Chapter 1

LABELING REGULATIONS AND SEGREGATION OF FIRST- AND SECOND-GENERATION GM PRODUCTS: INNOVATION INCENTIVES AND WELFARE EFFECTS

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Abstract: We review some of the most significant issues and results on the economic effects of genetically modified (GM) product innovation, with emphasis on the question of GM labeling and the need for costly segregation and identity preservation activities. The analysis is organized around an explicit model that can accommodate the features of both first-generation and second-generation GM products. The model accounts for the proprietary nature of GM innovations and for the critical role of consumer preferences vis-à-vis GM products, as well as for the impacts of segregation and identity preservation and the effects of a mandatory GM labeling regulation. We also investigate briefly a novel question in this setting, the choice of "research direction" when both cost-reducing and quality-enhancing GM innovations are feasible.

Key words: identity preservation, labeling, market failure, product differentiation, welfare

1. INTRODUCTION

The first nine years of genetically modified (GM) crops, since their introduction in 1996, have been a mixed success. Adoption has been fast and extensive by any standard, reaching a worldwide area of 200 million acres in 2004 (James 2005). But large-scale adoption has been confined to a handful of countries,[1] and, perhaps most important, the advent of GM crops has met

[1]The United States, Argentina, Brazil, Canada, and China accounted for about 96 percent of total GM crop cultivation in 2004 (James 2005).

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with considerable public opposition and a flurry of new restrictive regulations. In the European Union (EU), in particular, the initial laissez-faire attitude, which allowed several GM products to be approved, was reversed in 1998 with the introduction of a *de facto* moratorium on new GM products. Only in 2004 did progress appear with the unveiling of a new and extensive framework for GM approvals and marketing. Ostensibly meant to foster food safety, protect the environment, and ensure consumers' "right to know," the new (and already controversial) system is centered on the notions of mandatory GM labeling and traceability (European Union 2004). Meanwhile, the strain that the EU moratorium and GM regulations can have on trade has become apparent (Lapan and Moschini 2001, Sheldon 2002) and the prospects for its resolution are rather uncertain. A central question, it seems, concerns the economic effects of the GM product innovation, including both intended and unintended effects.

Assessing the economic implications of the introduction of GM products continues to be a challenging endeavor. It has become clear over time that a critical element of this new technology concerns consumers' acceptance. A portion of consumers clearly has a negative perception of food produced from GM products, at least based on what one can conclude from consumer surveys (e.g., Gaskell, Allum, and Stares 2003) and experimental results (e.g., Huffman et al. 2003; Noussair, Robin, and Ruffieux 2004). Furthermore, the first generation of GM crops, characterized by agronomic traits such as herbicide resistance and pest resistance, offered no direct benefit to consumers. Hence, from a consumer perspective, GM innovation has produced what Lapan and Moschini (2004) call "weakly inferior" substitutes. The fact that GM food is not a perfect substitute for conventional food per se simply implies a smaller potential market for the new GM products. But the introduction of first-generation GM crops means that, to deliver traditional GM-free food, additional costs must be incurred (relative to the pre-innovation situation). That is, costly (and hitherto unnecessary) segregation and identity preservation activities are required. Essentially, therefore, the GM innovation process has also introduced a new market failure, a type of externality on the production of traditional food products (Lapan and Moschini 2001).

Consumer acceptance is likely to be different for GM products that offer output traits of direct interest to end users, such as improved nutritional content (e.g., increased vitamin content, as in the widely publicized "golden rice"). This defines so-called second-generation GM products (Pew Initiative on Food and Biotechnology 2001). But whereas the attribute of the innovation may be of interest, per se, to consumers, the fact remains that the GM nature of the innovation is likely to continue to play a role in consumer acceptance. Hence, a sound economic assessment of the effects of GM product innovation needs to address directly the question of consumer preferences

and how these interact with the nature of the market failure discussed in the foregoing.

In this chapter we propose to review some of the most significant issues and studies that have dealt with the economic effects of GM product innovation. We will pay particular attention to the question of GM labeling and its relation to the need for costly segregation and identity preservation activities. To organize some of the main findings to date, we develop an explicit, simple model that can accommodate the features of both so-called first-generation and second-generation GM products. This model explicitly accounts for the effects of consumer preferences vis-à-vis GM products, as well as for the distinct impacts of segregation and identity preservation, and the effects of an EU-style GM labeling regulation. We also investigate briefly a novel question in this setting, specifically, the choice of "research direction" when both cost-reducing and quality-enhancing GM innovations are feasible.

