Identity Preservation and Labeling of Genetically Modified Products: System Design and Enforcement Issues

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Abstract

This paper analyzes economic issues that arise in devising a credible and enforceable system of identity preservation and labeling for genetically modified (GM) and non-GM products. The model represents three stages in the supply chain: farm production, marketing handlers, and final users. The possibility of accidental co-mingling of non-GM products is modeled at the marketing stage. Regulation takes the form of a threshold level of purity for non-GM products, a probability of government testing to verify compliance with the threshold level, and a fine for violators. Uncertainty is modeled explicitly, such that would-be suppliers of non-GM products always face some risk of failing the test and incurring a fine. The paper also presents a novel demand specification for differentiated GM and non-GM products that is particularly useful in our stochastic framework. The results emphasize the role and impact of an uncertain testing technology, a critical feature in this setting. We also highlight the somewhat nonstandard trade-off between frequency of testing and the size of the fine that applies here. Because testing can prevent mislabeled product from reaching the consumer, it can provide a direct welfare benefit. An equilibrium that includes production of the non-GM good may only be supportable with sufficiently high testing frequency (a high penalty for mislabeling may not suffice).

Keywords: biotechnology, enforcement, food labeling, identity preservation, regulation, uncertainty.

IDENTITY PRESERVATION AND LABELING OF GENETICALLY MODIFIED PRODUCTS: SYSTEM DESIGN AND ENFORCEMENT ISSUES

Introduction

The advent of genetically modified (GM) food crops represents one of the most significant developments affecting the evolution of agriculture in the twenty-first century. Adoption of transgenic crops has indeed been quite extensive in the short time since their introduction, reaching a record 167 million acres in 2003 (ISAAA 2003). But just as deep and widespread has been the public and consumer resistance toward such products. Nowhere is this more apparent than in the European Union, where opposition to GM products resulted in a moratorium on new GM approvals in 1998, which is now being replaced by a complex and stringent regulatory system, centered on the notions of GM food labeling and traceability. In addition to a number of other economic questions that have received some attention thus far (Nelson 2001; Shoemaker 2001; Sheldon 2002), it is apparent that the introduction of GM products is one of the foremost contributors to the transformation of the agricultural industry from producing largely "homogenous" commodities into one that eventually may be characterized by differentiated goods. For first-generation GM products that account for virtually all current GM planting (input traits such as Roundup Ready soybeans and Bt corn), the creation of differentiated products was unintentional and arises because some consumers view food derived from GM product as inferior in quality to conventional food. For second-generation GM products (output traits of direct interest to the consumer/buyer, such as improved nutritional content), these differences are meant to be an intrinsic part of the technological development.

Meeting the demand for differentiated food products requires a system that can credibly deliver such differentiated products to end users. What the features of such a system ought to be, from an economic perspective, is still unclear. Grading of products and government inspections have long been used in agricultural markets in pursuit of a variety of objectives (Dimitri 2003). But the type of control likely to emerge in the case of GM and non-GM products goes well beyond that. The two new E.U. regulations on labeling and traceability of GM food provide a useful illustration.[1] In the European Union, all foods produced from GM ingredients must now be labeled, regardless of whether or not the final products contain DNA or proteins of GM origin. Such labels will have to state: "This product contains genetically modified organisms," or "This product has been produced from genetically modified [name of organism]." Furthermore, the new rules introduce (for the first time) labeling requirements for GM feed (for example, soybean meal and corn gluten feed produced from GM varieties will have to be labeled as such). To avoid carrying a GM label, a high level of purity is required: the tolerance level for the presence of "authorized" GM products is set at 0.9 percent. This mandatory labeling is supplemented by traceability requirements, meant to facilitate monitoring of unintended environmental effects and to help enforce accurate labeling. Operators at all marketing stages using or handling GM products are required to transmit information about the GM nature of the product and to retain these records for five years, so as to allow complete identification of who supplies GM products to whom, from "farm to fork."

The need for labeling is considered particularly urgent because GM and the corresponding non-GM product appear identical and cannot be distinguished visually. If the superior non-GM product cannot be distinguished from the inferior GM one, the pooled equilibrium likely to emerge in the market would display the attributes of Akerlof's (1970) "lemons" model; that is, it would contain too high a proportion of low-quality product. Product diversity in such a setting could be efficiently achieved with certification systems paid for by sellers (Beales, Craswell, and Salop 1981). Whether such a system should take the form of mandatory labeling of the (inferior-quality) GM products, as with the new E.U. regulation, is, of course, highly questionable (Crespi and Marette 2003; Lapan and Moschini 2004). The crucial issue here is not simply one of asymmetric information (i.e., the seller has private information that may be valuable to buyers, and labeling requirements may force disclosure of such information), but the fact that the information to be disclosed to consumers needs to be "produced" through an ad hoc process. This is because the product is handled a number of times as it moves from farmers to consumers, and the possibility for (inadvertent) mixing of distinct products exists at each stage (Bullock and Desquilbet 2002). Thus, to satisfy the underlying differentiated demand for GM and non-GM products, costly identity preservation (IP) activities are necessary, and such activities obviously need to be carried out by the suppliers of the superior (non-GM) product.

In devising an optimal regulation structure to deal with the differentiated provision of GM and non-GM products, a number of economic problems need further investigation, including the fineness of the grading system, the penalties for mislabeling, and whether the system is voluntary (private) or mandatory (government). Because sellers have private incentives to claim higher standards for their product than may be the case, penalties (fines) need to be levied if the delivered product does not meet its claimed grade. The optimal structure of a penalty scheme in this context needs investigation. In particular, one needs to recognize that infinite penalties to ensure compliance are not feasible here, partly for political reasons but also because the seller can have only an estimate of the grade of the product he/she is selling and thus severe penalties may prove prohibitive with respect to marketing of the superior grade.

