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Grading, Minimum Quality Standards, and the Labeling of Genetically Modified Products

Abstract

In this paper we relate the economics of labeling genetically modified (GM) products to the theory of grading and minimum quality standards. The model represents three stages in the supply chain (farm production, marketing handlers, and final users) and allows explicitly for the accidental co-mingling of non-GM products at the marketing stage. Regulation takes the form of a threshold level of purity for non-GM products. The paper also presents a novel demand specification for differentiated GM and non-GM products that is particularly useful in our stochastic framework. First, we find that if the threshold purity level for non-GM products is too strict, this necessarily leads to the disappearance of non-GM product from the market. Second, we show that some quality standard is in the interest of farmers as well. Indeed, we show that the standard that is optimal from the perspective of producers is actually stricter than what is optimal for consumers and for societal welfare. We conclude with comparative statics effects that illustrate the impact of the model's parameters on market equilibrium and on the welfare-maximizing regulatory standard.

Key Words: biotechnology, grading, identity preservation, food labeling, minimum quality standards, regulation, uncertainty.

Introduction

The one billionth acre of genetically modified (GM) crop was planted in 2005, only ten years after this technology was first introduced. Whereas this milestone exemplifies the widespread and fast diffusion of a tremendously promising and radical innovation, there continues to be public resistance and opposition to GM food (Evenson and Santaniello, 2004). Nowhere is this more apparent than in the European Union (EU), where public opposition first led to a regulatory impasse with serious trade implications (Pew Initiative, 2005) and finally resulted in a new, complex, and stringent regulatory system centered on the notions of GM food labeling and traceability.[1] In the EU, 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]." 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%. This mandatory labeling is supplemented by traceability requirements, meant to facilitate monitoring of unintended environmental effects and to help enforce accurate labeling.

This drive toward GM labeling, mirrored in many other countries, is emerging as a key policy response to the introduction of GM products. This effect contributes to the ongoing transformation of the agricultural industry from one that produces largely "homogenous" commodities into one that eventually may be characterized by differentiated goods. Meeting the demand for differentiated food products requires a system that can credibly deliver such differentiated products to end users. Previous work in this area has centered on the notion of "grading" agricultural commodities. Grading of products and government inspections have long been used in agricultural markets in pursuit of a variety of objectives (Dimitri, 2003). In this setting it is useful to separate regulations that aim at improving the health safety of the food

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[1] This became effective in April 2004. See European Union (2004) for more details.

supply from quality regulations that have mostly an "informational" root vis-à-vis the quality of the good as perceived by consumers (Gardner, 2003). The latter are more germane when considering the issue of GM labeling (health safety considerations are arguably best dealt with at the approval stage of GM products). Specifically, the introduction of GM products that some consumers deem undesirable means that the corresponding non-GM pre-innovation traditional product attains, for these consumers, the status of a "superior" product.

Tapping the emerging demand for non-GM food is hampered by the fact that the GM and corresponding non-GM products 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. A credible labeling and certification system, distinguishing GM from non-GM products in the marketplace, would clearly be desirable. Whether such a system should take the form of mandatory labeling of the (inferior-quality) GM products, as with the new EU regulation, is of course highly questionable (Crespi and Marette, 2003; Lapan and Moschini, 2004). The problem 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.

Thus, accepting the need for a GM labeling system still leaves open the question of what features it should have from an economic perspective. In addition to the "voluntary" versus "mandatory" question, mentioned earlier, a critical element concerns what it means to be "non-

GM." Because of the aforementioned need for extensive IP measures at various production and

marketing stages, it is becoming apparent that 100% purity is simply not attainable.[2] Thus, a

critical element of emerging GM labeling regulations concerns the "threshold' or "tolerance"

level—i.e., the maximum level of impurity that is admissible in food while still allowing a claim

of non-GM. No uniformity appears to be emerging across countries on this matter. As mentioned,

the EU has set an extremely strict threshold level of 0.9%. Australia and New Zealand have an

almost-as-strict tolerance level of 1% (but, unlike in the EU, these countries exempt highly

refined products, such as vegetable oils, from the labeling requirements). Japan and South Korea,

on the other hand, have opted for laxer standards (e.g., Carter and Gruere, 2003). Their tolerance

levels are 5% and 3%, respectively, and only apply to the main ingredients of a food item (top

three ingredients in Japan and top five ingredients in South Korea).

The question of the appropriate threshold level for non-GM products can be viewed as

the establishment of a government-mandated "minimum quality standard" (MQS). The seminal

work of Leland (1979) exemplified the consequences of Akerlof's (1970) lemon problem and

showed that an MQS can improve the welfare attributes of an otherwise unregulated competitive

system. Gardner (2003) draws the links between this and related work for the assessment of food

quality standards. In this paper we wish to pursue in detail the question of setting an MQS for

non-GM food, as attempted by the GM labeling regulations discussed in the foregoing. Our

analysis relies on an explicit market equilibrium model that captures the stylized attribute of GM

innovation. Specifically, we develop a model that has the following basic elements: (i)

heterogeneous consumers with preferences over the differentiated goods (GM and non-GM

products); (ii) producers (farmers) for whom GM product provides an efficiency gain; (iii)

middlemen, who purchase from farmers, grade and label goods, and resell them to consumers;

and (iv) a government, which identifies the "optimal" grading system (i.e., the GM tolerance

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[2] Episodes of accidental GM contamination support this conclusion, including the high-profile Starlink and Prodigene cases (Taylor and Tick, 2003) and, more recently, the Bt10 corn mix-up (Herrera, 2005).

level). In the framework of analysis that we develop, uncertainty plays a critical role, and the need for IP activities to keep GM and non-GM products sufficiently segregated in the production and marketing system is explicitly addressed.

Background: Quality, Grading, and Minimum Quality Standards

Modeling of MQSs started with Leland (1979), who considered a market with the kind of asymmetric information introduced by Akerlof (1970). The MQSs in question parallel those of "licensing" in a profession (e.g., physicians). Without any mechanism, it is shown that in a market with such informational asymmetries the equilibrium under-provides quality. MQSs can increase welfare. Leland also shows that the MQSs chosen by a professional group or industry tend to exceed the socially optimal level. This quintessential market-power result highlights a distinctive feature of models in this area, where an MQS is typically presumed to work by eliminating from the market all products with quality below the set level. By raising quality, an MQS also reduces supply, and this effect can allow the exploitation of a degree of market power. Consumers do not uniformly gain by the establishment of an MQS (some are better off and some are worse off as a result).[3]

Most of the work on MQSs has been carried out in imperfectly competitive settings. When consumers differ in terms of their willingness to pay for quality, and in the vertical product differentiation (VPD) framework, imperfectly competitive firms may have an incentive to increase quality diversification in order to soften price competition (Shaked and Sutton, 1982). Given that, Ronnen (1991) uncovers another reason for MQSs to have positive welfare effects: by limiting the range of admissible quality differentiation, the ensuing price competition is more aggressive. He shows that an MQS can in fact make all consumers better off, and social welfare

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[3] Shapiro (1983) presents related results and endogenizes the supply of the various qualities.

can be improved by the standard.[4] But Valletti (2000) finds that such conclusions depend heavily

on the Bertrand-type competition that is presumed for the second stage of the game and he

concludes that an MQS is not welfare-increasing under Cournot competition. Ronnen's

conclusions have also been questioned by Scarpa (1998), who shows that an MQS can actually

reduce industry profit and welfare when more than two firms operate in the market. One of the

messages here is that "excessive" competition can represent a negative incentive to supply high-

quality goods.[5]

In the agricultural economics literature, MQSs were analyzed by Bockstael (1984), who

shows that under perfect competition and with observable quality an MQS would lead to welfare

losses. This is because an MQS, in that setting, simply amounts to an arbitrary restriction on an

otherwise undistorted competitive model (as also noted by Shapiro, 1983). Yet, another strand of

the agricultural economics literature discusses MQSs in the context of studying the economics of

"grading" agricultural commodities. Basically, grading is understood as identifying ranges of

qualities for which different markets (and different prices) arise. Earlier contributions are

reviewed by Bockstael (1987), who distinguishes between the contexts of perfect information and

of quality uncertainty. Some of the connections between grading and MQSs are informally

discussed in a recent paper by Gardner (2003), who emphasizes the usefulness of distinguishing

regulations that aim at (i) improving the health safety of the food supply from (ii) quality

regulations that have mostly an "informational" root vis-à-vis the quality of the good as perceived

by consumers. He also notes the traditional view that grades developed by the USDA usually

serve two distinct purposes: (a) to facilitate long-distance trade; and (b) to differentiate products

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[4] His model, as in much of this literature, relies on the common linear-in-quality utility unit demand specification introduced by Mussa and Rosen (1978), with the further restriction of a uniform distribution of consumer types.