2. THE ECONOMICS OF LABELING

Much has been written on the scope, merit, and effects of food labeling regulations.[2] An important distinction, for our purposes, is between "voluntary labeling" and "mandatory labeling." Voluntary labeling strategies naturally arise as firms compete in the marketplace and try to differentiate their products from those of competitors. The underlying assumption is that firms' products are in fact differentiated (in some dimension) and that consumers may value a product's specific attributes that labeling emphasizes. Here it is assumed that firms have some information that may be useful to consumers, that such attributes are not easily observable by consumers prior to the purchase, and that a label can credibly disclose the information about the "quality" of the good that consumers desire. Thus one is dealing with "experience goods" or "credence goods," rather than "search goods."[3] An issue that arises in this setting is whether firms disclose truthful information and whether they disclose all of the information. For positive attributes it is obviously in the strategic interest of firms to disclose the information, but more generally Grossman (1981) shows that, when consumers make rational inferences and assume that undisclosed attributes are of the worst possible quality, there is a powerful market incentive for full disclosure of information. The credibility of voluntary labeling can be enhanced by third-party services (producer associations, consumer groups, governments) that may supply standards, testing services, and certification.

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[2] Golan, Kuchler, and Mitchell (2001) provide a useful introduction and a review of the literature.

[3] See Tirole (1988, chapter 2) for definitions and an introduction.

Mandatory labeling is typically harder to justify on economic grounds, for a number of reasons. The presumption again is that there is asymmetric information: firms know something that consumers do not, and the latter would benefit from disclosure. But to advocate mandatory disclosure, one has to postulate that firms would not reveal the information without government intervention. Thus one must assume that various forms of "screening" or "signaling" that are feasible in the marketplace do not yield a desirable outcome in this setting. Often there may be much better policy tools, depending on the specific situation (bans, production standards, etc.).

2.1. Labeling of GM Products: Segregation and Identity Preservation

Some general issues concerning biotech labeling are discussed by Teisl and Caswell (2003) and Golan, Kuchler, and Mitchell (2001). One recurrent hypothesis, in discussions of GM food labeling, is that the good in question is a pure "credence good," whereby the true attribute of interest to the consumer cannot be observed after consumption. Many studies uncritically presume that non-GM goods in this case are credence goods, and that is taken as sufficient evidence of a market failure to warrant government intervention. But, arguably, GM products are not really prototypical "credence goods." It is in fact possible to uncover the nature of the product by "testing." Testing could be done by organizations, rather than by individuals, and need not be systematic: not every unit needs to be tested insofar as the outcome of testing can implicate a "brand."[4]

The presumption of "asymmetric" information (between firms and consumers) may oversimplify the issue as well in the context of GM labeling. Unlike Akerlof's (1970) classic problem, here the relevant information of interest to the consumer (i.e., the non-GM nature of the superior product) needs to be "produced" (by costly segregation, identity preservation, and systematic testing). Thus, in this context it is critical to distinguish between the "information" that needs to be created to supply consumers with a meaningful choice and the actual information disclosed by a label.

Segregation and identity preservation systems are sometimes held to mean different things, the latter entailing a higher degree of traceability for instance (e.g., Smyth and Phillips 2002). Here, however, there is no point in separating these concepts, and thus we will think of a segregation and identity preservation (SIP) system as the set of production, handling, processing, and

[4] The StarLink case is a good example. Traces of an unapproved (for human consumption) GM maize were found in taco shells sold in U.S. grocery stores by tests carried out by an independent lab on behalf of a coalition of consumer and environmental organizations, prompting Kraft Foods to recall 2.5 million boxes of Taco Bell brand taco shells. See Taylor and Tick (2003) for more details and a complete chronology of the StarLink case, and for a discussion of related regulatory issues.

distribution practices that maintain the purity of the good under consideration. To ensure the non-GM nature of the product, various costly activities need to be undertaken at various stages of the vertical production chain, from "farm to fork." Such activities may involve the need for seed of an appropriate degree of purity, isolation measures at the growing stage to prevent cross-pollination, clean and/or dedicated equipment for planting and harvesting, clean and/or dedicated storage and transportation facilities, segregated handling and processing facilities, and so on. In addition, of course, record keeping and multiple testing at various stages may be necessary (Bullock and Desquilbet 2002, Sundstrom et al. 2002).

The nature of such SIP activities has direct implications for the working of a GM labeling system. In some sense it is true that, because of the binary nature of the information (a product either is or is not GM), both positive and negative labels, when present, should convey the same information to consumers. But one cannot ignore the SIP costs that are necessary for the label "non-GM," or the absence of a label "GM," to be meaningful or credible in this setting. In particular, it is clear that simply requiring that GM products identify themselves as such by an EU-type mandatory labeling requirement does not diminish the costly segregation activities that are required by the suppliers of the (unlabeled) non-GM product.