To address these problems, in this paper we develop a model that has the following basic elements: (i) heterogeneous consumers with preferences over the differentiated goods (GM and GM-free products); (ii) producers (farmers), who decide how much to grow of each product, based upon prices; (iii) intermediaries, which purchase from farmers, grade and label goods, and resell them to consumers; and (iv) a government, which imposes grade levels, monitors claims, and levies fines. In the framework of the analysis that we develop, uncertainty plays a critical role. In particular, handlers of the product at the marketing stage cannot precisely determine the purity level of a particular shipment but can only determine the statistical distribution of purity. Yet, standards and penalties are likely to be based on the specific outcome of a test (itself a random variable).

The Model

In this model we consider three market stages: (1) the farm level, where agricultural output of either GM or non-GM type is produced; (2) the marketing level, which uses agricultural products as input in a chain that involves assembly, transportation, processing, and distribution, yielding food products that can be sold to consumers; and (3) the consumer level, where final users have the choice (in general) of GM and non-GM products.

In this setting, therefore, there are two output products at the farm level, and two output products at the marketing level, so that we need to distinguish four prices. The superscripts 0 and 1 will denote the farm and consumer levels, respectively, and the subscripts g and n will denote GM and non-GM products, respectively. Thus,

p_n^0 is the farmgate price of a non-GM product;

p_g^0 is the farmgate price of the GM product;

p_n^1 is the consumer price of the good certified as "non-GM"; and

p_g^1 is the consumer price of the GM good (unlabeled).

A fundamental part of the problem at hand is the possibility of the unintended co-mingling of GM and non-GM products, the IP activities that can control such contamination, and the regulation set forth by a government authority that aims to provide incentives for IP efforts as well as credible information to consumers. In our model the possibility of adventitious mixing of GM and non-GM products is confined to the marketing level. Whereas this approach provides for a tractable analysis and helps the interpretation of a number of results, it should be clear that mixing of GM and non-GM products at the farm level could also be accommodated in a general version of our model. The consumer level displays the property that the GM product is weakly inferior in quality to non-GM products, as in Lapan and Moschini 2004.

Farm Level

We consider a sector in which many competitive farmers produce both GM and non-GM products. The GM product is appealing to farmers because it decreases production costs. This is a property of so-called first-generation GM traits, as illustrated by herbicide-resistant crops (Falck-Zepeda, Traxler, and Nelson 2000; Moschini, Lapan, and Sobolevsky 2000). To represent this process in the most efficient way, we postulate that the GM product offers a constant unit cost savings equal to $\delta > 0$. Thus, the aggregate supplies of GM product (S_g) and non-GM product (S_n) at the farm level are written as

$$\left.\begin{array}{l} S_g = 0 \\ S_n = S(p_n^0) \end{array}\right\} \qquad \text{if } (p_n^0 - p_g^0) > \delta \tag{1}$$

$$\left.\begin{aligned} S_g &= S(p_g^0+\delta) \\ S_n &= 0 \end{aligned}\right\} \quad \text{if } (p_n^0 - p_g^0) < \delta \tag{2}$$

$$S_g + S_n = S(p_n^0) \quad \text{if } (p_n^0 - p_g^0) = \delta \tag{3}$$

The cost savings δ is taken as exogenously given. Thus, in any equilibrium where both GM and non-GM are produced and consumed, it will be the case that $p_n^0 = p_g^0 + \delta$ (i.e., the farm-level "premium" for non-GM product simply compensates for a production cost difference).

Because we are confining the possibility of adventitious mixing to the handling sector, we assume that verification of the product delivered by farmers is perfect and costless. Thus, there is no contamination at the farm level, and farmers produce and sell a GM-free (no impurity) good and/or a GM good.

Handling Sector

We consider a generic intermediary firm, referred to as the "processor," which performs all the relevant marketing functions between the farm level and the consumer level. The processor buys product of a declared type from the farmer, moves it through a distribution chain, and sells it to consumers. Because farmers can produce GM and/or non-GM products, any one processor may be buying either product from any one farmer.

As the good moves through the handling sector, there is a positive probability of contamination. This contamination can occur during storage, transportation, or elsewhere along the chain. It may occur because employees are careless, because containers are not perfectly cleaned, and so forth. In this paper we do not model explicitly the contamination process. Rather, we posit a distribution function for the impurity level of a given lot. Thus, for each non-GM lot that the processor purchases, we define as s_i the impurity level of lot *i* (i.e., the fraction of GM material in the final output). Naturally, $s_i \in [0,1]$. The density and distribution functions of s_i, which are assumed to be independently and identically distributed (i.i.d.), are written as $f(s)$ and $F(s)$, respectively. Because

$$F(s) = \int_{y=0}^{s} f(y)\,dy \tag{4}$$

then F represents the probability that a given lot has an impurity level no higher than s, and given a large number (continuum) of i.i.d. lots, it also represents the proportion of non-GM output that has an impurity level no higher than s when it reaches the marketing stage.

It is also true that, in this setting, some GM-free product may "contaminate" the GM good, but we shall ignore this possibility and assume that the GM product, when it reaches the marketing stage, is pure GM.

Regulation

We model regulation with a triple $\{R, \pi, T\}$. Here, R denotes the maximum impurity (threshold) level below which a good can be labeled as non-GM; π is the probability that a given lot will be tested; and T is the penalty that a processor incurs if a tested lot fails to meet the maximum impurity standard.

