Innovation and Trade with Endogenous Market Failure: The Case of Genetically Modified Products

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A partial-equilibrium, two-country model is developed to analyze implications from the introduction of genetically modified (GM) products. In the model, innovators hold proprietary rights, farmers are (competitive) adopters, some consumers deem GM food to be inferior in quality to traditional food, and the mere introduction of GM crops affects the costs of non-GM food (because of costly identity preservation). Among the results derived, it is shown that, although GM innovations have the potential to improve efficiency, some groups can be made worse off. Indeed, it is even possible that the costs induced by GM innovations outweigh the efficiency gains.

Key words: biotechnology, food labeling, identity preservation, innovations, intellectual property rights, international trade, nontariff barriers, regulation.

Biotechnology is emerging as one of the fundamental forces likely to shape agriculture in the twenty-first century. Scientific and technological breakthroughs in life sciences are making possible an increasing array of new products that have great potential commercial value and considerable scope for adoption. Among early biotechnology innovations for agriculture, transgenic crops have enjoyed a spectacular diffusion in a very short time. Virtually unknown before 1996, genetically modified (GM) crops engineered to be resistant to some herbicides and/or specific pests are currently estimated to account for 145 million acres worldwide (James). This success is attributable almost entirely to transgenic varieties of four crops: soybeans, cotton, corn, and canola. But many open questions remain (Nelson; Pardey; Shoemaker). In particular, speedy GM adoption has been concentrated in a few exporting countries (United States, Canada, and Argentina). And, perhaps most important, the introduction of GM crops has brought about a somewhat unexpected but vigorous public resistance, notably in Europe but global in nature, which has resulted in a flurry of new regulations aimed at GM products that have effectively halted the adoption process in Europe and elsewhere, with the potential of making future market expansion of GM products problematic (Sheldon).

Much of the controversial GM product regulation, such as mandatory labeling of GM food, ostensibly is in response to consumers' demand for the "right to know" whether or not the food they buy contains GM products. Apparently, GM products are "weakly inferior" in quality, relative to their non-GM counterparts. That is, final consumers deem food from GM ingredients to be, at best, equivalent to non-GM food, and indeed the latter is considered strictly superior by some consumers. If the superior product cannot be distinguished from the inferior one, the pooled equilibrium likely to emerge in the market would contain too high a proportion of low quality product, as in Akerlof's "lemons" model. Regulation in such a setting may be desirable to maintain product diversity, which typically can be efficiently achieved with certification systems paid for by sellers (Beales, Craswell, and Salop). Mandating that GM products be identified by a "GM label" may seem to address this informational problem and to preserve the consumers' right to choose between GM and non-GM products (Crespi and Marette). But it is important to distinguish between the information conveyed by a GM label (or lack of such a label, for non-GM products) and the costs required to verify the

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The support of the U.S. Department of Agriculture through a National Research Initiative grant, and of the Pioneer Hi-Bred International Chair in Science and Technology Policy, is gratefully acknowledged.

information that is relevant to the consumer. Even though non-GM food does not have to be labeled in such a setting, it is still the case that costly "identity preservation" (IP) activities are necessary to guarantee the truthfulness of the (implicit) non-GM claim. Furthermore, the incentives to incur the cost of segregating GM and non-GM crops naturally reside with the suppliers of the superior product (the non-GM food), and forcing the suppliers of the inferior product (the GM food) to also incur costs, as with the European Union's (EU) mandatory GM labeling, may be counterproductive from a welfare perspective.

An interesting additional feature of our setting is that the "lemons" problem is due to the innovation process that has brought the new GM products to market. Economic theory suggests that a new product will not be introduced unless it is profitable for the innovator to do so. Furthermore, if existing markets are competitive and distortion free, then the potential profitability of the innovation typically implies that its adoption is welfare enhancing. The case of new GM products—which are potentially inferior to, but not readily distinguishable from, existing products—is a possible exception to this generalization because the introduction of these products may be viewed as creating a negative externality that raises production costs for existing producers. The negative externality arises because, when both goods are present in a given market, distinguishing GM from non-GM products entails real costs (to segregate and test products in order to preserve the identity of the superior product). In this sense, the "lemons" market failure is endogenous to the innovation process. In such an environment, whether private decisions (by GM product innovators) will be socially optimal needs to be ascertained, and in fact there may be scope for government intervention that can be welfare enhancing.