[5] This view is also articulated by Maxwell (1998) in a different context. Specifically, he shows that, in the presence of an activist regulator, an innovative firm correctly anticipates that the MQS will be raised after an innovation. This reduces the profitability of new discoveries, thereby reducing the incentive to innovate, which may reduce welfare.

at the producer level. Within this taxonomy, the concerns of the present paper are with points (ii) and (b).

A major distinction between the notions of grading and of MQSs is that the former envision marketing of all product qualities, whereas the presumption in the latter is that an MQS excludes some qualities from the market. MQSs thus narrowly construed clearly do not apply to a number of realistic cases in agriculture. Organic standards set by the USDA, for example, identify the minimum quality (percentage of organic ingredients) necessary to belong to one of three organic product categories ("100 percent organic," "organic," and "made with organic ingredients"). Clearly, products failing an upper category can be marketed in the lower one, and products failing the lowest organic category standard can still be marketed as conventional products (and thus are not excluded from the market). The case of non-GM labeling that we posit in this paper is very much of the same nature: a product failing the non-GM standard can still be marketed as a GM product. That standards do not always prohibit marketing of lower qualities was noted by earlier studies. Bockstael (1984), for example, also considers the case in which substandard product is diverted into a pre-existing secondary market.[6] In what follows we will maintain this feature as an integral part of the model. Indeed, what gives rise to the potential for product differentiation in this setting (i.e., heterogeneous preferences for quality) also directly specifies the nature of the market for the lower standard product and specifies the substitution relationship between the higher-quality and the lower-quality products. In what follows, we describe an explicit model for the analysis.

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

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[6] Considering such a secondary market makes no difference as a MQS necessarily reduces welfare in her model.

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 farm-gate price of a non-GM product;

p_g^0 is the farm-gate 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).

The model that we develop envisions a competitive farm sector with a standard upward-sloping

supply curve.[7] The marketing level is also modeled as competitive and operating under constant

returns to scale and, in addition to the standard marketing services (e.g., storage, transportation,

processing, …), here it also provides the IP activities necessary for non-GM product. The final

consumption level displays differentiated demand for GM and non-GM products, which is

modeled as arising from preference heterogeneity. The consumer level displays the property that

the GM product is a weakly inferior substitute for the non-GM products, as in Lapan and

Moschini (2004).

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[7] This standard property can be rationalized as arising because of the inelastic supply of land at the aggregate level, which translates into an upward-sloping supply of land at the level of a particular agricultural industry.

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, if Q_g and Q_n denote the aggregate production of GM and non-GM products, respectively, the aggregate cost function of the farm sector is written as $C(Q_g + Q_n) + \delta Q_n$, where $C(\cdot)$ is a convex function (i.e., the marginal cost $C'(\cdot)$ is increasing). Let $S(\cdot)$ denote the inverse of the marginal cost function, that is, the function satisfying $S^{-1}(\cdot) = C'(\cdot)$. Then the aggregate supplies of the two farm-level products, arising from competitive profit maximization at the farm level, are

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

$$(2) \quad \left. \begin{array}{l} Q_g = S(p_g^0) \\ Q_n = 0 \end{array} \right\} \qquad \text{if } (p_n^0 - p_g^0) < \delta$$

$$(3) \quad \left. \begin{array}{l} Q_n + Q_g = S(p_g^0) \\ Q_n \in \left[0, S(p_g^0)\right] \quad \text{and} \quad Q_g \in \left[0, S(p_g^0)\right] \end{array} \right\} \qquad \text{if } (p_n^0 - p_g^0) = \delta$$

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 the non-GM product simply compensates for a production cost difference). Also, note that, in such an equilibrium, the supply of either product is infinitely elastic, although clearly total supply is upward sloping.

Marketing Sector

We consider a generic middleman, referred to as "processor," who 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.

A fundamental part of the problem at hand is the possibility of the unintended co-mingling of GM and non-GM products, which necessitates the use of IP activities that can control such contamination. As the good moves through the production and marketing sector, there is a positive probability of contamination. This contamination can occur during production, storage, transportation, or elsewhere along the chain. It may occur because of cross-pollination during primary production, because employees are careless during the post-harvest handling process, because containers are not perfectly cleaned, and so forth. Our model is agnostic as to where contamination takes place. We simply presume that some IP activities need to be carried out before a non-GM product can be sold as such to the consumer, and for simplicity we model IP as part of the marketing level.

Specifically, we assume that any lot of non-GM farm product that the processor purchases will, during the processing and distribution process, become contaminated with some (perhaps only trace amounts of) GM product, and that this "impurity" level has a given distribution function. Thus, for each non-GM lot that the processor purchased and then processed, 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

(4) $\qquad F(s) = \int_0^s f(y)\,dy$

then $F(s)$ 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.[8]

We conceive of marketing activities as supplied by a competitive sector displaying constant returns to scale at the aggregate level. This presumption may be viewed as an oversimplified representation of the many activities that take place between the farm gate and final consumption, but it is defensible if there are no major barriers to entry in the supply of marketing and processing services. With that, we represent the compensation of the activities incurred at the marketing level (except for IP) in terms of a constant unit cost $\eta > 0$ that is incurred for any unit of farm output that is handled (regardless of its type). Furthermore, for any unit of farm-level non-GM output that is handled, processors also need to supply segregation and IP, and thus also incur a constant unit IP cost $\sigma > 0$.

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. Thus, as in previous studies (e.g., Fulton and Giannakas, 2004; Lapan and Moschini, 2004), we model GM and non-GM products as "vertically differentiated" products. A demand specification that has proven useful in this context is the unit demand model of Mussa

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

and Rosen (1978), where consumers' differing valuation of quality is captured by an individual taste parameter. In what follows, we adapt this framework to capture the essence of the problem at hand.

An individual consumer is assumed to buy, at most, one unit of the product, which comes in two varieties—the GM product and the non-GM product. Each variety differs by the GM content s_i ($i \in \{n, g\}$). We posit that either variety provides the same basic level of utility u, but each also produces a disutility that is proportional to the GM content level, and this disutility differs across consumers. Specifically, the consumer of type β gets utility levels

$$U_n = u - a\beta\overline{s} - p_n^1 \qquad \text{if a unit of non-GM is bought}$$

(5) $$U_g = u - a\beta - p_g^1 \qquad \text{if a unit of GM is bought}$$

$$U_0 = 0 \qquad \text{if neither variety of this product is bought}$$

where $\beta \in [0,1]$ indexes the type of the consumer and $\overline{s} \equiv E[s_n]$ is the consumer's expectation of the fraction of GM material that is present in the non-GM good.[9] Whereas the parameter β captures the heterogeneity of consumers, vis-à-vis their preferences for the non-GM attribute, the parameter $a > 0$ captures the intensity of consumers' aversion to GM ingredients (due, for example, to the subjective perception of the harm that may derive from consuming GM products). Thus, the aversion factors $a\beta\overline{s}$ and $a\beta$ are directly related to the fraction of GM content present in the non-GM and GM products, respectively, are increasing in both arguments, and display positive cross effects.[10] The heterogeneity of consumer preferences is represented by assuming

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[9] Note that in this formulation we are making the simplifying assumption that consumers treat the GM product the same, regardless of the GM content s_g that is obtained in equilibrium (i.e., consumers behave as if $s_g = 1$).