An essential element of the regulatory system is monitoring, and modeling that process in our case requires an explicit representation of the inherent uncertainty because no IP system is perfect, such that the possibility of co-mingling between GM and non-GM products always exists. To represent uncertainty in our context, we can assume (i) that the firm knows the true impurity level, but that it also knows the government will measure this variable with error; (ii) that the firm measures the true impurity level with error such that, even if government testing is without error, the firm only knows the distribution of the government measurement; or (iii) both the firm and the government may have measurement errors. Here we adopt a representation that can be consistent with any one of these three interpretations. When the government tests a lot *i*, its measured value of impurity is given by $t_i(s_i, \lambda_i)$, where s_i represents either the true impurity level or the firm's beliefs about the impurity level, and $\lambda_i \geq 0$ is an i.i.d. random variable with density function $h(\lambda)$ and distribution function $H(\lambda)$. Specifically, we postulate a simplified representation of the testing technology in terms of a piecewise linear relationship between the test outcome and the impurity level:

$$t_i = \begin{cases} \lambda_i s_i & \text{if } \lambda_i s_i \leq 1 \\ 1 & \text{otherwise} \end{cases} . \tag{5}$$

We assume that the test is “unbiased” in that $E\left[\lambda_i\right]=1$. If we think of s_i as being the true value of impurity, then (λ_i-1) is the measurement error. Alternatively, if t_i is viewed as verifying the true level of impurity, then $(\lambda_i^{-1}-1)$ is the firm’s measurement error. Or, neither s_i nor t_i is the true value, they are just two random draws from the same underlying true distribution.

Unless there is further testing, it is immaterial to ascertain which of the interpretations holds. What is important is that fines are implemented based upon the government measurement, such that if $t_i > R$ the firm incurs fine T. Consumers form their expectations based upon the government threshold and the behavior of the government and firms in implementing this law, and firms know the government’s behavior, so that is all that matters for modeling purposes.

Processor’s Behavior

In modeling the processor’s behavior, for simplicity we suppose that the firm sells only one lot. The prices that are relevant to the processor are the “input” prices p_n^0 (the farmgate price of a non-GM product) and p_g^0 (the farmgate price of the GM product), and the “output” prices p_n^1 (the consumer price of the non-GM good) and p_g^1 (the consumer price of the GM good). These prices are endogenous to the system but are taken as given by an individual processor.

Now, consider the sales decision of a processor. The processor can buy any one of the two inputs and (try to) sell any one of the two outputs. Thus, for a processor that buys a GM input, its profits depend on whether it sells the GM good as GM or as non-GM. We assume that, regardless of the choice of product, processors incur a unit marketing cost of $M > 0$. Furthermore, if processors choose to buy non-GM product from farmers and intend to supply non-GM product to consumers, they also need to incur an additional cost to avoid co-mingling of the two varieties of products (i.e., IP activities). We represent IP cost by a (constant) unit cost $C > 0$. Absent the impact of regulation, to be discussed later, the firm’s possible terminal wealth states, $W_{i,j}$, arising from selling output of type j having bought input of type i are

$$W_{g,g} = W_0 + p_g^1 - p_g^0 - M \tag{6}$$

$$W_{g,n} = W_0 + p_n^1 - p_g^0 - M \tag{7}$$

$$W_{n,n} \equiv W_0 + p_n^1 - p_n^0 - M - C \tag{8}$$

$$W_{n,g} \equiv W_0 + p_g^1 - p_n^0 - M - C \tag{9}$$

where W_0 denotes initial wealth.[2] Note that $(W_{n,n} - W_{n,g}) = (W_{g,n} - W_{g,g}) = (p_n^1 - p_g^1) \equiv \Delta$.

A firm that sells non-GM product is tested with probability π. We assume that if it tries to sell a GM lot as non-GM it will get caught if the lot is inspected (i.e., the government's measurement errors, relative to the threshold level R, are not large enough to measure a GM lot as being GM free). Thus, a firm that markets non-GM output having bought GM product obtains wealth $W_{g,n}$ with probability $(1-\pi)$ and profit $(W_{g,g} - T)$ with probability π.

Let $U(W)$ denote the firm's utility function, where W represents (net) terminal wealth. Whether an expected-utility maximizing firm will choose to sell the GM product as GM or non-GM depends on the parameters set by regulation. We assume that the probability of testing π and the fine T are set such that the incentive compatibility constraint holds:

$$U\left(W_{g,g}\right) \ge (1-\pi) U\left(W_{g,n}\right) + \pi U\left(W_{g,g} - T\right) \quad (ICC_g) \tag{10}$$

where W_0 denotes initial wealth. Under risk-neutrality the condition in (10) becomes:

$$\pi T \ge (1-\pi)\Delta \qquad (ICC'_g) \tag{11}$$

where $\Delta \equiv (p_n^1 - p_g^1)$ reflects the premium consumers are willing to pay for (what they believe is) the non-GM good and hence is the gain from cheating. Equation (11) reflects the usual symmetry between the probability of getting caught and the penalty if caught. The participation constraint here is simply

$$p_g^1 \ge p_g^0 + M . \qquad (PC_g) \tag{12}$$

We turn next to the firm that buys GM-free output. When the output reaches the marketing stage, the firm measures the impurity level and decides whether to sell the product as GM-free or GM. Define $\theta(s,R)$ as the probability the firm assigns to the event that a lot of impurity level s, as measured by the firm, will be rejected (if tested). Given the earlier specification $t = Min\{\lambda s, 1\}$, then

$$\theta(s,R) = Prob[\lambda > (R/s)] = \int_{R/s}^{\infty} h(\lambda)\,d\lambda \quad = 1 - H(R/s). \tag{13}$$

For example, suppose that $\lambda \in [\lambda_L, \lambda_U]$. Then, clearly, if $s \le (R/\lambda_U)$, then $\theta = 0$ and the firm will market the good as non-GM. Similarly, if $s \ge (R/\lambda_L)$, then the lot will definitely fail government inspection. In such a case, given the incentive-compatibility constraint (IC_g), the firm will not market the good as non-GM (even though the firm purchased a non-GM input).