In this article, we address some of the critical economic issues that arise because of biotechnology innovation in the agricultural and food industry, with particular emphasis on the international trade implications. Interest in international economic issues in this context is natural given that the three countries that have embraced GM crops are also large exporters of agricultural commodities, while the most restrictive domestic regulations aimed at genetically modified organisms (GMOs), which necessarily interfere with imports, are being implemented by countries that are natural importers of agricultural products (Sheldon). Indeed, controversy over the international trade implications of GM product policies is escalating, as emphasized by the World Trade Organization (WTO) case against the EU filed by the United States in May 2003.

To address the international trade implications of GM product innovation, in this article we build a partial-equilibrium, two-country trade model that captures some critical elements of the problem. On the supply side, the model explicitly represents the interplay between a monopolistic innovator that sells the seeds of new GM crops and a farming industry that implements these innovations subject to the adoption incentives of a competitive industry (Lapan and Moschini 2000). On the demand side, the model allows for differentiated demand for GM and non-GM products (Giannakas and Fulton), with the former being modeled as goods of weakly inferior quality. Furthermore, the analysis of market equilibrium explicitly models the effects of segregation and IP costs that are necessary in order to meet the differentiated demands for GM and non-GM products (Desquilbet and Bullock). A number of questions, related to both the introduction of new GM products and the effects of regulation and GMO labeling requirements, are investigated. A country's decision to impose GMO labeling requirements, or to enforce standards banning importation of some GM products, has immediate implications for international trade and may entail welfare redistribution effects across national boundaries. The specific impacts that arise from the need for segregation and IP to meet GMO labeling requirements are also studied.

Background

Agricultural biotechnology innovations that have been most successful to date are crops that have been modified to express a particularly useful agronomic trait that allows a reduction in production costs and/or an increase in yields. The most widespread trait to date is herbicide resistance (e.g., "Roundup Ready" varieties which are resistant to glyphosate, a very effective postemergence herbicide), but a few insect resistant traits have also found considerable adoption (e.g., Bt-cotton, resistant to bollworm infestation, and Bt-corn, resistant to the European corn borer). As reported in James, almost the totality of the area planted to GM crops currently affects four commodities: soybeans, cotton, corn, and canola. Although at least twelve countries are growing some commercial transgenic crops, 98% of current GM crop production takes place in three countries: the United States, Canada, and Argentina (James). The geographical concentration of production for GM crops can be explained by restrictive regulations in many countries, justified by apparent public opposition to the introduction of GM products.[1] The EU experience is emblematic in this setting. The earlier regulatory approach to these new crops was not unlike that of the United States, and eighteen products were approved prior to 1998. But following considerable public resistance and mounting consumer concerns, the EU instituted a de facto moratorium on new approvals, pending an extensive reexamination of the regulatory framework for GM products. No new GM varieties have been approved since October 1998; in fact, many EU countries have taken steps to unilaterally ban, within their own national borders, products already approved in the EU.

A major element of existing EU regulations is the requirement that food and feed consisting of, or produced from, GM crops be clearly labeled as such, and that a system be instituted to guarantee full traceability of products put on the marketplace. The stated objective for such regulations is to protect human health by achieving a high degree of food safety, to protect the environment, and to ensure consumers' "right to know." The mandatory labeling requirement will apply to feed produced from GM crops (such as corn gluten feed and soybean meal) and also to food products from GM products even when they do not contain protein or DNA from the GM crop (such as soybean oil or corn syrup). Extensive testing (for GM content) of all import shipments is envisioned, as well as extensive record keeping to ensure traceability. The latest EU decisions on this matter allow a 0.9% adventitious presence of (authorized) GM products in food that will not need to be labeled (Commission of the European Communities).[2] Although the proposed EU rules might be the toughest yet proposed, they are part of a wider trend. At least sixteen countries, in addition to the EU, have adopted or announced plans to implement mandatory labeling of GM products.