Golan, Kuchler, and Mitchell (2001) conclude that the potential of GM labeling for the purpose of addressing problems of missing or asymmetric information is limited. The question of the appropriate type of GM labeling was also discussed by Runge and Jackson (2000) in the context of a choice between "positive labeling" (e.g., this product contains GM organisms) and "negative labeling" (e.g., this product does not contain GM organisms). Crespi and Marette (2003) contrast some of the implications of voluntary and mandatory labeling regimes but neglect to consider explicitly SIP costs. As emphasized by Lapan and Moschini (2001), it is critical to understand the incentive-compatibility requirements of alternative labeling systems. The first generation of GM products essentially confers no attribute that is directly desirable from the consumers' point of view. Hence a positive labeling for first-generation GM products would need to be mandatory, whereas a negative labeling system in this setting could be voluntary. But either labeling system, to be credible, must impose SIP costs on the non-GM good. An explicit two-country trade model with costly SIP and GM labeling is developed by Lapan and Moschini (2001, 2004), where mandatory GM labeling is taken as adding costs to GM producers without detracting from SIP costs incurred by non-GM suppliers. Fulton and Giannakas (2004) analyze labeling and no-labeling regimes, with IP costs impacting the marketing margin for the non-GM product (but with no differentiation between voluntary and mandatory labeling systems).

2.2. The New GM Labeling and Traceability Rules in the European Union

Whereas many countries are introducing GM labeling requirements (Carter and Gruère 2003), the sweeping nature of EU rules deserves special attention. Since April 2004, GM food and feed in the EU have been regulated under Regulation (EC) No. 1829/2003 "on genetically modified food and feed." This framework provides for a single EU procedure for the authorization of all food and feed derived from GM products and of GM products themselves. Furthermore, since April 2004, products consisting of or containing GM organisms and food products obtained from GM organisms have been also subject to traceability and labeling requirements, as established in Regulation (EC) 1830/2003 "concerning the traceability and labeling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC" (European Union 2004).

The EU "mandatory labeling" of GM products specifically requires that all pre-packaged products consisting of or containing (authorized) GM material and food products produced from GM products must carry a label stating that "This product contains genetically modified organisms" or "This product contains genetically modified [name of organism(s)]." In the case of non-prepackaged products (such as food offered by restaurants), these words must appear with the display of the product. GM foods must be labeled regardless of whether or not DNA or proteins derived from genetic modification are contained in the final product, and thus the GM labeling requirement also pertains to highly refined products (e.g., vegetable oil). The same labeling rules apply to animal feed, including any compound feed that contains GM products (e.g., soybeans or maize) or that is derived from GM products (e.g., corn gluten feed).

The mandate of "traceability" states that all persons who place a GM product on the market or receive a GM product placed on the market within the EU must be able to identify their supplier and the companies to which the products have been supplied. Operators handling GM product must transmit in writing to those receiving the product information to the effect that the product in question is of GM origin, and the unique identifier(s) assigned to those GM products. Operators must hold the information for a period of five years from each transaction and be able to identify the operator by whom and to whom the products have been made available. The regulation covers all GM products that have received EU authorization for their placing on the market, including previously authorized GM product transacted in bulk quantities (e.g., soybean and maize).

Exemption from the requirement of GM labeling and traceability includes products obtained from animals fed with genetically modified feed

(e.g., meat, milk, or eggs). Conventional products are also not subject to traceability and labeling. Conventional products that are accidentally contaminated by GM products must carry the GM label only if the (authorized) GMO content exceeds 0.9 percent, provided the presence of this material is adventitious or technically unavoidable. In this case, operators must be able to demonstrate that they have taken adequate measures to avoid the presence of GM material.[5]

To summarize, it seems clear that the new EU rules impose substantial costs on the suppliers of GM products. In order to fulfill the traceability requirements, for instance, each operator must have in place an information system capable of documenting for public authorities, on demand, each transaction that took place for the last five years. For example, a company selling GM seed would have to inform buyers that the seed is genetically modified and provide more information so the specific GMO can be precisely identified. The company is also obliged to keep a register of business operators who have bought the seed. The farmer would have to inform any purchaser of the harvest that the product is GM and keep a register of operators to whom he has made the harvest available. Downstream handlers and processors also need to undertake similar steps as they carry out market transactions that involve GM products. As noted by Buckwell, Brookes, and Bradley (1999), a critical element determining the cost of SIP activities is the purity threshold level that is sought; the 0.9 percent level prescribed by EU rules appears to be very strict.

The mandatory nature of the EU system is in sharp contrast with the regulatory approach pursued in the United States, where at most a voluntary GM labeling system can be envisioned (U.S. Food and Drug Administration 2001). What is unclear is whether, by mandating explicit disclosure of everything GM that goes through the system, the EU rules may in fact decrease somewhat the implementation of an SIP system for non-GM products. Many of the real costs of such an SIP system would seem to be unaffected. Thus, to a first approximation at least, we will construe the new rules as (i) increasing the cost of supplying GM products, and (ii) leaving unchanged the SIP costs of supplying non-GM products. Finally we will note that at this point it is unclear what sort of monitoring system will be in place to enforce the new EU system. That this may be a challenging task is apparent, for example, when one notes that the mandatory disclosure for highly refined products (e.g., vegetable oils) appears to be an open invitation to cheat.

[5] The presence of GM products that are not yet approved in the EU, but which have received a favorable scientific assessment, is tolerated up to the stricter threshold of 0.5 percent (marketing of products with more than 0.5 percent of such material is prohibited).