[10] 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.

that the individual preference parameter β is distributed in the market according to the absolutely continuous distribution function $H(\beta)$.[11]

Given this preference specification, the consumer of type β will not consume the GM product if $p_n^1(\beta) < p_g^1(\beta)$; he will not buy the GM product if $p_n^1(\beta) > p_g^1(\beta)$; and he will be indifferent between the two products if $p_n^1(\beta) = p_g^1(\beta)$, where

(6) $\qquad p_n^1(\beta) \equiv p_n^1 + a\beta\overline{s}$

(7) $\qquad p_g^1(\beta) \equiv p_g^1 + a\beta$

can be interpreted as the "personalized prices" of the non-GM and GM products, respectively. It may be useful to observe that Tirole (1988, pp. 96-97) shows that the standard setup of Mussa and Rosen (1978), in which quality produces a different utility level for each individual, can be re-formulated as the case in which quality produces the same surplus from the good but individuals face a personalized price which, in that setting, reflects the impact of income distribution (i.e., the preference parameter is isomorphic to the reciprocal of the marginal utility of income). Similarly, in our setting the consumer's aversion to the GM content is conveniently reflected as augmenting the effective price of the two products, with the augmenting factor being proportional to the individual consumer preference parameter β.[12]

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[11] As noted earlier, it is very common in this setting to further assume that the distribution of types is uniform. Whereas in this model it is always possible to presume a uniform distribution of types by simply redefining the variable that indexes quality, as noted by Stivers (2003) and others, such a redefinition affects the underlying preferences, i.e., the uniform distribution is still restrictive. Thus, we derive most of our results for a general distribution of types (although we do resort to the uniform distribution assumption to derive unambiguous comparative statics analysis).

[12] One advantage of the formulation that we propose is that the personalized prices are linear in the taste parameter β, whereas in Tirole's (1988) reformulation of the standard unit demand model of VPD the personalized price is nonlinear in the taste parameter.

Based on the foregoing, it follows that, for given consumer prices p_n^1 and p_g^1, there exists a consumer type $\hat{\beta}$ such that consumers of type $\beta < \hat{\beta}$ will not purchase the non-GM product, whereas consumers of type $\beta \geq \hat{\beta}$ will not purchase the GM product, where[13]

$$(8) \qquad \hat{\beta} \equiv \frac{(p_n^1 - p_g^1)}{a(1-\overline{s})}.$$

Thus, $\hat{\beta}$ denotes the type of consumer who is indifferent (at given prices) between consuming the GM and the non-GM product. Similarly, let $\tilde{\beta}$ denote the type of consumer who would be indifferent (at given prices) between consuming the non-GM product or nothing, and let β^0 denote the type of consumer who would be indifferent between purchasing the GM product or nothing:

$$(9) \qquad \tilde{\beta} \equiv \frac{u - p_n^1}{a\overline{s}}$$

$$(10) \qquad \beta^0 \equiv \frac{u - p_g^1}{a}.$$

Assuming $p_n^1 > p_g^1$, the critical types $\{\tilde{\beta}, \beta^0, \hat{\beta}\}$ must be ordered either as $\tilde{\beta} < \beta^0 < \hat{\beta}$ or as $\tilde{\beta} \geq \beta^0 \geq \hat{\beta}$. In the former case, no non-GM product will be sold and the marginal consumer who buys the GM good is given by $Min\{\beta^0, 1\}$. In the latter case, if $\hat{\beta} \geq 1$, then the market will be covered, and again no non-GM product will be sold, whereas finally if $\hat{\beta} < 1$, then some non-GM good will be demanded, and the marginal consumer will be $Min\{\tilde{\beta}, 1\}$. Figure 1 illustrates

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[13] Note that the consumer will make a purchase only if $u \geq Min\{p_n^1(\beta), p_g^1(\beta)\}$. Thus, for $\beta < \hat{\beta}$ the consumer will buy the GM product *if* $u > p_g^1(\beta)$, whereas for $\beta \geq \hat{\beta}$ he will buy the non-GM product if $u \geq p_n^1(\beta)$. We assume that $u > p_g^1(0) = p_g^1$, guaranteeing that the market exists.

the case of $\tilde{\beta} < 1$. 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 for the case pictured in the figure are[14]

(11) $\qquad D_g(p_n^1, p_g^1) = \int_0^{\hat{\beta}} h(\beta) d\beta = H(\hat{\beta})$

(12) $\qquad D_n(p_n^1, p_g^1) = \int_{\hat{\beta}}^{\tilde{\beta}} h(\beta) d\beta = H(\tilde{\beta}) - H(\hat{\beta})$

where $H(\beta)$ is the distribution function of consumer types, $h(\beta) \equiv H'(\beta)$ is the corresponding density function, and (without loss of generality) the mass of consumers in the market is normalized to one.

Regulation

Government regulation in this setting takes the particular simple form of a scalar R, which denotes the maximum impurity (threshold) level below which a good can be sold to consumers as non-GM. Thus, for example, the 0.9% EU standard discussed earlier would be equivalent to setting $R = 0.009$ in our model, whereas the 5% Japan standard would be equivalent to setting $R = 0.05$. Throughout we assume that the regulation set by the government can be enforced costlessly. Still, a given standard R affects the expected impurity $\bar{s}$ of marketed non-GM product, given the "purification technology" discussed earlier.[15] Specifically,

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[14] In general, the demands can be written as:

$D_g(p_n^1, p_g^1) = \int_0^{Min\{\hat{\beta}, \beta^0, 1\}} h(\beta) d\beta$

$D_n(p_n^1, p_g^1) = \int_{Min\{\hat{\beta}, 1\}}^{Min\{\tilde{\beta}, 1\}} h(\beta) d\beta$ for $\tilde{\beta} \geq \hat{\beta}$ and $D_n(p_n^1, p_g^1) = 0$ for $\tilde{\beta} \leq \hat{\beta}$.

[15] We note that the stochastic production of the high-quality good in our setting is similar to the setup analyzed by Stivers (2003). He considers a standard monopoly quality setting within the VPD model. Production of quality is stochastic, so that a distribution of quality is harvested (he provides the examples of timber production and diamond mining).

$$(13) \qquad \overline{s} = \frac{\int\limits_0^R yf(y)dy}{F(R)} \equiv \overline{s}(R)$$

Pooling and Separating Equilibria

Before considering the effects of regulation it is important to articulate the conditions that, in our model, govern whether a "pooling" or a "separating" equilibrium emerges.

Pooling Equilibrium

Consider first the equilibrium in which no labeling of products occurs. In this case, because sellers of the non-GM product have no way of differentiating their superior (but more expensive) product from that of the GM product, in the resulting "pooling" equilibrium only the GM product is sold. Because only the GM product is sold, the marketing sector's profits are

$$(14) \qquad \pi_g^M = \left(p_g^1 - p_g^0 - \eta \right) Q_g .$$

Assuming free entry in the marketing sector, this implies

$$(15) \qquad p_g^1 = p_g^0 + \eta .$$

Using the supply and demand functions for the GM good developed earlier, the market clearing condition that equates excess supply $Z\left(p_g^0 \right) \equiv S\left(p_g^0 \right) - D\left(p_g^0 + \eta \right)$ to zero requires

$$(16) \qquad S\left(p_g^0 \right) - \int\limits_0^{Min\{\beta^0,1\}} h(\beta)d\beta = 0 .$$

The willingness to pay for the highest β type is $\hat{p}_g^1 = (u-a) \rightarrow \hat{p}_g^0 = (u-a-\eta)$; if supply at that price is at least equal to this maximum demand, then the market will be "covered." Using

(16), if $S(u-a-\eta) - \int\limits_0^1 h(\beta)d\beta \geq 0$, then the market is covered. Because maximum market size

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is normalized to 1, and supply is the inverse marginal cost curve, this means the market is covered if $\left(u - a - \eta - C'(1)\right) \geq 0$.