Mandatory labeling of GM products adopted in the EU, and forthcoming elsewhere, is a highly controversial feature that sets regulation in these countries apart from that of the United States. In the United States, the predominant view has been that there is no compelling need to label foods obtained from GM products, based on the regulatory philosophy that the "product," rather than the "process," should be the object of concern (Miller 1999a). If, as is arguably the case for existing products, foods derived from GM products are substantially equivalent to traditional ones (Miller 1999b), there should be no need to label a GM food as such. In the United States, and in a handful of other countries including Canada, labeling of GM products is envisioned to be only on a voluntary basis and subject to some restrictions on the possible claims (U.S. FDA).

To understand the economics of mandatory versus voluntary GM labeling, it is crucial to note that innovation here is bringing about goods that are considered by some consumers to be of inferior quality (at least weakly). At best, consumers may be indifferent between GM and non-GM food, and some consumers may in fact strictly prefer non-GM food.[3] Indeed, even the mere presence of trace amounts of an unwanted product may be unacceptable, as illustrated by the recent StarLink fiasco (Lin, Price, and Allen). Whereas a form of labeling is necessary for consumers to choose between GM and non-GM food, to provide consumers with a meaningful choice one needs an "IP" system such that GM products and non-GM products must be segregated at all stages of production, marketing, and processing (Bullock and Desquilbet). IP systems have emerged independently of GM crop adoption, as part of a preexisting trend of specialty crops (such as high-oil corn and synchrony-treated soybeans) and organic farming that tries to tap specific niche markets. A crucial element of IP

[1] At least four reasons are cited for this opposition: food safety risk, concern about the environment, ethical beliefs, and the concentration of ownership of these new crops in the hands of a few multinational companies (Moschini).

[2] Zero tolerance applies to EU-unauthorized GM products, except those that have received a favorable EU risk assessment (for which a 0.5% threshold applies for a maximum of three years). Because a number of GM products approved in the United States are not yet authorized in the EU, the implicit requirement of zero tolerance for such GM products is proving prohibitive for the current commodity-based trade system.

[3] These considerations apply to so-called first-generation GM crops (where the GM trait enhances production efficiency but is not of interest to the consumers per se). Whether consumers will have a different attitude toward higher-generation GM products (with specific output traits of direct interest, such as increased nutritional attributes) remains an open question.

systems is the specified “tolerance” level, that is, the acceptable percentage deviation from purity for the trait of interest. The strict tolerance levels being proposed for GM-free food (0.9% is the threshold level proposed by the EU) suggest that it is likely to be quite costly to keep GM and traditional products strictly separated. But, unlike the case of existing specialty crops mentioned earlier, adopters of new GM crops have no incentive to set up an IP system to keep their output segregated from non-GM crops. The incentive to undertake such IP costs lies squarely with the providers of the higher quality (non-GM) product who, having undertaken the required IP activities, have no additional real cost in identifying their product as non-GM by a (voluntary) label. To further require GM products to undertake costly testing and traceability, and identify themselves by a mandatory GM label, would seem to be vacuous in this context.

Finally, it is necessary to note that the new GM crops in agriculture have been developed by the seed and chemical industries that supply inputs to agriculture, are protected by intellectual property rights (IPRs), and are being marketed by a small number of seed companies that can exploit the market power endowed by their ownership of this intellectual property (Heisey, Srinivasan, and Thirtle). Effective IPRs essentially endow innovators with monopoly power, such that they can use their discovery exclusively or they can license it to others for a fee. The particular organization of agricultural production, distinguished by structural features typically leading to small production units (Allen and Lueck), makes the first option unworkable for the case of GM crop innovations, and the second solution applies. For example, the new Roundup Ready soybean technology has been transferred to U.S. farmers by written licenses in exchange for a “technology fee” that, in the past few years, has entailed a 40% price markup of GM seed price relative to corresponding conventional crop seed prices (U.S. GAO). The market power of GM seed suppliers influences the price that can be charged for these innovated inputs, which in turn affects their adoption and the resulting private and social benefits and costs. To accurately model the production, trade, and welfare effects of new GM crop introduction, it is therefore necessary to explicitly model the structure that characterizes these privately produced innovations in agriculture (Moschini and Lapan).