Hence, the decision of the firm as to how to market the good will depend upon its measured impurity level (s), as well as the government parameters. In particular, the firm will sell the good as non-GM if and only if

$$(1-\pi\theta)U\left(W_{n,n}\right) + \pi\theta U\left(W_{n,g} - T\right) \ge U\left(W_{n,g}\right). \tag{14}$$

Clearly, for $s = 0$ $(\theta = 0)$ the inequality in (14) holds strictly, while for $s = 1$ it will fail (remember our earlier assumption that the measurement error is not large enough to mistake a true GM product as GM-free). Hence:[3]

PROPOSITION 1. *Given a government policy* $\{T, \pi, R\}$ *that defines a threshold level* R*, a probability of testing lots* π*, and a fine* T *if a lot labeled as non-GM is measured to exceed that threshold, there exists a unique* $\hat{s}(T, \pi, R)$ *such that the firm will sell its non-GM input as non-GM output if and only if* $s \le \hat{s}$.

Proof. Let $\hat{\theta}$ denote the critical value of θ that makes equation (14) hold as an equality, such that

$$\pi\hat{\theta} = \frac{U\left(W_{n,n}\right) - U\left(W_{n,g}\right)}{U\left(W_{n,n}\right) - U\left(W_{n,g} - T\right)} . \tag{15}$$

Note that under risk neutrality (15) reduces to

$$\pi\hat{\theta} = \frac{\Delta}{\Delta + T} . \tag{16}$$

Then $\hat{s}$ is implicitly defined by $\theta\left(\hat{s}, R\right) = \hat{\theta}$. ■

PROPOSITION 2. *The critical impurity level,* $\hat{s}$*, used by the firm is (i) directly proportional to the threshold* R *set by the government; (ii) a decreasing function of the fine* T *and of the probability of testing* π *; (iii) an increasing function of the consumer price of the non-GM good* p_n^1*; and (iv) under risk-neutrality or CARA (constant absolute risk aversion), a decreasing function of the consumer price of the GM good* p_g^1 *.*

Proof. All of the results follow directly from (14) or (15). From (15), neither the threshold R nor the testing probability π appears on the right-hand side (RHS). Hence, if R changes, then $\hat{s}$ must change so that $\hat{\theta}$ is constant, implying $\left(R/s\right)$ is unchanged, proving claim (i). Similarly, if π (or T) increases, $\hat{\theta}$ must decrease, which means $\hat{s}$ decreases. For (iii), note that the RHS of (15) is an increasing function of p_n^1, because $U(W_{n,g}) > U(W_{n,g} - T)$. Hence $\hat{\theta}$, and therefore $\hat{s}$, must increase with p_n^1. As to the impact of a change in p_g^1 in (iv), for the risk-neutral case it is clear from (16) that only the difference between the two consumer prices matters, and hence the result holds. More generally, however, the comparative statics of interest may depend on risk attitudes. Under the special case of CARA, however, the RHS of (15) can be expressed in terms of the difference between the two consumer prices, and thus the result holds. ■

Therefore, among other things, Proposition 2 yields the interesting (although perhaps not surprising) result that, *ceteris paribus*, when consumers place a higher value on purity, and hence the reward to providing purity p_n^1 increases, for given regulation parameters, firms will be tempted to lower their standards (that is, increase $\hat{s}$) because the benefits of selling the non-GM good rise.

It is also interesting to note that, in general, the standard $(\hat{s})$ used by the firm depends upon, but is not equal to, the threshold level R set by the government. It turns out that the firm's standard can be higher or lower than the government threshold. Furthermore, increases in the government's measurement error can either increase or decrease the standard used by the firm. More specifically, we have the following:

PROPOSITION 3. *Under risk neutrality, and assuming* $H(1)=1/2$*, (i)* $\hat{s} \overset{>}{\underset{<}{=}} R$ *as* $\pi(\Delta+T) \overset{<}{\underset{>}{=}} (2\Delta)$*; (ii) an increase in measurement error, as defined by a (particular) mean-preserving spread of the distribution of* λ*, will increase the firm's threshold level* $\hat{s}$ *if* $\hat{s} > R$ *(and decrease it if* $\hat{s} < R$*).*