If the market is covered for this case, it must also be covered if the non-GM product is also made available, in which case total sales — and the farm price — will be independent of government policy. Because one of our — and society's — concerns is how regulation affects producers, we assume that, absent non-GM sales, the market is *not* covered.

Assumption 1: $C'(1) > (u - \eta - a)$.

Given this assumption, from (16) the equilibrium price $p_g^{0,e}$ solves

(17) $\qquad S\left(p_g^{0,e}\right) - \int_0^{\beta^{0,e}} h(\beta)d\beta = 0$

and the marginal buyer $\beta^{0,e}$ satisfies

(18) $\qquad \beta^{0,e} = \dfrac{u - \eta - p_g^{0,e}}{a} < 1$.

Separating Equilibrium

We now analyze the case in which a labeling regime makes it possible for the processing sector to consider selling the higher quality non-GM good. For any lot handled at this marketing stage, the prices that are relevant to the processor's decisions are the "input" prices p_n^0 (the farm-gate price of a non-GM product) and p_g^0 (the farm-gate 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.

Suppose that the marketing sector handles quantities Q_n and Q_g of farm-level output of non-GM and GM products, respectively. As discussed earlier, farmers will supply non-GM product only if $p_n^0 > p_g^0$, specifically,

(19) $p_n^0 = p_g^0 + \delta$.

Consequently, (expected) profit-maximizing middlemen will handle Q_n only with the intention of selling it as (certified) non-GM to consumers, provided $p_n^1 > p_g^1$. But owing to the government-set standard R, only a fraction $F(R)$ of non-GM farm product is expected to be sold as non-GM product to the consumer, and the remaining fraction $[1 - F(R)]$ that exceeds the threshold level R must be sold at the lower consumer GM product price. Hence, the marketing sector's profits π_g^M and π_n^M for handling GM and non-GM products, respectively, are

(20) $\pi_g^M = \left(p_g^1 - p_g^0 - \eta \right) Q_g$

(21) $\pi_n^M = \left(p_n^1 F(R) + p_g^1 [1 - F(R)] - p_n^0 - \eta - \sigma \right) Q_n$.

In a competitive equilibrium, the marketing sector's expected profit vanishes. Thus, if $\pi_g^M = \pi_n^M = 0$, in an equilibrium with both products produced in strictly positive amounts, it must be that

(22) $p_g^1 = p_g^0 + \eta$

(23) $p_n^1 F(R) + p_g^1 [1 - F(R)] - p_n^0 - \eta - \sigma = 0$.

By using (19) and (22), the equilibrium condition in (23) can be rewritten as

(24) $p_n^1 = p_g^1 + \dfrac{\delta + \sigma}{F(R)}$.

Hence, in an equilibrium with positive production of both GM and non-GM products, the four prices of our model are linked by three arbitrage relations. Equation (19) specifies that the

farm-level price premium for non-GM product must exactly equal the cost efficiency gain δ

provided by the new GM crop. Equation (22) specifies that, for GM product, the difference

between the consumer price and the farm price must exactly equal the unit marketing cost η.

And, equation (24) links the retail price premium $\left(p_n^1 - p_g^1 \right)$ to the effective unit efficiency

handicap $(\delta + \sigma)$ (which includes the IP cost σ) via the standard-dictated amount $F(R)$, which

is the fraction of farm-level non-GM product that can actually be sold as such to consumers.

Given the three price arbitrage relations just discussed, and for a given level of the

regulation standard R, the equilibrium value of the remaining price, p_g^{0*}, solves the market

equilibrium condition that is obtained by equating total supply with total demand. Several

possible situations may arise. In particular, as is standard in models of this type with a finite

number of heterogeneous consumers, it is necessary to distinguish the case in which all

consumers buy one variety of the good (the market is "covered") from the case in which some

consumers do not buy either variety (the market is said to be "uncovered"). Furthermore, here we

need to distinguish the case in which both varieties (GM and non-GM) are provided from that in

which only one variety is provided[16].

Both GM and non-GM products are produced and consumed when, for the given R, the

equilibrium price is such that $0 < \hat{\beta} < Min\left[\tilde{\beta}, 1 \right]$. This situation can, of course, take the form of

either an uncovered market (i.e., in equilibrium $\tilde{\beta} < 1$) or of a covered market (i.e., in equilibrium

$\tilde{\beta} \geq 1$). The most interesting equilibrium situation, for our purposes, is when both goods are

produced and the market is uncovered, in which case the equilibrium price p_g^{0*} solves

(25) $\qquad S\left(p_g^{0*} \right) = H\left(\dfrac{1}{a\overline{s}(R)}\left[u - p_g^{0*} - \eta - \dfrac{(\delta + \sigma)}{F(R)} \right] \right).$

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[16] Assumption 1 rules out the case of a covered market if regulations are such that only GM goods are sold.

For the covered market case, the equilibrium price simply solves $S\left(p_g^{0*}\right)=1$.[17] The other

possible equilibria in this model include the cases $Q_g=0$ (i.e., no GM product is produced) and

$Q_n=0$ (i.e., no non-GM product is produced). Because farmers have a *ceteris paribus* incentive

to produce the (more efficient) GM product, and because consumers with low enough β will

always want to consume this product when $p_n^1 > p_g^1$, it is clear that the possibility of $Q_g=0$ in

equilibrium can safely be ignored (given standard regularity conditions on the distribution of

consumer types).[18] The equilibrium with $Q_n=0$, on the other hand, in our model is a real

possibility, and we analyze that next.

Regulatory Standard and Equilibrium Outcomes

We have already analyzed the case in which non-GM goods were not supplied to the market

because there was no labeling standard that allowed consumers to differentiate them from the

(weakly) inferior GM good. However, the presence of a labeling standard is not sufficient to

guarantee that the non-GM good will be supplied *in equilibrium*. In fact, a regulatory standard

that is "too stringent" is just as bad — in the context of bringing diversity to the marketplace —

as a non-existent system.

Proposition 1. There exists a standard level $\underline{R}\in(0,1]$ such that, in equilibrium, for $R<\underline{R}$ the

non-GM product is not supplied to the market, whereas for $R>\underline{R}$ both goods are marketed in

equilibrium.

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[17] Since each consumer buys, at most, one unit, when all consumers participate, total demand is equal to
the mass of consumers, which we have normalized to equal one.

[18] We similarly can ignore the possibility that, in equilibrium, neither of the two goods is produced.

Proof. Let $\beta^{0,e}$ denote, as earlier, the marginal buyer when there is no labeling. For a given R, let $\hat{\beta}(R)$ denote the consumer who is indifferent between the GM and non-GM good (i.e., $p_n^1(\hat{\beta}) = p_g^1(\hat{\beta})$). If $\hat{\beta}(R) < \beta^{0,e}$, then introducing labeling, with this standard, will result in an equilibrium with both goods marketed and with a higher farm price. The latter conclusion follows because $\hat{\beta}(R) < \beta^{0,e} \rightarrow \tilde{\beta} > \beta^{0,e}$ so that at the original farm price level not only will some non-GM good be sold but more types will want to buy the product. Hence, the introduction of labeling leads to excess demand at $p_g^{0,e}$, and price must rise to clear the market. However, if $\hat{\beta}(R) \geq \beta^{0,e}$, then allowing labeling — with this standard — will not affect the equilibrium outcome since the introduction of the labeled good will alter neither quantity demanded nor quantity supplied at that price.[19] Given the personalized price definitions in equations (6)-(7), and the market arbitrage relations (19), (22), and (24), it is readily verified that

(26)　　$\hat{\beta}(R) = \dfrac{\delta + \sigma}{aF(R)\left[1 - \overline{s}(R)\right]}$.