The Model

We develop a two-country, partial-equilibrium model of an agricultural industry. Initially, both countries produce and consume the traditional non-GM product, and there is free trade, with the home country being the exporter and the foreign country being the importer. For simplicity, and to gain a modicum of real-world relevance, we will label the home country as “United States” and the foreign country as “Europe.” The GM product is developed by a U.S. firm that, by virtue of having secured IPRs on this discovery, behaves as a monopolist for the seed of the new GM crop.[4] The exercise of the monopoly power is constrained by availability of non-GM seed, which is competitively supplied. The GM product is adopted only in the United States, which then can conceivably export both GM and non-GM output to Europe.[5] Whether that will be the case in equilibrium depends, in addition to the decisions of the monopolist seed supplier, on consumer preferences for the new product and on possible regulations and/or protectionist policies by the importing country. Whereas consumers in the United States are assumed to be indifferent between the old non-GM product and the new GM product, consumers in Europe view the two products as imperfect substitutes and, in particular, treat the new GM product as a weakly inferior product. More details on the specification of demand and supply functions follow.

Supply

The model assumes that in the United States there is a fixed amount of land L that can be allocated either to producing the non-GM crop or the GM crop. This land is of heterogeneous quality, which is indexed on a continuum by the variable z, with density function $\theta(z)$.[6]

[4] The assumption of a monopolistic GM seed supplier is a modeling abstraction meant to capture in a simple way the market power that exists in this industry. We recognize that, in reality, the seed industry’s ownership of GM traits, while concentrated, does not conform to the textbook “monopoly” structure.

[5] Although here we limit our analysis to this setting, it is possible to contemplate the case where the GM product is adopted both at home and abroad. The additional complication (and interesting feature) of such an extension is that the United States would then export both the final agricultural products as well as the intermediate input (the GM seeds) that make foreign GM production competitive with the domestic GM output (Moschini, Lapan, and Sobolevsky).

[6] Alternatively, one can think of z as indexing farmers, whose farms are of a given acreage size.

We adopt the convention that land quality decreases with z, so that the total amount of land at least as good as type z (i.e., with index no larger than z) is

$$(1) \qquad \Theta(z) \equiv \int_{q=0}^{z} \theta(q)\, dq.$$

Because we are assuming that the amount of land available for production in this industry is fixed, we normalize $z \in [0, 1]$, and thus $\Theta(1) = L$ denotes the total available land.[7]

The critical assumption of our supply model is that, from the farmer's perspective, the profitability of the new GM crop relative to the non-GM crop depends on the land quality z. An effective way to capture this feature is to postulate that the traditional non-GM crop is equally profitable on all units of land, whereas the profitability of the new GM crop decreases as the index z increases. Production on each unit of land satisfies a strictly concave production function, which by duality can be represented by a unit (per-acre, say) profit function (e.g., Cornes). Thus, we represent the unit profit for the traditional non-GM crop π^n, and the unit profit for the new GM crop π^g, as:

$$(2) \qquad \pi^n = \pi(p^n)$$

$$(3) \qquad \pi^g = \pi(p^g) + \eta(z) - \tau\alpha$$

where $\pi(\cdot)$ is a (convex) unit profit function, p^n is the price farmers receive for their non-GM output, and p^g is the price of the GM crop.[8] The parameter α denotes the amount of seed per acre (which is assumed constant, for reasons discussed in Moschini, Lapan, and Sobolevsky), and τ denotes the noncompetitive premium of GM seed price over the price of non-GM seeds (e.g., the "technology fee" that is charged by seed suppliers). The effects of all other input prices (including the seed price of the traditional crop) are subsumed in the unit profit function $\pi(p)$.

The function $\eta(z)$ represents the (*ceteris paribus*) increase in profitability attributable to the new technology. We assume:

$$(4) \qquad \eta(z) > 0 \quad \text{and} \quad \eta'(z) < 0, \qquad \forall z$$

This ensures that GM crops are a true technological innovation from the farmers' point of view—given the same seed prices and the same output prices, the GM technology would yield a higher per-acre profit. Furthermore, as mentioned earlier, the profit differential due to GM crops varies according to the land index. By the convention in (4) we assume that low-indexed land is land on which GM crops are most profitable. Naturally, the foregoing does not necessarily imply that only GM crops will be grown, because (*a*) the monopoly supplier of GM seeds will charge a price premium; and (*b*) if the two outputs are perceived as imperfect substitutes in consumption, then it may be that $p^g < p^n$. Finally, note that the particular additive form of (3) implies that, *ceteris paribus*, GM and non-GM crops have the same yield (per-acre production) function: by using Hotelling's lemma it is readily verified that, for both crops, yield as a function of output price is $\pi_p(p)$.[9] Albeit somewhat special, this modeling strategy allows us to sharpen the analysis considerably.[10] But we note that the assumption of equal yields may be appropriate anyway for innovations that are essentially cost reducing (the most important attribute of GM crops that are herbicide-resistant, for example).