3. THE MODEL

The simple model we develop here captures the main economic elements of interest and, in fact, can accommodate the features of both first-generation and second-generation GM innovations. The pre-innovation situation is characterized by a conventional product that is supplied competitively. We simplify the analysis substantially here by considering a constant-returns-to-scale industry. Whereas this assumption may be consistent with an individual (small) agricultural industry, it clearly cannot apply to the agricultural sector as a whole (because of the inelastic supply of land, for example), so a generalization of the setup to an increasing-cost industry (as in Lapan and Moschini 2004, for example) is desirable. But with our simplifying assumption, the pre-innovation conventional product is assumed to be produced with a constant unit production cost equal to c. This conventional product also has a given quality, and without loss of generality we normalize that quality to equal unity.

In this framework, a GM innovation can work in two directions: it can increase efficiency by reducing the unit production cost c and/or it can increase the quality level of the product. The first type of efficiency-enhancing innovations characterizes the so-called first-generation GM products, which embody agronomic traits such as herbicide-resistant soybeans and cotton, and Bt maize and cotton (for example).[6] An increase in the quality of the product, on the other hand, is what so-called second-generation GM products are attempting to do (Pew Initiative on Food and Biotechnology 2001). For such products the attribute contributed by GM innovation is of direct interest to the user of the product, such as improved nutritional content (e.g., increased vitamin content, as in the widely publicized "golden rice").

Specifically, a given GM innovation (labeled by the subscript i) is modeled as decreasing unit cost from c to $c - a_i$ and increasing quality from 1 to $1 + b_i$. Of course, the polar cases of a pure first-generation GM product ($b_i = 0$) and a pure second-generation GM product ($a_i = 0$) are readily encompassed by this framework. The pre-innovation conventional product and the potential new GM product are illustrated in Figure 1.

3.1. Preferences

Consumers are assumed to have heterogeneous preferences with respect to the new product. Following Mussa and Rosen (1978), we represent individual preferences through a simplified vertical product differentiation model (see also Tirole 1988, chapter 7). Specifically, the individual consumer with

[6] Some of these innovations may be better thought of as increasing expected yields (e.g., Bt maize). But given our constant unit cost assumption, by duality an increase in yield is fully equivalent to a decrease in unit cost.

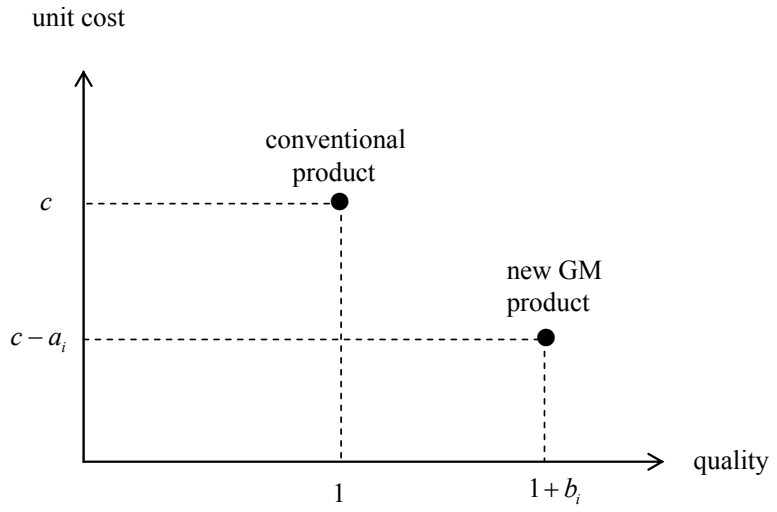

Figure 1. A GM Innovation Combining Efficiency Enhancement and Quality Improvement

preference parameter $\theta \in [0,1]$ obtains the following utility levels by consuming the two possible products:

$V_0 = u - p_0$ if the consumer buys one unit of conventional product, (1)

$V_i = (1 + b_i)u - \theta\delta - p_i$ if the consumer buys one unit of GM product, (2)

where $u > 0$ is the utility of a unit of conventional product, $b_i \geq 0$ is the quality augmentation parameter of the GM product discussed earlier, and $\delta > 0$ is the maximum disutility of a unit of GM product (for the consumers with $\theta = 1$). The prices of non-GM and GM products are denoted p_0 and p_i, respectively. Consumer differences vis-à-vis GM product acceptance is captured by postulating that the parameter θ, in the population of consumers, is distributed on [0,1] with a distribution function $F(\theta)$. A direct interpretation of equation (2) is that consumers all place the same value on the quality enhancement but have different disutility from the GM attribute. In any event, what formulation (2) maintains is that, *ceteris paribus*, consumers dislike the GM nature of the product irrespective of whether the GM innovation is of the first or second generation type.[7]

[7] Note that this formulation can capture the opposition to GM products that arises because of perceived shortcomings that are directly borne by the individual (such as, for example, the

3.2. Segregation and Identity Preservation

In the post-innovation situation, after a GM product has been introduced, SIP costs are necessary for the conventional non-GM product to be sold as such to consumers. Some SIP activities are also necessary for the quality-improved product to retain enough purity of its valuable character (Bender et al. 1999). We model such costs by a constant unit segregation cost undertaken by the non-GM product (s_i) and by the GM-product (σ_i). Of course, when the GM product is a first-generation product, with $b_i = 0$, no segregation cost is required for the GM product (i.e., in that case $\sigma_i = 0$).