It is also clear that $\hat{\beta}(R)$ is a decreasing function of R because

(27)　　$\hat{\beta}'(R) = -\dfrac{f(R)}{F(R)} \hat{\beta}(R) \left(\dfrac{1-R}{1-\overline{s}(R)}\right) < 0$

where we have used

(28)　　$\overline{s}'(R) = \dfrac{f(R)}{F(R)}\left[R - \overline{s}(R)\right] > 0$.

Now, if $\hat{\beta}(1) \geq \beta^{0,e}$, then no consumer exists that would buy the non-GM product. Otherwise, because we have shown that $\hat{\beta}(R)$ is a decreasing function of R, and because $\lim_{R \to 0} \hat{\beta}(R) \to \infty$ (as is apparent from equation (26)), there exists a $\underline{R} \in (0,1)$ such that

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[19] It is easy to show that equilibrium is unique, since supply is positively sloped and demand is negatively (or not positively) sloped.

$\hat{\beta}(\underline{R}) = \beta^{0,e}$. Hence, if $R \in [0, \underline{R})$, $\hat{\beta}(R) < \beta^{0,e}$, introducing the labeled good with a standard in this interval will result in the same equilibrium as when no labeling occurs. ∎

A critical element of the foregoing proof is that $F(0) = 0$, i.e., perfect purity is not attainable *ex ante*. This condition reflects the often-made argument, by agricultural and food industry operators who deal with the emerging GM regulation, that "zero tolerance is not possible." Proposition 1 thus provides the important policy conclusion that GM labeling standards may go too far. Setting a standard that is too strict (i.e., a threshold level R that is too low) may not help the consumer at all if the equilibrium outcome is that no non-GM product is supplied. The root of this result, of course, is that providing increased levels of "purity" is increasingly costly in this setting.

Effect of the Purity Standard on Farmers' Returns

In the rest of the paper we consider the scenario in which it is feasible to set the regulatory standard such that both goods will be marketed and the regulator chooses to do so:

Assumption 2: $\hat{\beta}(1) \equiv \dfrac{\delta + \sigma}{a[1 - \overline{s}(1)]} < \beta^{0,e}$ and $R > \underline{R}$.

Even though we have previously assumed that without labeling the market was uncovered, it is possible that with labeling there may be a regulatory standard that would increase demand sufficiently so that the market would be covered. To illustrate, consider the personalized price for the non-GM good of the highest type ($\beta = 1$):

(29) $p_n^1(1) = p_n^1 + a\overline{s}(R) \equiv p_g^0 + \eta + V(R)$

where

(30) $V(R) \equiv \dfrac{\delta + \sigma}{F(R)} + a\bar{s}(R)$.

Given $R > \underline{R}$, it follows that we know $p_n^1(1) < p_g^1(1)$. Define:[20]

(31) $\widehat{R} = \underset{R \in [0,1]}{\arg\min} \, V(R)$.

Thus, $\widehat{R}$ represents the "best" standard for the most "GM averse" consumer. We then have the following.

Proposition 2: If $u - V(\widehat{R}) > C'(1) + \eta > u - a$, then there exist values of R such that the market is covered when labeling occurs but is uncovered otherwise.

Proof: As shown earlier, $C'(1)$ is the supply (farm-gate) price needed to produce enough output to cover the market, and η is the processor's handling cost for the GM product. By Assumption 1, the second inequality holds. $\left(C'(1) + \eta + V(R)\right)$ is the personalized supply price for type $\beta = 1$ when the market is covered and the regulatory standard R is used. If this price is less than consumers' willingness to pay (u), then all agents of type $\beta \leq 1$ face a personalized price less than their willingness to pay, and in equilibrium the market will be covered. If $\left[u - V(\widehat{R})\right] < \left[C'(1) + \eta\right]$, then there is no R that can lead to a covered market. ∎

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[20] It is readily shown that $V'(R) = \dfrac{f(R)}{F(R)}[aR - V(R)]$. Since, by assumption, $\hat{\beta}(1) < 1$, this implies $a > V(1)$; thus, $V'(0) < 0 < V'(1)$. Further, it is readily seen that $V''(R) > 0$ at $V'(R) = 0$. Hence, there is a unique interior value of R that minimizes $V(R)$.

In the following analysis, we focus on the more interesting scenario in which the market is uncovered (so that aggregate demand is downward sloping). We therefore make the following assumption.

Assumption 3: $C'(1) + \eta + V(\widehat{R}) < \left[C'(1) + \eta \right] > u$

Thus, for any $R \in (\underline{R}, 1]$ consumers in the interval $\left[0, \hat{\beta}(R) \right]$ will buy the GM good, consumers in the interval $\left[\hat{\beta}(R), \tilde{\beta}\left(R, p_g^0\right) \right]$ will buy the non-GM good, and those in $\left[\tilde{\beta}\left(R, p_g^0\right), 1 \right]$ will purchase neither good.

From the earlier specification of the farm-level production, aggregate supply $S(p_g^0)$ is an increasing function of p_g^0, and so producer surplus is also an increasing function of p_g^0. Relaxing the purity standard (i.e., increasing R) lowers the equilibrium market price premium for the non-GM product, which, because of (24), satisfies $p_n^1 - p_g^1 = (\delta + \sigma)/F(R)$. This effect will have offsetting impacts on total demand and hence on the equilibrium farm price p_g^{0*}. An increase in R has an ambiguous impact on demand — by lowering the premium it increases demand, but by lowering the purity level it decreases demand if it raises the "personalized price" for the marginal (high β type) buyer. The overall impact will depend on the individual weights put on purity and on the standard R. Thus, the equilibrium farm price should be a non-monotonic function of R. In fact, we have the following result.

Proposition 3. In the uncovered market case, there exists a critical standard level R^{ps} such that below this level farmers gain from relaxing the standard while above this level farmers lose.

Proof. Given Assumptions 1-3, the market will be uncovered, but positive non-GM sales will occur for $R > \underline{R}$. Furthermore, since producer surplus is increasing in p_g^0, it is clear that producers want to maximize p_g^0, which entails choosing the standard that maximizes sales. The equilibrium price $p_g^{0*}(R)$ is determined from

(32) $\quad Z\left(p_g^0, R\right) = S\left(p_g^{0*}\right) - H\left(\tilde{\beta}\left(R, p_g^{0*}\right)\right) = 0$

implying

$$\tilde{\beta}\left(R, p_g^0\right) \equiv \frac{\left(u - p_g^0 - \eta\right) - \dfrac{\delta + \sigma}{F(R)}}{a\bar{s}(R)}.$$

As noted, $S\left(p_g^0\right) = \Pi'\left(p_g^0\right)$, where $\Pi\left(p_g^0\right)$ is total farmers' profits. Further,

(33) $\quad \dfrac{dp_g^{0*}}{dR} = \dfrac{-\partial Z / \partial R}{\partial Z / \partial p_g^{0*}}$

where $\partial Z / \partial p_g^{0*} > 0$ (supply and demand have their conventional slopes). Also:

(34) $\quad \left(\dfrac{\partial Z}{\partial R}\right) = -h\left(\tilde{\beta}\left(R, p_g^0\right)\right)\dfrac{\partial \tilde{\beta}}{\partial R}$

where $\dfrac{\partial \tilde{\beta}}{\partial R} \equiv \dfrac{f(R)}{F(R)\bar{s}(R)}\left[\hat{\beta}(R)(1 - \bar{s}(R)) - \tilde{\beta}(R, p_g^0)(R - \bar{s}(R))\right]$.