The adoption of GM crops by a competitive farmer of type z will be profitable if

$$(5) \qquad \pi(p^g) + \eta(z) - \alpha\tau \geq \pi(p^n).$$

If the inequality holds for all land types [i.e., if $\pi(p^g) + \eta(1) - \alpha\tau \geq \pi(p^n)$], then adoption will be complete. Otherwise, the marginal adopter, indexed by $\hat{z} = \hat{z}(\tau, p^n, p^g)$, is determined by

$$(6) \qquad \pi(p^g) + \eta(\hat{z}) - \alpha\tau = \pi(p^n).$$

Hence, a monopolist choosing the seed price premium τ will sell a total amount of seed $\alpha\,\Theta(\hat{z})$ and will determine the marginal adopting farm $\hat{z}$ (see figure 1). Alternatively, we can think of the monopolist as choosing the marginal farmer $\hat{z}$ directly, with the seed price premium τ determined by equation (6). For

[7] The assumption that land is fixed is for analytical simplicity, and could easily be relaxed in the context of our model by specifying an upward-sloping supply of land to this industry that depends on the profitability of the industry (Lapan and Moschini 2000).

[8] From now onward, all variables pertaining to the traditional non-GM good are superscripted by n and those pertaining to the new GM product are superscripted by g.

[9] Of course, if in equilibrium the prices of non-GM and GM crops differ, realized yields may differ.

[10] If the innovation were to change yields, its efficiency and distributional effects would depend on the response of trade policy and thus the characterization of such a general case is considerably more complex. Because we wish to focus on how market equilibrium is affected by the demand shift induced by the introduction of GM products (and related IP and regulation costs), the assumption that yields are unaffected (*ceteris paribus*) allows us to concentrate on the distinguishing features of the case at hand.

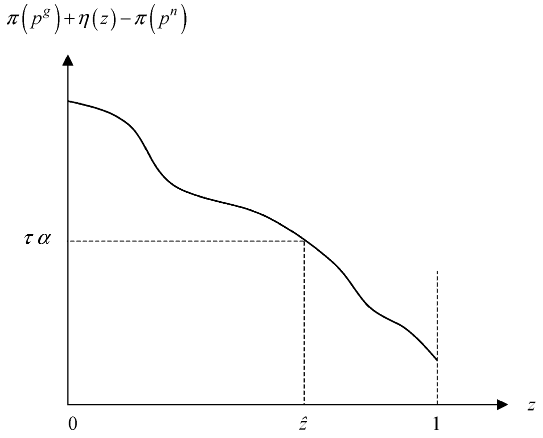

Figure 1. Unit profits, pricing of innovation, and adoption

modeling convenience, in what follows we opt for the latter approach. The profit of the monopolist supplying GM seeds is therefore given by

$$(7) \quad \Pi^M(p^n, p^g, \hat{z}) = [\pi(p^g) + \eta(\hat{z}) - \pi(p^n)]\Theta(\hat{z}).$$

Given $\hat{z}$ as determined by the innovator/monopolist's choice, the supplies of non-GM and GM products are

$$(8) \quad S^n(p^n, \hat{z}) = \int_{z=\hat{z}}^{1} \pi_p(p^n)\theta(z)\,dz = [L - \Theta(\hat{z})]\pi_p(p^n)$$

$$(9) \quad S^g(p^g, \hat{z}) = \int_{z=0}^{\hat{z}} \pi_p(p^g)\theta(z)\,dz = \Theta(\hat{z})\pi_p(p^g)$$

where, again, L is total land, $\Theta(\hat{z})$ is the land allocated to the GM crop, and $L - \Theta(\hat{z})$ is the land allocated to the traditional crop. The preinnovation situation can be represented by letting $\hat{z} = 0$.