Furthermore, we wish to account for the additional costs of a system of mandatory GM labeling and GM traceability such as the one implemented by the European Union. This additional burden is represented by the unit cost t_i that must be incurred by the GM product (as in Lapan and Moschini 2004). Because the suppliers of a pure first-generation product (with $b_i = 0$) have no incentive to do any segregation at all, for such a producer the EU regulations can be seen as adding a new additional cost. For the suppliers of a second-generation good, on the other hand, some of the activities required by the EU rules are likely to be undertaken voluntarily as part of the effort to capture the additional value of the innovation.[8]

3.3. Innovating Firm

Assuming that the GM product is fully protected by appropriate intellectual property rights (a patent, for example), the innovator has a temporary monopoly that allows it to profit from the innovation (Moschini and Lapan 1997). Because we have assumed a constant-returns-to-scale agricultural industry, it is not necessary that we explicitly model the innovation adoption by farmers. Instead, we can think of the innovator as producing the GM product directly and selling it to final users.

The demand for the innovation can be derived from the preference structure that was postulated. To this end, we postulate that the individual preference parameter θ, in the population of consumers, is distributed on [0,1] with a distribution function $F(\theta)$. The distribution function $F(\theta)$ is assumed to be strictly increasing and twice differentiable. We also assume that u is large enough to have a "covered market" outcome such that all consumers buy one

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risk of an adverse health effect). But in this setting what consumers may also care about could be a "public good"—e.g., the environmental implications of GM products. Arguably, such concerns would not be reflected in the willingness to pay displayed by private consumption decisions.

[8] Thus we may want to think of such costs as being related to the quality of the innovation, i.e., $t_i = t_i(b_i) \geq 0$, with $t_i'(b_i) \leq 0$, but in this chapter we will not pursue this hypothesis further.

unit of the good (either conventional or GM product). From our consumer preference specification, an individual with preference parameter θ will buy the GM product if and only if $V_0 \le V_i$, which requires that

$$u - p_0 \le u(1+b_i) - \theta\delta - p_i \quad \Leftrightarrow \quad \theta \le \frac{ub_i - p_i + p_0}{\delta} \equiv \hat{\theta}_i \,. \tag{3}$$

At given prices p_i and p_0, the quantity of GM product sold on the market is $Q_i = NF(\hat{\theta}_i)$, where N is the market size (e.g., the number of consumers). Without loss of generality, we can normalize the market size and put $N = 1$. Given that, the profit of the GM innovator is

$$\pi_i \equiv F(\hat{\theta}_i)\cdot\left(p_i - (c - a_i) - \sigma_i - t_i\right). \tag{4}$$

Noting that from (3) we can write $\hat{\theta}_i\delta \equiv ub_i - p_i + p_0$, and putting $p_0 = c + s_i$ as dictated by the assumed competitive conditions for the farm sector, the innovator's profit maximization problem can be stated as

$$\max_{\hat{\theta}_i} \quad \pi_i = F(\hat{\theta}_i)\left(r_i - \delta\hat{\theta}_i\right), \tag{5}$$

where we have used the definition $r_i \equiv ub_i + a_i + s_i - \sigma_i - t_i$.

4. RESULTS

The simple model outlined in the foregoing permits us to derive some important conclusions. The optimality condition for the program in (5), for an interior solution $0 < \hat{\theta}_i^* < 1$, is[9]

$$f(\hat{\theta}_i^*)\cdot\left(r_i - \delta\hat{\theta}_i^*\right) - \delta F(\hat{\theta}_i^*) = 0\,, \tag{6}$$

where $f(\theta) \equiv F'(\theta)$ denotes the density function of the distribution of consumer types. The second-order sufficient condition for an interior solution is

$$-\delta\cdot\left[1 + \frac{d}{d\theta}\left(\frac{F(\hat{\theta}_i^*)}{f(\hat{\theta}_i^*)}\right)\right] < 0\,. \tag{7}$$

[9] An interior solution is guaranteed if $0 < r_i < (1 + 1/f(1))\delta$.

Thus, a sufficient condition that guarantees that (7) holds is

$$\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right) \geq 0 . \tag{8}$$

This condition that the ratio $F(\theta)/f(\theta)$ is nondecreasing, sometimes referred to as the "monotone hazard rate property," is often invoked in the mechanism design literature (e.g., Laffont and Tirole 1993, chapter 1) and it is satisfied if the distribution function $F(\theta)$ is log-concave, a property enjoyed by most commonly used distributions (such as the uniform, the exponential, and the normal). The condition in (8) will be assumed to hold from this point onward.