Proof. (i) Recall that $H(\lambda)$ is the distribution function, and by assumption $E[\lambda]=1$. The assumption $H(1)=1/2$ asserts that half the mass of the distribution is on each side of the mean. From (16), under risk-neutrality, $\pi\hat{\theta}=\Delta/(\Delta+T)$; thus, $\hat{\theta} \overset{>}{\underset{<}{=}} (1/2)$ as $\pi(\Delta+T) \overset{<}{\underset{>}{=}} 2\Delta$. Because $\hat{\theta}=1-H(\hat{\lambda})$, where $\hat{\lambda} \equiv (R/\hat{s})$, then $\hat{\theta}>1/2 \Rightarrow \hat{\lambda}<1 \Rightarrow \hat{s}>R$. Hence, statement (i) follows. For (ii), consider an alternative distribution for the measurement error, $G(\lambda)$, that has the same mean $E[\lambda]=1$ but is more dispersed than $H(\lambda)$ in the sense that $G(\lambda) \overset{>}{\underset{<}{=}} H(\lambda)$ as $\lambda \overset{<}{\underset{>}{=}} 1$.[4] Now let $\hat{\lambda}_H$ and $\hat{\lambda}_G$ represent the values of λ that solve (16) for each distribution. A change in the distribution of λ has no impact on the formula in (16) and hence no impact on the equilibrium value of $\hat{\theta}$. Thus, it must be that $H(\hat{\lambda}_H)=G(\hat{\lambda}_G)$. By assumption, $G(\lambda) \overset{>}{\underset{<}{=}} H(\lambda)$ as $\lambda \overset{<}{\underset{>}{=}} 1$. Thus, $\hat{\lambda}_G \overset{>}{\underset{<}{=}} \hat{\lambda}_H$ as $\lambda \overset{>}{\underset{<}{=}} 1$, which implies $\hat{s}_G < \hat{s}_H$ when $\hat{s}_H < R$ and $\hat{s}_G > \hat{s}_H$ when $\hat{s}_H > R$. Figure 1 illustrates for the case $\hat{s}_H < R$. ■

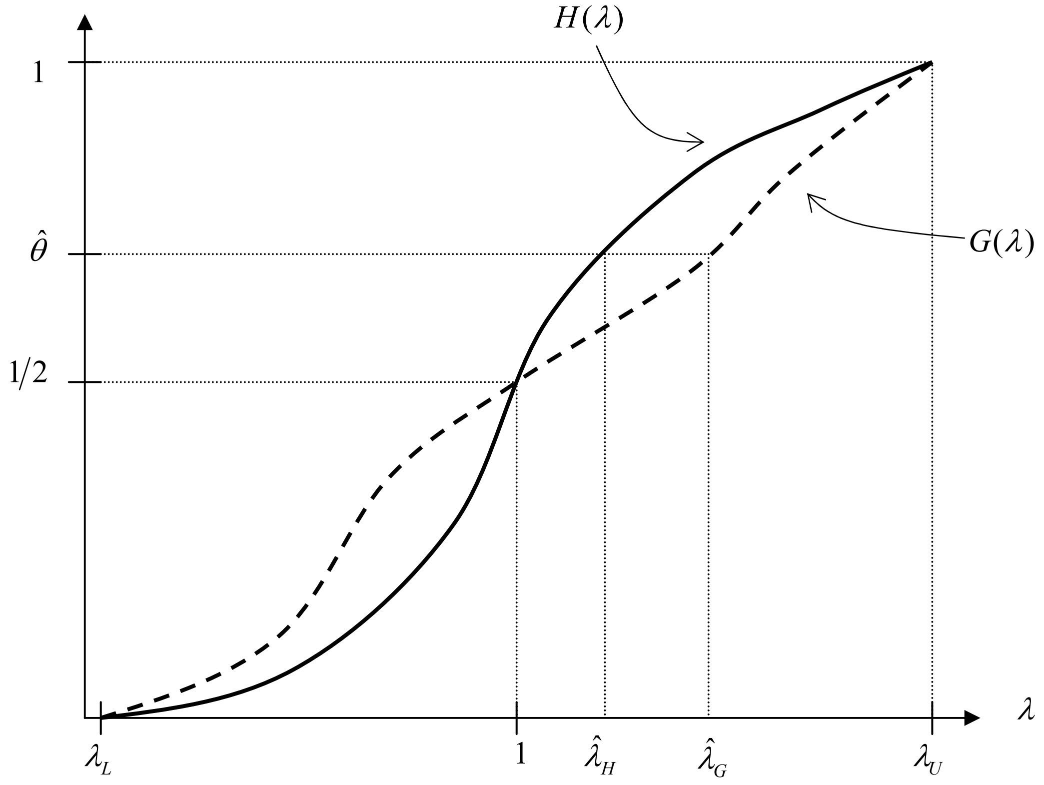

FIGURE 1. Effects of an increase in test measurement error

Thus, Proposition 3 highlights the impact that imperfection in the testing technology can have on the efficacy of regulation. In particular, it emerges that the larger is the government measurement error, the further is the firm's threshold level from the "true" standard set by the government.

Finally, the expected utility of a processor that buys non-GM input is given by

$$U_n^e = \int_{s=0}^{\hat{s}} \left\{ [1-\pi\theta(s,R)]U(W_{n,n}) + \pi\theta(s,R)U(W_{n,g}-T) \right\} f\left(s,C\right)ds + \int_{\hat{s}}^{1} U(W_{n,g})f(s,C)ds\,. \tag{17}$$

The participation constraint for a processor that purchases non-GM input is thus

$$U_n^e \geq U\left(W_0\right). \tag{18}$$

If processors are identical, then an equilibrium in which both non-GM and GM inputs are purchased requires $U_n^e = U\left(W_{g,g}\right)$. In such a case, then, it follows that

$$U\left(W_{g,g}\right) \equiv U\left(W_{n,g} + [p_n^0 - p_g^0] + C\right) = U_n^e \tag{19}$$

where U_n^e is defined in equation (17). Equation (19) illustrates the fact that the processor that buys non-GM input must be compensated for the premium it pays for the non-GM input $(p_n^0 - p_g^0)$, the extra costs C undertaken to ensure IP, and for the risk born (if the firm is risk averse).