Supply conditions in Europe are modeled in a similar fashion under the assumption, mentioned earlier, that the foreign country produces only the non-GM product. Throughout, we use an overbar to denote variables pertaining to Europe (the foreign country). Specifically, if $\bar{\pi}(\bar{p}^n)$ denotes the per-acre profit in production of non-GM output and $\bar{L}$ is the land allocated to this industry in Europe, the supply of non-GM product in this region is

$$(10) \quad \bar{S}^n(p^n) = \bar{L}\bar{\pi}_p(\bar{p}^n).$$

The assumption that the GM good is produced only in the United States is made so that the analysis can emphasize the trade implications of GM product introduction and of GM regulation by the importing country. But we can note that if there were transportation costs in the model, then Europe would likely not produce the GM crop if it had a strong preference for the non-GM variety.

Demand

In both countries we postulate a continuum of households with preferences defined over the consumption of the non-GM product N, of the GM product G, and of a composite (*numéraire*) good. But whereas we postulate that goods N and G are imperfect substitutes in Europe, we assume that these goods are perfect substitutes in the United States. Because of that, it is useful to consider the preferences of European consumers first. Assuming that the households' utility function is quasilinear in the *numéraire* good, individual preferences can be exactly aggregated, and the aggregate indirect utility function can be written as

$$(11) \quad \bar{V}(\bar{y}, \bar{p}^g, \bar{p}^n) = \bar{y} + \bar{\phi}(\bar{p}^g, \bar{p}^n)$$

where $\bar{y}$ is aggregate income. Although exact aggregation holds here, there need not be any normative significance to this aggregate utility function.[11] But by Roy's identity, this aggregate utility function yields aggregate demands:

$$(12) \quad \bar{G}^* = -\bar{\phi}_g(\bar{p}^g, \bar{p}^n) \equiv \bar{D}^g(\bar{p}^g, \bar{p}^n)$$
$$\bar{N}^* = -\bar{\phi}_n(\bar{p}^g, \bar{p}^n) \equiv \bar{D}^n(\bar{p}^g, \bar{p}^n).$$

Throughout the article we shall assume that good G is weakly inferior in quality relative to N, such that $\bar{G}^* = 0$ if $\bar{p}^g \geq \bar{p}^n$. Furthermore, the assumption that the two goods are substitutes of course implies that $(\partial \bar{D}^g/\partial \bar{p}^n) = (\partial \bar{D}^n/\partial \bar{p}^g) \geq 0$. Convexity of the aggregate indirect utility function in prices guarantees that $\partial \bar{D}^n/\partial \bar{p}^n \leq 0$, $\partial \bar{D}^g/\partial \bar{p}^g \leq 0$, and $[(\partial \bar{D}^g/\partial \bar{p}^g)(\partial \bar{D}^n/\partial \bar{p}^n) - (\partial \bar{D}^g/\partial \bar{p}^n)(\partial \bar{D}^n/\partial \bar{p}^g)] \geq 0$. In the analysis that

[11] A welfare interpretation is possible, however, if interpersonal transfers (through the *numéraire* good) are feasible, and that is what we will assume in the welfare analysis of this article.

follows, we will find it convenient to appeal to one more assumption, which we state as:

CONDITION 1. *For both GM and non-GM demands, the own-price effects are at least as large as the cross-price effects, that is,* $|\partial \bar{D}^n/\partial \bar{p}^n| \geq |\partial \bar{D}^n/\partial \bar{p}^g|$ *and* $|\partial \bar{D}^g/\partial \bar{p}^g| \geq |\partial \bar{D}^g/\partial \bar{p}^n|$.