At $\left(\underline{R}, p_g^{0,e}\right)$, $\hat{\beta}(\underline{R}) = \tilde{\beta}\left(\underline{R}, p_g^{0,e}\right) = \beta^0\left(\underline{R}, p_g^{0,e}\right)$, so that $\left.\left(\partial \tilde{\beta} / \partial R\right)\right|_{\underline{R}} > 0 \rightarrow \left.\left(\partial p_g^{0,*} / \partial R\right)\right|_{\underline{R}} > 0$. Thus, demand and equilibrium price are increasing in R at $\underline{R}$. However, at $R = 1$,

(35) $\quad \left.\dfrac{\partial \tilde{\beta}}{\partial R}\right|_{R=1} \equiv \dfrac{f(1)}{\bar{s}(1)}\left[\hat{\beta}(1)(1 - \bar{s}(1)) - \tilde{\beta}(1, p_g^0)(1 - \bar{s}(1))\right] < 0.$

Hence, the regulatory standard R^{ps} that maximizes producer surplus must satisfy $R^{ps} \in (\underline{R}, 1)$.

Indeed, the foregoing analysis establishes that R^{ps} solves

(36) $\hat{\beta}(R^{PS})\left(1-\overline{s}(R^{PS})\right)-\tilde{\beta}(R^{PS})\left(R^{PS}-\overline{s}(R^{PS})\right)=0$. ∎

Thus, Proposition 3 establishes the interesting conclusion that some regulation, in the form of a minimum quality standard defining what can be identified as "non-GM," may be desirable from the producers' perspective, even though in any equilibrium with positive production of both goods farmers are actually indifferent as to which good to produce. The quality standard here helps to exploit optimally consumers' preference for product differentiation. A corollary to this result is that the absence of a standard (or, equivalently, $R=1$) is generally *not* in the interest of agricultural producers.

Welfare Effect of the Purity Standard

In the model that we have developed there is no profit at the marketing level, because marketing services are provided at constant unit costs (i.e., by a constant returns-to-scale industry), but the purity standard has the potential to affect the welfare of farmers and of final consumers. Having discussed the qualitative impact on producer surplus in the preceding section, let us now turn to aggregate welfare. Summing producer and aggregate consumer surplus, for a given pair (p_g^0, R) the welfare function is

(37) $W(p_g^0, R) = \Pi(p_g^0) + \int_0^{\hat{\beta}} U_g(p_g^0, R) h(\beta) d\beta + \int_{\hat{\beta}}^{\tilde{\beta}} U_n(p_g^0, R) h(\beta) d\beta$

where $\Pi(p_g^0)$ is the producer surplus; that is,

(38) $\Pi(p_g^0) \equiv \int_0^{p_g^0} S(p) dp$

and the individual utility functions that enter aggregate consumer surplus are

(39) $U_g(p_g^0, R) = u - p_g^0 - \eta - a\beta$

(40) $U_n(p_g^0, R) = u - p_g^0 - \eta - \dfrac{\delta + \sigma}{F(R)} - a\beta\bar{s}(R)$

where we have used the arbitrage equilibrium relations $p_n^0 = p_g^0 + \delta$, $p_g^1 = p_g^0 + \eta$, and

$p_n^1 = p_g^1 + (\delta + \sigma)/F(R)$. Let R^* denote the standard that maximizes the welfare function in

(37). Then R^* exists by virtue of Weierstrass's theorem,[21] and for an interior solution it satisfies

$\partial W(p_g^{0*}, R^*)/\partial R = 0$, where p_g^{0*} is the equilibrium price, which therefore must satisfy

$\partial W(p_g^{0*}, R^*)/\partial p_g^0 = 0$ [22].

　　　Differentiating the welfare function in equation (37), we obtain

(41) $\left. \dfrac{\partial W}{\partial p_g^0} \right|_{p_g^{0*}, R^*} = \Pi'(p_g^{0*}) - H\left(\dfrac{1}{a\bar{s}(R^*)} \left[u - p_g^{0*} - \eta - \dfrac{(\delta + \sigma)}{F(R^*)} \right] \right) = 0$

(42) $\left. \dfrac{\partial W}{\partial R} \right|_{p_g^{0*}, R^*} = \dfrac{f(R^*)}{F(R^*)} \int_{\hat{\beta}^*}^{\tilde{\beta}^*} \left(\dfrac{\delta + \sigma}{F(R^*)} - a\beta\left(R^* - \bar{s}(R^*) \right) \right) h(\beta)\, d\beta = 0$

where the limits of integration satisfy $\hat{\beta}^* = \hat{\beta}(R^*)$ and $\tilde{\beta}^* = \tilde{\beta}(R^*)$. Note that the condition in

(41) is equivalent to the equilibrium condition in (25) because Hotelling's lemma implies

$\Pi'(p_g^0) = S(p_g^0)$.

　　　It is possible to characterize this welfare-maximizing standard relative to the standard

R^{PS} that is optimal from the producers' perspective. In particular, we find the following.

Proposition 4. The welfare-maximizing regulatory level is such that $R^* > R^{PS}$. That is,

consumers prefer a more lax regulatory standard than do producers.

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[21] The problem involves the maximization of a continuous function defined over a compact set (the unit interval).

[22] Note that, for any given *R,* the competitive equilibrium price *minimizes* the sum of producer and consumer surplus, for reasons similar to those articulated in Smith (1963).

Proof. The condition for the welfare-maximizing optimal standard R^* in equation (42) can be rewritten as

$$(43) \quad J\left(R^*\right) \equiv \int_{\hat{\beta}^*}^{\tilde{\beta}^*} \left(\hat{\beta}(R^*)\left(1-\bar{s}(R^*)\right) - \beta\left(R^* - \bar{s}(R^*)\right) \right) h(\beta) d\beta = 0 .$$

Evaluating this function at the standard R^{ps} that maximizes producer surplus, which solves equation (36), we obtain

$$(44) \quad J\left(R^{ps}\right) \equiv \int_{\hat{\beta}}^{\tilde{\beta}} \left(\tilde{\beta}(R^{ps}) - \beta \right)\left(R^{ps} - \bar{s}(R^{ps})\right) h(\beta) d\beta > 0$$

where the limits of integration here are $\hat{\beta} = \hat{\beta}(R^{ps})$ and $\tilde{\beta} = \tilde{\beta}(R^{ps})$. This result, together with the fact that the sufficient conditions for welfare maximization require $J'\left(R^*\right) < 0$, establishes that $R^* > R^{ps}$. ∎

The fact that producers prefer a stricter standard than do consumers may be a bit surprising, especially in light of the fact that the regulation of GM labeling is commonly understood as a response to consumers' concerns. To a certain extent this result reflects the special features of the unit demand assumption that underlies the Mussa-Rosen model of demand for quality (but note that our result has been derived without any restriction on the distribution of consumer types).[23] Still, especially when considered along with our Proposition 1, the result in Proposition 4 does provide a further check on the simplistic approach that seems to underpin much of the discussion concerning GM labeling policies in the EU and elsewhere, whereby the observation that (some) consumers are averse to the presence of GM content in food is invoked to justify very strict regulations. But any reasonable analysis of this situation must grant the premise

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[23] Insofar as that is the case, the result is a reminder that the Mussa-Rosen model of differentiated demand remains a particular specification (albeit a very useful one) of a general class of preferences.

that consumers are really heterogeneous in their aversion to GM content, as reflected in the model that we have developed here. Hence, the notion of "consumers' welfare" in this setting is really about some "average" consumer. In particular, in moving from R^{ps} to R^*, not all consumers benefit from such a relaxation of the purity standards, although aggregate consumer surplus does increase.

The reason producers prefer a tighter standard than do consumers (on average) may be understood as follows. As previously discussed, an increase in R has two offsetting effects. It increases the number of lots accepted, as raising R lowers — by the same amount for everybody — the actual market price of the non-GM good. At the same time, this loosening of standards raises the expected GM content of approved goods, which hurts high β types the most. Since each person buys, at most, one unit, the producer wants to choose R to make the highest possible β type participate; thus, at R^{ps} the standard is chosen so that, for this highest participating type $\tilde{\beta}$, the two effects offset and therefore the "personalized" price for type $\tilde{\beta}$ is minimized. But this implies that *every* consumer of type $\beta \in (\hat{\beta}, \tilde{\beta})$ would benefit by an infinitesimal weakening of the standard; hence, $R^* > R^{ps}$. At the consumer optimum, a marginal increase in R would benefit some consumers and hurt others, so that average consumer surplus would be unchanged. At the welfare optimum, of course, aggregate consumer surplus is still increasing in R, while producer surplus is decreasing in R.