PROPOSITION 4. *Consider the set of testing probabilities and fines that leave the marketing strategy* $\tilde{s}$ *of the firm unchanged, i.e.,* $\left\{(\pi,T) \middle| \hat{s}\left(T,\pi,R\right) = s^0\right\}$. *Then the expected utility of the firm is the same for all elements in this set.*

Proof. Rewrite (17) as

$$U_n^e = \int_{s=0}^{\hat{s}} \left\{\left[1-\pi\theta(s,R)\right]U(W_{n,n}) + \pi\theta(s,R)U(W_{n,g}-T) - U(W_{n,g})\right\} f\left(s,C\right)ds + U(W_{n,g})\,. \tag{20}$$

Because $\hat{s}$ is unchanged, we can use (15) to eliminate π and thus rewrite (20) as

$$U_n^e = \left[U\left(W_{n,n}\right) - U\left(W_{n,g}\right)\right] \int_{s=0}^{\hat{s}} \left[1 - \frac{\theta(s,R)}{\hat{\theta}}\right] f\left(s,C\right)ds + U\left(W_{n,g}\right). \tag{21}$$

Because (21) depends only on $\hat{\theta}$ and not on π or T individually, the result holds. ■

The important message of Proposition 4 from a policy perspective is that there are an infinite number of combinations of fines and testing probabilities that have the same impact on the firm's behavior and on the firm's expected utility, given the IP cost, C. Hence, here we find the standard perfect substitutability between fines and penalties that holds in most economic models of law enforcement. Note that because fines are transfer payments, whereas testing involves a real cost, there is always an economic incentive to increase fines and lower the probability of testing (e.g., Becker 1968; Polinsky and Shavell 1979 and 2000). Naturally, limited liability issues, considerations of fairness, or the ability of a firm to appeal a penalty would modify this conclusion.

Because the presence of measurement error changes the decision rule of the firm concerning whether to sell its product as GM-free or not, it is clear that, from an *ex ante* perspective, the existence of measurement error will affect the firm's expected utility (expected profits) and hence the price premium required to induce the firm to supply the non-GM output (alter the participation constraint). Note that in (21), the underlying distribution for the government's measurement error does not appear explicitly, but it does appear implicitly, because it affects $\hat{s}$ and $\theta(s)$. To explore this issue in more detail, as earlier, let $H(\lambda)$ and $G(\lambda)$ reflect two distributions for the measurement error, and assume G is riskier than H. Let $\hat{s}_H, \hat{s}_G$ denote the critical purity levels under each distribution. Then we have the following result.

PROPOSITION 5. *Suppose that the government fine* (T) *or the probability of testing* (π) *is sufficiently high so that the standard used by the firm is at least as stringent as that used by the government (i.e.,* $\hat{s}_H \le R$*). Then an increase in government measurement error lowers the expected utility (profits) for the firm.*

Proof. As earlier, $G(\lambda)$ has the same mean $E[\lambda]=1$ as $H(\lambda)$, but it is more dispersed in the sense that $G(\lambda) \overset{>}{\underset{<}{=}} H(\lambda)$ as $\lambda \overset{<}{\underset{>}{=}} 1$. Let $\theta_H(s), \theta_G(s)$ denote the probability, for a given sample, of failing the government test under the two distributions. Then for each distribution we can rewrite (21) as

$$U_n^e\Big|_H = \left[U(W_{n,n}) - U(W_{n,g})\right] \int_{s=0}^{\hat{s}_H} \left[1 - \frac{\theta_H(s,R)}{\hat{\theta}}\right] f(s,C)\,ds + U(W_{n,g}) \tag{22}$$

$$U_n^e\Big|_G = \left[U(W_{n,n}) - U(W_{n,g})\right] \int_{s=0}^{\hat{s}_G} \left[1 - \frac{\theta_G(s,R)}{\hat{\theta}}\right] f(s,C)\,ds + U(W_{n,g})\,. \tag{23}$$

As shown, if $\hat{s}_H \le R$ then $\hat{s}_G \le \hat{s}_H$ (and equality in one implies equality in both). Thus, under the assumption $\hat{s}_H \le R$,

$$\left(U_n^e\Big|_H - U_n^e\Big|_G\right) = \left[U(W_{n,n}) - U(W_{n,g})\right]\left\{\int_{s=0}^{\hat{s}_G}\left[\frac{\theta_G(s,R)-\theta_H(s,R)}{\hat{\theta}}\right] f\left(s,C\right)ds + \int_{\hat{s}_G}^{\hat{s}_H}\left[1-\frac{\theta_H(s,R)}{\hat{\theta}}\right] f\left(s,C\right)ds\right\} . \tag{24}$$

The second integral on the RHS of (24) is non-negative because the integrand is non-negative. As for the first integral on the RHS of (24), note that, by definition,

$$\theta_G(s,R)-\theta_H(s,R) = \left[1-G(R/s)\right]-\left[1-H(R/s)\right] = H(R/s)-G(R/s) . \tag{25}$$

By assumption, $H\left(\lambda\right) > G\left(\lambda\right)$ for $\lambda > 1$. Thus, $\lambda = (R/s) > 1$, $\forall s \in \left(0, \hat{s}_G\right)$, provided that $\hat{s}_G < R$. Therefore, the first integrand in (24) is strictly positive and the result holds.[5] ■

To gauge the fuller implications of this result, one must recall the participation constraint. Because less precise measurement lowers expected utility, then, if the participation constraint binds, this means that the marketing firm will require a higher consumer premium to supply the non-GM good.