Note that standard consumer theory (convexity of $\bar{\phi}$) implies that either $|\partial \bar{D}^n/\partial \bar{p}^n| \geq |\partial \bar{D}^n/\partial \bar{p}^g|$ or $|\partial \bar{D}^g/\partial \bar{p}^g| \geq |\partial \bar{D}^g/\partial \bar{p}^n|$ must hold. Condition 1 extends that slightly by assuming that both inequalities are satisfied, which essentially maintains a notion of generalized substitutability among goods.[12]

For the United States, we similarly postulate a continuum of households with quasi-linear preferences. But because we shall assume that consumers in the United States treat the GM and non-GM good as perfect substitutes, the domestic aggregate indirect utility function specializes to

$$(13) \quad V(y, p) = y + \upsilon(p)$$

where $p = \min\{p^g, p^n\}$. Thus, by Roy's identity, the total (undifferentiated) demand in the United States is given by $D(p^g) = -\upsilon'(p^g)$ if $p^g \leq p^n$, and $D(p^n) = -\upsilon'(p^n)$ if $p^g \geq p^n$.

GMO Innovation and Trade with Costless Identity Preservation

To understand the effects of innovation when GM and non-GM products are seen as imperfect substitutes, and to assess the impact of IP and regulation costs in this context, it is useful to first analyze the situation where the two varieties can be segregated at zero cost. Intuitively, under the three assumptions that (*a*) yields are the same on the GM and non-GM product, (*b*) IP costs are zero, and (*c*) U.S. consumers are indifferent between the two varieties, the introduction of the GM good should have no effect on market price provided that the output of the GM good is less than U.S. consumption. As GM production initially increases, all that happens is that U.S. consumers substitute the GM variety for the non-GM variety, while U.S. exports remain composed entirely of the non-GM variety. Provided that total GM output is smaller than total U.S. consumption, increased plantings of the GM variety will have no price effects. However, once the land allocated to the GM variety reaches that critical level where GM production just equals U.S. consumption, any further allocation of land to the GM variety will reduce the potential exports of the GM-free good to Europe, and prices must respond to ensure that markets clear. Thus, there is a critical value of land allocation (z^0) such that if the amount of land allocated to the GM variety is less than z^0, there are no price effects, whereas for land allocations above that level, the prices of the GM and non-GM products will differ and will change as GM plantings increase.

Turning to the formal analysis, the supply equations in the United States are as outlined in (8) and (9), whereas U.S. demands are derived from (13), with $p = p^g \leq p^n$. Note that if $p^g = p^n$, U.S. consumers are strictly indifferent as to which good they buy, whereas for $p^g < p^n$ they will buy only the GM product. On the other hand, demands in Europe are given by (12), with the demand for the GM product equal to zero if $p^g \geq p^n$.[13] Given the aggregate sales of GM seeds chosen by the monopolist, the marginal farm $\hat{z}$ is determined, and final product supplies are given by equations (8)–(10).

The U.S. excess demand for GM products can be written as [14]

$$(14) \quad X^g(p^g, \hat{z}, \psi) \equiv \psi D(p^g) - S^g(p^g, \hat{z})$$

where the variable ψ is used to handle the fact that the two products are perfect substitutes in the United States (thus $\psi = 1$ if $p^g < p^n$, and $\psi \in [0, 1]$ if $p^g = p^n$). Similarly, the world excess demand for the non-GM output is given by

$$(15) \quad X^n(p^n, p^g, \bar{p}^n, \bar{p}^g, \hat{z}, \psi) \equiv \bar{D}^n(\bar{p}^n, \bar{p}^g) + (1 - \psi)D(p^g) - S^n(p^n, \hat{z}) - \bar{S}^n(\bar{p}^n).$$

Given that here we have no trade barriers, $p^n = \bar{p}^n$ and $p^g = \bar{p}^g$.

Suppose that $p^n = p^g = p$ (so that $\bar{p}^n = \bar{p}^g = p$). If there exists p^e and $\psi^e \in [0, 1]$ such that

[12] Let $\bar{p}^m$ denote the price of the *numéraire* good m, such that the demand for goods N and G are written as $\bar{D}^i(\bar{p}^n/\bar{p}^m, \bar{p}^g/\bar{p}^m)$, $i = \{n, g\}$. Then, Condition 1 ensures that $\partial \bar{D}^i/\partial \bar{p}^m \geq 0$, $i = \{n, g\}$, when evaluated at $\bar{p}^n = \bar{p}^g$ (i.e., at this point the GM and non-GM goods behave as substitutes with respect to the *numéraire* good).

[13] In terms of modeling, it would make little difference if there were a mass of consumers in the foreign country who were indifferent between the two varieties.