Given the optimality condition in (6), the maximized profit of the innovator is

$$\pi_i^* \equiv F(\hat{\theta}_i^*) \cdot \left(r_i - \delta\hat{\theta}_i^*\right) = \frac{\delta \cdot \left[F(\hat{\theta}_i^*)\right]^2}{f(\hat{\theta}_i^*)} . \tag{9}$$

From the optimality condition in equation (6), and given that the condition in (8) holds, it follows that

$$\frac{\partial\hat{\theta}_i^*}{\partial r_i} \geq 0 \quad \text{and} \quad \frac{\partial\hat{\theta}_i^*}{\partial\delta} \leq 0 . \tag{10}$$

Recalling the definition $r_i \equiv ub_i + a_i + s_i - \sigma_i - t_i$, the comparative statics results in (10) immediately establish the behavior of the adoption rate with respect to the parameters of the problem. Furthermore, from (9), sign $(\partial\pi_i^*/\partial r_i) =$ sign $(\partial\hat{\theta}_i^* / \partial r)$ if the monotone hazard rate condition in (8) holds. Hence, we can conclude the following:

Result 1. Adoption of the GM product, and the profit of the innovator, are (i) an increasing function of the quality improvement b_i and of the efficiency gain a_i; (ii) a decreasing function of the consumer GM disutility parameter δ; (iii) inversely related to the (GM product) segregation cost σ_i and directly related to the (conventional product) segregation cost s_i; and (iv) inversely related to the "regulation cost" t_i.

This result clearly summarizes some of the main features of GM product innovation. Both quality improvements and efficiency gains can further GM product adoption and provide profit incentives for innovators. Segregation

costs—unnecessary in the pre-innovation situation but critically necessary in the post-GM innovation case—play a significant and subtle role. In particular, segregation costs that have to be borne by GM producers discourage adoption, but the extent of the segregation costs that have to be incurred by the producers of the conventional product to supply non-GM product has a positive impact on GM crop adoption and innovators' profit.

4.1. Welfare

For a GM innovation characterized by the cost-decreasing parameter a_i and the quality-increasing parameter b_i, if W_0 represents the level of welfare prior to the innovation and W_i represents the welfare after the innovation, for a given adoption level $\hat{\theta}$ we have

$$W_0 = u - c \tag{11}$$

$$W_i = \left(u - c - s_i\right)\left(1 - F(\hat{\theta})\right) + \int_0^{\hat{\theta}} \left(u(1+b_i) - c + a_i - \sigma_i - t_i - \theta\delta\right) dF(\theta)\,. \tag{12}$$

Evaluating the latter at the innovator's profit-maximizing solution $\hat{\theta} = \hat{\theta}_i^*$ we obtain

$$W_i^* = \left(u - c - s_i\right) + H(\hat{\theta}^*) + \pi_i^*, \tag{13}$$

where π_i^* is given by equation (9) and $H(\hat{\theta}_i^*) \equiv \int_0^{\hat{\theta}_i^*} \delta(\hat{\theta}_i^* - \theta) dF(\theta)$. From (11) to (13) we therefore obtain

$$W_i^* - W_0 = -s_i + H(\hat{\theta}^*) + \pi_i^*. \tag{14}$$

Hence, we have the following:

Result 2. For negligible segregation cost for the non-GM product (i.e., $s_i \to 0$) the GM innovation is welfare-increasing. For a given disutility parameter $\delta > 0$, however, the need for segregation costs may entail that the GM innovation decreases welfare.

The first part of Result 2 follows from the observation that $H(\hat{\theta}_i^*) > 0$ and $\pi_i^* > 0$ whenever $\hat{\theta}_i^* > 0$. To see the second part of Result 2 it suffices to observe the behavior of the welfare function for low equilibrium adoption rates: because $H(\hat{\theta}_i^*) \to 0$ and $\pi_i^* \to 0$ whenever $\hat{\theta}_i^* \to 0$, then $(W_i^* - W_0) \to -s_i < 0$

as $\hat{\theta}_i^* \to 0$. But it should be clear that welfare can be decreased by the innovation even for large adoption rates. Indeed, note that if s_i is large enough we obtain the corner solution with $\hat{\theta}_i^* = 1$. Specifically, complete adoption obtains when $r_i/\delta \geq 1 + 1/f(1)$. And with complete adoption the equilibrium welfare is

$$W_i^* = (u - c - s_i) + \pi_i^* + \int_0^1 \delta(1-\theta) dF(\theta). \tag{15}$$

Given that in this corner solution case we have $\pi_i^* = r - \delta$, and recalling that $r_i \equiv ub_i + a_i + s_i - \sigma_i - t_i$, the condition

$$\delta\left(1 + 1/f(1)\right) \leq \left(ub_i + a_i + s_i - \sigma_i - t_i\right) < s_i + \delta\int_0^1 \theta dF(\theta) \tag{16}$$

would ensure both a corner solution with complete adoption and the decreased welfare result $W_i^* < W_0$.