Consumer Demand

Underlying the perceived need for costly IP, and for government regulation, there must be willingness to pay for non-GM product on the part of at least some consumers. As discussed earlier, the premise is that, whereas consumers never prefer the GM product when the equivalent non-GM good is available at the same price, some consumers are willing to pay something to avoid the GM product. Specifications of demand for such a particular case of differentiated products have been offered by Fulton and Giannakas (2004) and Lapan and Moschini (2004). Here we pursue a slightly different specification that holds some advantage with respect to the problem at hand.

As in the aforementioned studies, we postulate that consumers are heterogeneous with respect to their preferences for non-GM food (vis-à-vis GM food), but we specifically relate this heterogeneity to the inherent characteristic that consumers are supposedly concerned about: the content of a GM ingredient. In particular, we assume the following quasilinear specification for an individual consumer's utility function:

$$U(q_n, q_g, z | \beta) = z + u(q_n + q_g) - A(\beta, s_n q_n + s_g q_g) \qquad (26)$$

where q_n denotes the quantity consumed of non-GM product, q_g denotes the quantity consumed of GM product, z denotes a composite commodity (all other goods), s_n denotes the GM content of a non-GM good (the impurity level), s_g is the GM content of the GM product, and $\beta \in [0,1]$ indexes the type of the consumer.

The function $u(.)$ is assumed strictly concave, as usual, and the function $A(\cdot)$ represents the consumer aversion to GM ingredients (due, for example, to the subjective perception of the harm that may derive from consuming GM products). This aversion is related to the total ingestion of GM material and to the consumer type, and it is increasing in both arguments and displays positive cross effects.[6] From the consumer perspective, the two purity levels are random variables. Without much loss of generality, however, we use $s_g = 1$ and, consistent with the notation of the foregoing sections, drop the subscript from s_n. Furthermore, we represent the GM-aversion function as a linear function: $A(\cdot) = (s q_n + q_g) a\beta$, where $a > 0$.

Assuming that consumers maximize expected utility, and that the conditions for an interior solution for $(q_n + q_g)$ hold, the optimization problem of the β-type consumer can be represented as

$$\max_{q_n, q_g} \quad u(q_n + q_g) - (\bar{s} a\beta + p_n^1) q_n - (a\beta + p_g^1) q_g \qquad (27)$$

where $\bar{s} \equiv E[s]$. From the optimality condition for this maximization problem, the consumer of type β will

consume only q_n if $(p_n^1 - p_g^1) < (1 - \bar{s}) a\beta$

consume only q_g if $(p_n^1 - p_g^1) > (1 - \bar{s}) a\beta$

be indifferent between q_g and q_n if $(p_n^1 - p_g^1) = (1 - \bar{s}) a\beta$.

Thus, for given consumer prices p_n^1 and p_g^1, the consumer of type $\hat{\beta} \equiv (p_n^1 - p_g^1) / [(1-\bar{s})a]$ is indifferent between GM and non-GM product.

Note that the maximum consumer willingness to pay, arising from consumers with $\beta = 1$, is $(1-\bar{s})a$. Thus, if $\Delta \equiv (p_n^1 - p_g^1)$ is greater than this maximum level, no non-GM product is demanded by consumers. If Δ is less than that, both goods are consumed in the market. In such a case, aggregate demand for the two goods can be found by integrating over all consumer types. If $B(\beta)$ denotes the distribution function of consumer types, then the aggregate demand functions $D_n(p_n^1, p_g^1)$ and $D_g(p_n^1, p_g^1)$ for non-GM and GM products are

$$D_g(p_n^1, p_g^1) = \int_0^{\hat{\beta}} q(a\beta + p_g^1)dB(\beta) \tag{28}$$

$$D_n(p_n^1, p_g^1) = \int_{\hat{\beta}}^1 q(\bar{s}a\beta + p_n^1)dB(\beta) \tag{29}$$

where the individual demand function $q(p)$ satisfies $q^{-1}(\cdot) = u'(\cdot)$.

Equilibrium

We consider a competitive equilibrium with many handlers, where both GM and non-GM goods are produced. For this to happen, it is necessary that both farmers and handlers be indifferent between supplying GM and non-GM products (at their respective market stages). Indifference for farmers requires

$$(p_n^0)^* = (p_g^0)^* + \delta \tag{30}$$

where a superscripted star denotes equilibrium values. Indifference for handlers requires that, at equilibrium values, $U_n^e = U(W_{g,g})$.

Here we characterize the risk-neutral situation only. By using (21), we obtain

$$\left[(p_n^1)^* - (p_g^1)^*\right] \int_{s=0}^{\hat{s}^*} \left[1 - \frac{\theta(s,R)}{\theta(\hat{s}^*,R)}\right] f\left(s,C\right) ds = \left[(p_n^0)^* - (p_g^0)^*\right] + C \tag{31}$$

where $\hat{s}^*$, by using (13) and (16), satisfies

$$\pi\left[1-H\left(R/\hat{s}^*\right)\right]=\frac{(p_n^1)^*-(p_g^1)^*}{(p_n^1)^*-(p_g^1)^*+T}. \tag{32}$$

Market-clearing requires

$$D_g\left((p_n^1)^*,(p_g^1)^*\right)+D_n\left((p_n^1)^*,(p_g^1)^*\right)=S\left((p_g^0)^*+\delta\right). \tag{33}$$