It is also useful to note that the result in Proposition 4 is distinct from a seemingly similar finding of the minimum quality standard literature, where it also emerges that a standard collectively set by producers may be too strict. That result actually reflects the exercise of monopoly power, whereby returns to producers may increase with reduced marketed quantities, and in such models one of the effects of a stricter standard is in fact that of reducing the quantity

supplied by producers (e.g., Leland, 1979). Here, by contrast, competitive conditions are maintained and producers supply both goods to the market.

Comparative Statics of Equilibrium

Having characterized the optimality conditions for the optimal purity standard, we wish to investigate how this level is affected by some of the model's critical parameters. To get unambiguous results, however, here we have to restrict the analysis by assuming that the distribution of consumer types $H(\beta)$ is uniform, which means that $h(\beta) = 1, \forall \beta \in [0,1]$.[24] Our findings are summarized in the following.

Proposition 5. Assuming uniform distribution of types, the welfare-maximizing purity standard R^* and equilibrium price p_g^{0*} satisfy the following comparative statics properties:

    (i) $\partial R^*/\partial\sigma > 0$ and $\partial p_g^{0*}/\partial\sigma < 0$;

    (ii) $\partial R^*/\partial\delta > 0$ and $\partial p_g^{0*}/\partial\delta < 0$;

    (iii) $\partial R^*/\partial a < 0$ and $\partial p_g^{0*}/\partial a < 0$;

    (iv) $\partial R^*/\partial u < 0$ and $\partial p_g^{0*}/\partial u > 0$; and

    (v) $\partial R^*/\partial\eta > 0$ and $\partial p_g^{0*}/\partial\eta < 0$.

Details of the proof are reported in the Appendix. Thus, the optimal purity level R^* should be sensitive to the costliness of the required segregation activities (even if, as in our formulation, the unit segregation cost σ is itself independent of the required purity level set by the government).

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[24] Whereas the assumption of uniform distribution of types is somewhat restrictive, it is routinely made in papers that study quality with the Mussa-Rosen setup (e.g., Scarpa, 1998; Valletti, 2000; Stivers, 2003; Fulton and Giannakas, 2004).

Specifically, as segregation becomes costlier (σ increases) the optimal impurity level R^* increases (and the equilibrium farm price declines). Exactly the same qualitative effects apply to an increase in the size of the efficiency gains due to the GM innovation (an increase in δ). On the other hand, as the population of consumers becomes more averse to GM content (as measured by an increase in the parameter a), the optimal standard R^* should be tightened (and the equilibrium farm price is reduced because of the negative demand effect). An increase in the base willingness to pay for the two goods (the parameter u) obviously increases the equilibrium farm price and should also result in a tightening of the optimal standard R^*. This comparative statics effect is amenable to an interesting interpretation if we note that, in this context, the parameter u is inversely related to the (absolute) value of the elasticity of total demand. Hence, this result suggests that tighter purity standards (i.e., lower R^*) should be associated with foods that have a more inelastic demand. Finally, the comparative statics effect of the parameter η (the unit costs of marketing services) illustrates the intuitive conclusion that an increase in the cost of marketing depresses the equilibrium farm price and should also result in a laxer optimal standard R^*.

Concluding Remarks

In this paper we developed a framework of analysis for a critical economic issue that arises in the pursuit of a credible and enforceable system of IP and labeling for GM and non-GM products, namely, the setting of a standard for "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. Uncertainty is modeled explicitly, and the equilibrium solution includes a novel specification of the demand for (vertically) differentiated GM and non-GM products that is particularly useful in the stochastic framework of this paper.

The results of the model are quite interesting and showed that even in a competitive setting where agents have no scope for strategic behavior, government regulation of the labeling of GM products still presents a meaningful problem. We showed that there exists a welfare-maximizing standard for products that claim a non-GM status, and this welfare standard has intuitive comparative statics properties. In particular, the lack of any standard leads to a pooling equilibrium whereby only the GM product is produced, which is typically suboptimal from a welfare perspective. Similarly, a standard that is too strict (i.e., high purity of the non-GM product) may also lead to a collapse of the market for the non-GM product. In addition, we showed that the labeling standard that is optimal from society's viewpoint typically differs from the standard that would be preferred by farmers. Somewhat surprisingly, the standard that farmers would prefer is actually stricter than what society would find optimal.

Appendix — Proof of Proposition 5 (Comparative Statics Results)

With a uniform distribution of types $H(\beta) = \beta$, and thus in the uncovered market when both GM and non-GM products are produced, market demands are, respectively, $D_g = \hat{\beta}$ and $D_n = \tilde{\beta} - \hat{\beta}$, so that total demand is $D_T \equiv D_n + D_g = \tilde{\beta}$. Upon recalling the arbitrage relations of competitive equilibrium, that is,

$$p_n^0 = p_g^0 + \delta$$
$$p_g^1 = p_g^0 + \eta$$
$$\left(p_n^1 - p_g^1 \right) F(R) = \delta + \sigma$$

we have

$$\tilde{\beta}(R) \equiv \frac{u - p_g^0 - \eta - \dfrac{\delta + \sigma}{F(R)}}{a\overline{s}(R)}$$

$$\hat{\beta}(R) = \frac{\delta + \sigma}{aF(R)\left[1 - \overline{s}(R)\right]}.$$

In what follows we simplify notation and omit the functional dependence on R by writing $F(R) = F$, $f(R) = f$ and $\overline{s}(R) = \overline{s}$. Also, we define $k \equiv \delta + \sigma$, $A \equiv u - p_g^0 - \eta$, and $P \equiv p_g^0$, so that

$$\hat{\beta} = \frac{k}{Fa(1 - \overline{s})}$$

$$\tilde{\beta} = \frac{AF - k}{Fa\overline{s}}.$$

Aggregate consumer surplus here is $CS = \dfrac{1}{2}a\left[\tilde{\beta}^2 \overline{s} + \hat{\beta}^2 (1 - \overline{s}) \right]$. Substituting and simplifying obtains

$$CS = \frac{1}{2a}\left[\frac{\left(A - \dfrac{k}{F} \right)^2}{\overline{s}} + \frac{\left(\dfrac{k}{F} \right)^2}{(1 - \overline{s})} \right].$$

Hence, the welfare function is

$$W = \Pi(P) + \frac{1}{2a}\left[\frac{\left(A - \frac{k}{F}\right)^2}{\overline{s}} + \frac{\left(\frac{k}{F}\right)^2}{(1-\overline{s})}\right]$$

where $\Pi(P)$ is producer surplus. The optimality conditions for welfare maximization (yielding the optimal standard purity R^* and the competitive farm-level equilibrium price P^*) are

(45) $\quad W_P = \Pi'(P) - \dfrac{1}{a}\dfrac{\left(A - \frac{k}{F}\right)}{\overline{s}} = 0$

(46) $\quad W_R = \dfrac{1}{2a}\left[\dfrac{2\left(A - \frac{k}{F}\right)\frac{k}{F^2}f}{\overline{s}} - \dfrac{\left(A - \frac{k}{F}\right)^2}{\overline{s}^2}\dfrac{f}{F}(R - \overline{s}) - \dfrac{2\left(\frac{k}{F}\right)^2\frac{f}{F}}{(1-\overline{s})} + \dfrac{\left(\frac{k}{F}\right)^2}{(1-\overline{s})^2}\dfrac{f}{F}(R - \overline{s})\right] = 0.$