Thus, Result 2 displays the conclusion that an efficiency-enhancing (or quality-enhancing) innovation may turn out to be welfare-decreasing because it brings about a novel market failure, a type of externality (i.e., the need for hitherto unnecessary SIP activities for the pre-existing non-GM product to be available as such to consumers).[10]

Moving on to analyze the impact of an EU-style mandatory labeling regime, note that, because $\partial\hat{\theta}_i^*/\partial t_i < 0$ and $\partial\pi_i^*/\partial t_i < 0$, from (13) it is clear that $\partial W_i^*/\partial t_i < 0$. Hence, we have the following:

Result 3. Taking for given that GM products are introduced, regulation that increases the cost of GM product marketing but does not affect the SIP costs for the non-GM product, such as the EU labeling and traceability requirements, reduces welfare.

Results 1 and 2 summarize conclusions that, in one form or another, have appeared in various studies that have attempted an assessment of the economic implications of the introduction of GM products. Earlier studies documented sizeable efficiency gains from new GM crops (e.g., Moschini, Lapan, and Sobolevsky 2000; Falck-Zepeda, Traxler, and Nelson 2000) but ignored the critical element of this new technology discussed in the introduction: consumer preferences and the inferior-substitute nature of first-generation GM products. Once the "unintended" economic effects of GM crop innova-

[10] The "market failure" is not an externality in the usual sense because—to a first approximation at least—it is the presence of GM products, not the extent of their cultivation, which is the problem (and thus it is essentially a nonconvexity of the aggregate production set).

tions are accounted for, the efficiency and welfare implications of first-generation GM products are ambiguous at best (e.g., Fulton and Giannakas 2004; Furtan, Gray, and Holzman 2003; Lapan and Moschini 2004; Sobolevsky, Moschini, and Lapan 2005). A version of Result 3 can be found in Lapan and Moschini (2004). None of these studies concerned the potential impact of second-generation GM products. The model that we have outlined provides a useful starting point in that direction.

4.2. Choice of Research Direction

Many a commentator has lamented the fact that input-trait GM products, which offered no direct benefit to the consumer, were the first and most visible output of the biotechnology industry. The (somewhat plausible but untested) presumption here is that, had output-trait GM product been marketed first, consumer acceptance would have been different. Whether or not that is true, there are technological reasons as to why the biotechnology industry went the way it did: input traits based on a single-gene transformation (such as Roundup Ready soybeans or Bt maize) are easier than the multiple-gene transformations often associated with quality improvements. But the question remains as to whether there are other explanations, and in particular whether the inherent market failure of GM innovation (the concomitant creation of the need for costly SIP) also had an effect.

To try to address this question in the context of our simple model, consider an innovator facing two possible innovations, a purely efficiency-enhancing innovation and a purely quality-enhancing innovation. Thus, $i = 1$ denotes a "first-generation" GM product, whereby $a_1 \equiv a > 0$ and $b_1 = 0$. Similarly, $i = 2$ denotes a "second-generation" GM product, whereby $a_2 = 0$ and $b_2 \equiv b > 0$. Figure 2 illustrates. Given this choice of research direction, we want to know what factors determine the choice of the innovators and whether the private choice of the innovating firm is consistent with the direction that maximizes social welfare.

Ex post, from the innovating firm's point of view, the first-generation (i.e., cost-reducing) innovation is more attractive if $\pi_1^* > \pi_2^*$. From equation (9) we have

$$\pi_1^* > \pi_2^* \quad \Leftrightarrow \quad \frac{\left[F(\hat{\theta}_1^*)\right]^2}{f(\hat{\theta}_1^*)} > \frac{\left[F(\hat{\theta}_2^*)\right]^2}{f(\hat{\theta}_2^*)}, \tag{17}$$

and thus, given that the monotone hazard rate condition in equation (8) holds, we can conclude that the innovation providing the highest profit to the innovator is the one that would attain the highest adoption rate (in the

