. It finds that the interest of the non-GM consumers cannot be protected if relatively inefficient testing technology is used. This is also likely to be true in the situations of higher efficiency gap between the GM and the non-GM production technology. As the paper analyses the effect of these parameters on the coexistence between the GM and non-GM varieties on the production side it finds out that irrespective of the accuracy of the testing technology used by the authority for the relatively efficient non-GM production technologies the coexistence of different varieties of a product is always possible. However it is less likely to be the case with an inefficient non-GM production technology. Interestingly, the paper finds out that the scope of coexistence reduces with the imposition of punishment on the faltering producers. The similar result is found in the presence of an adverse production shock to both the GM and the non-GM variety of the product and for the adoption higher quality standard for the non-GM consumers. The results explain what type of testing technology to be chosen in what situation. The results also explain why in the technologically poor developing countries with lax enforcement the adoption of GM production may endanger both the protection of non-GM consumers as well as the coexistence of the varieties in those countries.

The model we propose in this paper offers important insights in number of issues related to mandatory labelling of the GM products and regulation of GM/non GM coexistence. First, it shows that it is important to pay attention to the way the controls are implemented, and especially to the measurement uncertainties related to testing technology. An increase in the efficiency of testing technology is not necessarily a way to increase the market share of non GM products compliant with the labelling rule. Among other criteria, it depends on the gap between GM and non-GM production efficiency. Second, production shocks that equally affect both the varieties symmetrically may have adverse consequence on the coexistence between the products with the unchanged policy and technology parameters. Third, better purity level of the non-GM variety must be supported with better testing technology both for the sake of protection of the non-GM consumers as well as for the sake of coexistence between the varieties. Fourth, the liability rules which lead to penalize faltering producers are not necessarily a good way to favour the supply of non-GM products compliant with the labelling threshold. Once again, it will depend on the gap between GM and non-GM production efficiency.

Clearly, these results must be considered in relation with some limitations that open up the scope for further research. The paper restricts itself with the case of a vertically integrated producer. So, it avoids the problem of contamination at different stages of production and therefore the issue if traceability. Once we consider the problem of the supply chain the effect of double moral hazard in the context of enforcement becomes important. The optimum design of the enforcement effort at different stages of production also turns out as an important research topic. We plan to explore them in our future research.

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Appendix

Proof of Proposition 1. (i) From lemma 3 we know that $\delta < \dfrac{(a-w)-g(\bar{e})}{2}$ implies $\alpha_2 > \alpha_1$.

Now consider the situation when $0 < \alpha \leq \alpha_1$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, $\pi_h* = 0$ and π_o* > 0 respectively. So, π_h* - $\pi_o* < 0$.

Next consider the situation when $\alpha_1 < \alpha < \alpha_2$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, both $\pi_h* > 0$ and $\pi_o* > 0$. But, we also find as $\alpha \to \alpha_1$, $\pi_h* \to 0$ but $\pi_o* > 0$. Therefore, (π_h*- π_o*) $\to$ - $\pi_o* < 0$. Similarly, we find as $\alpha \to \alpha_2$, $\pi_h* > 0$ but $\pi_o* \to 0$. Therefore, (π_h*- π_o*) $\to$ $\pi_h* > 0$. Next we use lemma 1 and 2 to observe in this situation:

$$\frac{\partial(\pi_h* - \pi_o*)}{\partial\alpha} = \frac{\partial\pi_h*}{\partial\alpha} - \frac{\partial\pi_o*}{\partial\alpha} > 0.$$

So, (π_h*- π_o*) is continuous and monotonically rising function of α. Therefore, it must be there exists a value of $\alpha = \alpha^* \in (\alpha_1, \alpha_2)$ such that π_h*- $\pi_o* = 0$. It follows that for all values of $\alpha < \alpha^*$, π_h*- $\pi_o* < 0$ and for all values of $\alpha \geq \alpha^*$, π_h*- $\pi_o* \geq 0$.

Last consider the situation when $1 > \alpha \geq \alpha_2$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, $\pi_h* > 0$ and π_o* $= 0$ respectively. So, π_h*- $\pi_o* > 0$.

This completes the proof of part (i).

(ii) From lemma 3 we know that $\delta = \dfrac{(a-w)-g(\bar{e})}{2}$ implies $\alpha_2 = \alpha_1$.

Define $\alpha_0 = \alpha_1 = \alpha_2$ and consider the situation when $\alpha < \alpha_0$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, $\pi_h* =$ 0 and $\pi_o* > 0$ respectively. So, π_h*- $\pi_o* < 0$.

Now consider the situation when $\alpha = \alpha_0$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, both $q_s* = 0$ and $q_i* = 0$. So, in this situation the firm chooses to produce only the GM variety.

Next consider the situation when $\alpha > \alpha_0$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, $\pi_h * > 0$ and $\pi_o * = 0$ respectively. So, $\pi_h * - \pi_o * > 0$.

This completes the proof of part (ii).

(iii) From lemma 3 we know that $\delta > \dfrac{(a-w)-g(\overline{e})}{2}$ implies $\alpha_1 > \alpha_2$.

Consider the situation when $0 < \alpha < \alpha_2$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, $\pi_h * = 0$ and $\pi_o * > 0$ respectively. So, $\pi_h * - \pi_o * < 0$.

Now consider the situation when $\alpha_2 \leq \alpha \leq \alpha_1$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, both $q_s* = 0$ and $q_i* = 0$. So, in this situation the firm chooses to produce only the GM variety.

Next consider the situation when $1 > \alpha \geq \alpha_1$. From the discussion of the firm's behaviour in sections 2.1 and 2.2 above it follows, in this situation, $\pi_h * > 0$ and $\pi_o * = 0$ respectively. So, $\pi_h * - \pi_o * > 0$.

This completes the proof of part (iii). □