Finally, to close the model, the handlers' participation constraint in equation (12) must bind (zero profit condition), such that

$$(p_g^1)^*=(p_g^0)^*+M\,. \tag{34}$$

Thus, for given cost parameters $\{\delta,M,C\}$ and regulation parameters $\{R,\pi,T\}$, equations (30)-(34) can be solved for four equilibrium prices, $(p_g^0)^*,(p_n^0)^*,(p_g^1)^*,(p_n^1)^*$, as well as the equilibrium threshold level $\hat{s}^*$ used by handlers. Furthermore, the consumers' maximum willingness to pay for non-GM product must not be violated by the equilibrium if both goods are to be consumed. That is, it is necessary that $(p_n^1)^*-(p_g^1)^*$ $<(1-\bar{s}^*)a\beta$, where the equilibrium value of the "average" impurity level of non-GM food is

$$\bar{s}^*=(1-\pi)E\left[s\,\middle|\,s\le\hat{s}^*\right]+\pi E\left[s\,\middle|\,s\le\hat{s}^*\text{ and }\lambda s\le R\right]. \tag{35}$$

Note that the regulation parameters $\{R,\pi,T\}$ will affect the equilibrium impurity level $\bar{s}^*$ and thus directly affect the consumer demand for the two goods, *ceteris paribus*. How the regulation parameters affect production decisions, *ceteris paribus*, was considered earlier. What becomes apparent, at this point, is that π and T are *not* equivalent in this equilibrium. Recall that, from the perspective of handlers, a set of $\{\pi,T\}$ that yields the same $\hat{s}$, given prices, results in the same expected utility. But, of course, from a welfare perspective one should prefer a higher fine T and lower monitoring probability π because monitoring entails real costs, whereas fines are simply a net transfer.

From the perspective of the system's equilibrium, however, in light of (35) it is necessary to account for the effect on demand. In particular, an increase in π and a comparable decrease in T that would leave $\hat{s}$ unchanged, given prices, would also increase the number of shipments rejected, thereby lowering $\bar{s}$, *ceteris paribus*, because

$$E\left[s \middle| s \le \hat{s}\right] \ge E\left[s \middle| s \le \hat{s} \text{ and } \lambda s \le R\right]. \tag{36}$$

But as $\bar{s}$ decreases, given prices, the demand for the non-GM good increases and the demand for the GM good decreases because $\hat{\beta}$ declines (such that more consumers elect to consume the non-GM product) and because the "real" price for the non-GM good $(\bar{s}a\beta + p_n^1)$ also declines. Thus, we can conclude the following:

PROPOSITION 6. *Fines and the probability of testing do not have equivalent effects on the equilibrium of the system. An increase in testing and a decrease in fines that holds producer behavior constant have a positive social benefit (as well as a social cost).*

Thus, one of the conclusions of standard models of law enforcement does not hold in this more general setting. The intuition is as follows. In the crime model, the penalty T and the enforcement π provide a positive welfare effect because they deter crime *ex ante*. In equilibrium some criminals are caught and convicted, but because conviction happens after the crime has been committed there is no additional welfare impact (unless one were to assume a limited pool of criminals). In our model, the "offence" is committed when a product is mislabeled, but the damages actually occur only when the product reaches the market. Hence, when the government, through testing, prevents mislabeled product from reaching the consumer, it provides a direct welfare benefit (and, as the consumers know that, it inspires "more confidence" in the food system). In addition, the foregoing discussion also suggests that an equilibrium that includes positive production of the non-GM good may only be supportable with sufficiently high π.

Concluding Remarks

In this paper we have developed a framework of analysis for the main economic issues that arise in the pursuit of a credible and enforceable system of IP and labeling for GM and non-GM products. The model represents three stages in the supply chain: farm production, marketing handlers, and final users. The possibility of accidental co-mingling of non-GM products is modeled at the marketing stage. Regulation takes the form of a threshold level of purity for non-GM products, a probability of government testing to verify compliance with the threshold level, and a fine for violators. Uncertainty is modeled explicitly, such that would-be suppliers of non-GM products always face some risk of failing the test and incurring a fine. The equilibrium solution includes a novel specification of the demand for differentiated GM and non-GM products that is particularly useful in the stochastic framework of this paper. The results emphasize the role and impact of an uncertain testing technology, a critical feature of the problem at hand. We also highlight the somewhat non-standard trade-off between frequency of testing and the size of the fine that applies here. Specifically, because through testing the authority can prevent mislabeled product from reaching the consumer, it can provide a direct welfare benefit. An equilibrium that includes positive production of the non-GM good may only be supportable with sufficiently high testing frequency (a high penalty for mislabeling may not suffice).

Endnotes

1. Regulation (EC) No. 1829/2003 on GM food and feed and Regulation (EC) No. 1830/2003 concerning the traceability and labeling of GM organisms and the traceability of food and feed products produced from GM organisms are in force and effective as of April 2004. See Commission of the European Union 2004 for more details, and Craddock 2004 for an informal discussion of related issues.

2. At present it may not be apparent why a firm would want to sell the GM product to consumers after having bought non-GM product from farmers (yielding the wealth outcome $W_{n,g}$). As illustrated in what follows, this eventuality may arise because of the effects of regulation.

3. We assume that when $\theta = 1$, the fine is large enough so that the firm will sell the good as GM. Under risk neutrality this is precisely the same condition as the incentive-compatibility constraint for the firm that buys a GM input. With risk aversion, the threshold fine (and probability) need not be the same because of wealth effects of the input cost; under CARA, the required fine is the same in both cases.

4. Hence, the distribution $G(\lambda)$ represents a "mean-preserving spread" of $H(\lambda)$ (Rothschild and Stiglitz 1970).

5. Note that a precise result for $\hat{s}_H > R$ does not seem feasible.

6. Thus, the highest preference for the non-GM product is expressed by the consumer with $\beta = 1$, whereas for consumers with $\beta = 0$, GM and non-GM goods are perfect substitutes.

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