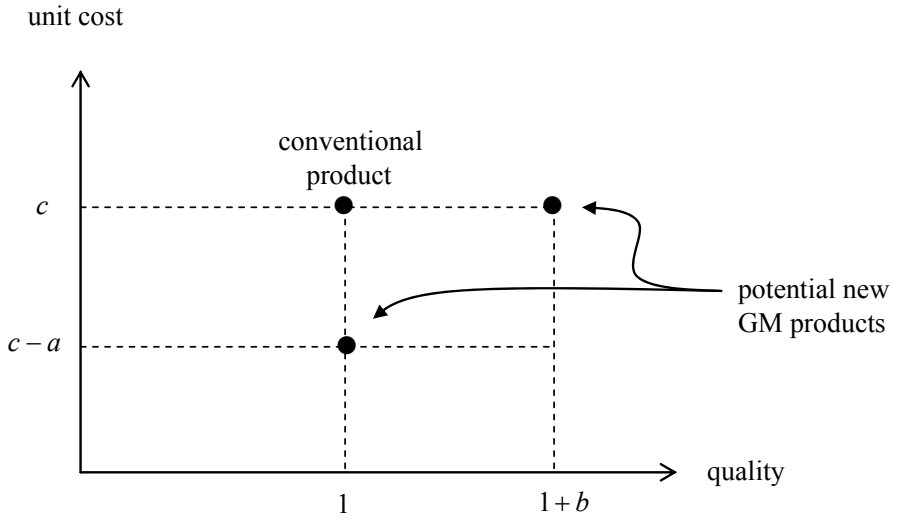

Figure 2. First-Generation and Second-Generation GM Products

monopoly pricing equilibrium); that is, $\pi_1^* > \pi_2^* \Leftrightarrow \hat{\theta}_1^* > \hat{\theta}_2^*$. Hence, given the choice between the two innovations, the condition for $\pi_1^* > \pi_2^*$ reduces to

$$a + s_1 - \sigma_1 - t_1 > ub + s_2 - \sigma_2 - t_2 \Leftrightarrow a - ub > (s_2 - s_1) - (\sigma_2 - \sigma_1) + (t_1 - t_2). \tag{18}$$

Without externality effects, i.e., with $s_i = \sigma_i = t_i = 0$, the choice of research direction depends only on the magnitude of cost reduction relative to the quality enhancement, so that $\pi_1^* > \pi_2^*$ iff $a > ub$. With external effects, however, it is clear that the choice of the innovator is affected by the presence of segregation costs.

To consider the welfare-maximizing research direction, conditional on the innovation being provided by an innovator-monopolist, the condition is

$$W_1^* > W_2^* \quad \Leftrightarrow \quad \left(\pi_1^* - \pi_2^*\right) + \left(H(\hat{\theta}_1^*) - H(\hat{\theta}_2^*)\right) > \left(s_1 - s_2\right). \tag{19}$$

From equation (19) we can conclude the following:

Result 4. With $s_1 = s_2$ the social ordering of the research directions is the same as the private ordering (based on the innovator's profit functions). With $s_1 \neq s_2$, however, that need not be the case. Specifically, with $s_1 > s_2$ the

rule for the privately chosen research direction is tilted in favor of efficiency-enhancing innovations.

To show Result 4, recall the definition

$$H(\hat{\theta}_i^*) \equiv \int_0^{\hat{\theta}_i^*} \delta\left(\hat{\theta}_i^* - \theta\right) dF(\theta),$$

so that it follows that sign $(H(\hat{\theta}_1^*) - H(\hat{\theta}_2^*))$ = sign $\hat{\theta}_1^* - \hat{\theta}_2^*$. Also, because we have shown that $\pi_1^* > \pi_2^* \Leftrightarrow \hat{\theta}_1^* > \hat{\theta}_2^*$, then sign $(\hat{\theta}_1^* - \hat{\theta}_2^*)$ = sign $(\pi_1^* - \pi_2^*)$. Hence, with $s_1 = s_2$ the social ordering of the research directions is the same as the private ordering (based on the innovator's profit functions). The case $s_1 > s_2$ is of interest under the presumption that when the GM product carries out its own SIP (the incentive for which exists for quality-improving innovations), it is less costly for the non-GM product to achieve a given SIP level.

5. CONCLUSION

GM product innovations clearly increase the efficiency of production and also have the potential to offer new and/or quality-improved products to the consumer. But because some consumers are apparently opposed to the GM technology of the new products, a portion of the market has a preference for the pre-existing conventional products. Regulations aimed at ensuring the consumers' "right to know" about the GM nature of the food consumed, so as to preserve their ability to choose, require some form of GM labeling. In particular, for example, the new 2004 EU regulations have introduced mandatory labeling and traceability of all GM food and food ingredients and of GM feed. To fulfill such requirements requires costly steps to be undertaken by the suppliers of GM product. Somewhat paradoxically, however, it does not seem that the new regulations make it easier to supply non-GM products to consumers, because costly segregation and identity preservation (SIP) activities are still required.

In this chapter we have reviewed some of the significant issues concerning the effects of GM product innovation, with an emphasis on the issues of GM regulations that focus on labeling. We have developed a simple model that allows a characterization of the main features of both first- and second-generation GM product innovation, and we have used that model to offer an interpretative review of some of the existing studies that have dealt with the assessment of the economic impacts of GM product innovation. We can conclude that introduction of GM products entails the real possibility of a welfare-decreasing innovation because of the externality-like effects that it has on the agricultural and food system's ability to deliver non-GM products.

But because the costly SIP activities need to be undertaken by the suppliers of the superior (non-GM) products, it is also apparent that EU-style mandatory labeling of GM products cannot help (taking for given that GM products are introduced), and indeed it is itself a wasteful regulation in our model. We have also shown that the existence and nature of SIP costs may have a role in the choice of research directions by GM innovating firms.

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