Upon substitution and simplification we obtain

(47)

$$W_R = \left(\frac{af}{2F}\right)(\tilde{\beta} - \hat{\beta})\left[\hat{\beta}\big((1-\overline{s}) + (1-R)\big) - \tilde{\beta}(R - \overline{s})\right] = 0 \rightarrow \left[\hat{\beta}\big((1-\overline{s}) + (1-R)\big) - \tilde{\beta}(R - \overline{s})\right] = 0.$$

Consider now the comparative statics effect of the parameter $k \equiv \sigma + \delta$. Differentiating the optimality conditions in (45) and (46) and expressing the results in matrix form yields

$$\begin{bmatrix} W_{RR} & W_{RP} \\ W_{PR} & W_{PP} \end{bmatrix}\begin{bmatrix} R_k \\ P_k \end{bmatrix} = \begin{bmatrix} -W_{Rk} \\ -W_{Pk} \end{bmatrix}.$$

Solving by Cramer's rule obtains

$$R_k = \frac{1}{\Delta}\begin{vmatrix} -W_{Rk} & W_{RP} \\ -W_{Pk} & W_{PP} \end{vmatrix} = \frac{-W_{Rk}W_{PP} + W_{Pk}W_{RP}}{\Delta}$$

$$P_k = \frac{1}{\Delta}\begin{vmatrix} W_{RR} & -W_{Rk} \\ W_{PR} & -W_{Pk} \end{vmatrix} = \frac{-W_{RR}W_{Pk} + W_{PR}W_{Rk}}{\Delta}$$

where $\Delta = \begin{vmatrix} W_{RR} & W_{RP} \\ W_{PR} & W_{PP} \end{vmatrix} < 0$, $W_{RR} < 0$ and $W_{PP} > 0$ by the second-order conditions of the welfare optimization problem (saddle point).

We now compute the partial effects that enter these comparative statics expressions. Differentiating the optimality conditions in (45) and (46) yields

$$W_{PR} = -\frac{1}{a}\frac{k}{F^2}\frac{f}{\overline{s}} + \frac{1}{a}\frac{\left(A - \dfrac{k}{F}\right)}{\overline{s}^2}\frac{f}{F}(R - \overline{s})$$

which can be simplified to

$$W_{PR} = \frac{f}{F\overline{s}}\left[-\hat{\beta}(1-\overline{s}) + \tilde{\beta}(R-\overline{s})\right].$$

Evaluating this partial effect at the optimality conditions, such that (47) holds, we obtain

$$W_{PR} = \frac{f}{F\overline{s}}\hat{\beta}(1-R) \quad > 0.$$

Next, differentiating (45) we find

$$W_{Pk} = \frac{1}{aF\overline{s}} > 0.$$

And differentiating (46) we obtain

$$W_{Rk} = \frac{1}{a}\left[-\frac{kf}{F^3\overline{s}} + \left(A - \frac{k}{F}\right)\frac{1}{\left(F\overline{s}\right)^2}\left(f\overline{s} + f(R-\overline{s})\right) - \frac{k}{F^3}\frac{f}{(1-\overline{s})} + \frac{k}{F^2}\frac{1}{(1-\overline{s})^2}\frac{f}{F}(R-\overline{s})\right]$$

which simplifies to

$$W_{Rk} = \frac{f}{F^2}\frac{1}{\overline{s}(1-\overline{s})}\left[\tilde{\beta}R(1-\overline{s}) - \hat{\beta}\left((1-\overline{s})^2 + \overline{s}(1-R)\right)\right].$$

Evaluating this partial effect at the optimality conditions, such that (47) holds, we obtain

$$W_{kR} = \frac{f}{F^2}\frac{1}{\overline{s}(1-\overline{s})}\hat{\beta}\left[\frac{(1-R)\left[R(1-\overline{s}) - \overline{s}(R-\overline{s})\right] + \overline{s}(1-\overline{s})^2}{(R-\overline{s})}\right].$$

Thus, a sufficient condition for $W_{kR} > 0$ is $R(1-\overline{s}) \ge \overline{s}(R-\overline{s})$, which does hold because $R \ge \overline{s}$ and $R \le 1$. Hence, we conclude that $W_{kR} > 0$.

The foregoing partial effects allow us to sign the comparative statics effect on farm price:

$$P_k = \frac{W_{RR}W_{Pk} - W_{PR}W_{Rk}}{-\Delta} < 0.$$

But $sign(R_k) = sign(W_{Rk}W_{PP} - W_{Pk}W_{RP})$. Note that

$$W_{PP} = \Pi''(p_g^0) + \frac{1}{a\bar{s}}.$$

Because $\Pi''(p_g^0) = S'(p_g^0) > 0$ (the profit function is convex) and $W_{Rk} > 0$, to conclude that $R_k > 0$ it suffices to show that $Z \equiv W_{Rk} \frac{1}{a\bar{s}} - W_{Pk} W_{RP} \geq 0$. From earlier derivations,

$$Z \equiv \frac{f}{F^2} \frac{1}{\bar{s}(1-\bar{s})} \hat{\beta} \left[\frac{(1-R)[R(1-\bar{s}) - \bar{s}(R-\bar{s})] + \bar{s}(1-\bar{s})^2}{(R-\bar{s})} \right] \frac{1}{a\bar{s}} - \frac{1}{aF\bar{s}} \frac{f}{F\bar{s}} \hat{\beta}(1-R)$$

which can be simplified to yield

$$Z = \frac{1}{a} \frac{f}{F^2} \frac{1}{\bar{s}^2(1-\bar{s})} \hat{\beta} \left[\frac{\bar{s}(1-R)^2 + \bar{s}(1-\bar{s})^2}{(R-\bar{s})} \right] > 0$$

and so we can conclude that $R_k > 0$. Recalling that $k \equiv \delta + \sigma$, we have therefore established parts (i) and (ii) of Proposition 4.

The comparative statics analysis for the parameter k is readily adapted to the comparative statics of the "GM aversion" parameter a. Specifically,

$$R_a = \frac{W_{Ra} W_{PP} - W_{Pa} W_{RP}}{-\Delta}$$

$$P_a = \frac{W_{RR} W_{Pa} - W_{PR} W_{Ra}}{-\Delta}.$$

The partial effects of interest here are

$$W_{Pa} = \frac{1}{a^2 F\bar{s}} (AF - k) = \frac{1}{a} \tilde{\beta} > 0$$

$$W_{Ra} = -\frac{1}{a} W_R = 0$$

and so we find

$$P_a = \frac{W_{RR} W_{Pa}}{-\Delta} < 0$$

$$R_a = \frac{-W_{Pa} W_{RP}}{-\Delta} < 0$$

which establishes part (iii) of Proposition 4.

Finally, concerning the parameters u and η, we note that they enter the problem only through the term $A \equiv u - p_g^0 - \eta$. For the comparative statics of this term we have

$$R_A = \frac{W_{RA}W_{PP} - W_{PA}W_{RP}}{-\Delta}$$

$$P_A = \frac{W_{RR}W_{PA} - W_{PR}W_{RA}}{-\Delta}.$$

The partial effects of interest here are

$$W_{PA} = -\frac{1}{a\bar{s}} < 0$$

and $W_{RA} < 0$ because $W_{RA} = -W_{PR}$ and we showed earlier that $W_{PR} > 0$. Thus we can immediately conclude that $P_A > 0$. The sign of R_A is the sign of $Z \equiv (W_{RA}W_{PP} - W_{PA}W_{RP})$. By using $W_{RA} = -W_{PR}$ we find $Z \equiv W_{RA}(W_{PP} + W_{PA})$, and by noting that $W_{PP} = \Pi''(p_g^0) - W_{PA}$ we get $Z \equiv W_{RA}\Pi''(p_g^0) < 0$, and so we conclude that $R_A < 0$. Recalling again that $A \equiv u - p_g^0 - \eta$, this concludes the comparative statics of parameters u and η (part (iv) of Proposition 5).

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Figure 1. Heterogeneous preferences for quality and unit demand