[14] Clearly, for $p^g > p^n$ no meaningful equilibrium occurs in which the GM crop is produced.

$X^n = X^g = 0$, then this constitutes an equilibrium (when $\psi \in (0, 1)$ both goods are consumed in the United States and only the non-GM good is consumed in Europe).

PROPOSITION 1. *Let p^0 denote the equilibrium price of the non-GM good prior to the introduction of the GM product, let z^0 be defined by $\Theta(z^0)\pi_p(p^0) = D(p^0)$. Then, for all levels of GM seeds sales such that $\hat{z} \leq z^0$, equilibrium prices are such that $p^g = p^n = p^0$. Hence, for all $\hat{z} \leq z^0$ the introduction (and adoption) of the GM crop does not affect domestic or foreign consumers, nor does it affect domestic or foreign producers of the non-GM crop. Economic efficiency and the profits of the GM crop producers increase as $\hat{z}$ increases.*[15]

For low levels of GM adoption, output prices are unchanged, and thus neither consumers nor producers of the non-GM product are affected. In this situation the per-acre price premium of GM seeds is simply equal to $\eta(\hat{z})$ and, because $\eta'(\hat{z}) < 0$, GM farmers gain as $\hat{z}$ increases. Further, aggregate (GM plus non-GM) output stays the same, but total production costs decline as $\hat{z}$ increases. Thus, as long as we are in a domain where the goods are perfect substitutes to U.S. consumers, economic efficiency must increase.[16]

The optimal marketing decision for the monopolist seller of GM seeds depends upon the rate at which profitability declines as use expands and upon the density of users. A priori, it is not possible to specify whether the monopolist's optimal sales of seed will entail selling to producers beyond z^0. Assuming that Π^M is concave in z, then, from (7), $\{\eta'(z^0)\Theta(z^0) + \eta(z^0)\theta(z^0)\} \leq 0$ guarantees that $\hat{z} \leq z^0$, such that the equilibrium output price will be unaffected by the introduction of the GM crop, and no GM product will be exported.

But it is quite possible that the optimal sales of GM seeds by the monopolist, absent trade barriers, is large enough such that $\hat{z} > z^0$. In that case, an equilibrium requires $p^n > p^g$. Furthermore, in this equilibrium some GM product will be exported if $\bar{D}^g(\bar{p}^g, \bar{p}^n) > 0$. For this case, equilibrium prices are determined from

$$(16) \quad D(p^g) + \bar{D}^g(\bar{p}^g, \bar{p}^n) - S^g(p^g, \hat{z}) = 0$$

$$(17) \quad \bar{D}^n(\bar{p}^n, \bar{p}^g) - S^n(p^n, \hat{z}) - \bar{S}^n(\bar{p}^n) = 0.$$

Totally, differentiating (16) and (17) yields the comparative statics effects of a change in the adoption rate of the new technology on equilibrium prices. Because in this case we have $p^g < p^n$, actual yields per acre will be higher on non-GM lands and thus, given prices, total output (GM plus non-GM product) declines as land planted with the GM crop expands. Convexity assumptions, together with Condition 1, permit the following conclusion.

PROPOSITION 2. *Given Condition 1 and $\hat{z} > z^0$, (a) the equilibrium price of the non-GM product increases as GM crop cultivation increases, that is, $(dp^n/d\hat{z}) > 0$; (b) the price of the non-GM product must rise more than that of the GM product as cultivation increases, that is, $(dp^n/d\hat{z}) > (dp^g/d\hat{z})$; and, (c) increased GM seed sales lower Europe's welfare if its imports of the non-GM product exceed those of the GM product.*

Intuition suggests that the price of the GM product must fall as acreage allocated to it rises, but in fact that is not necessarily true because, given prices, total output declines because the GM and non-GM products are (potentially) close substitutes. Thus, one cannot rule out the possibility that $dp^g/d\hat{z} \geq 0$. However, Proposition 2 ensures that, even if the price of the GM product increases, it increases less than the price of the non-GM product. From a welfare perspective, efficiency would entail adoption of the GM product until profits per acre were the same for each type of crop. But it is clear that monopoly pricing of the innovation leads to lower levels of adoption. Thus, if the monopolist chooses to expand GM acreage (by selling more seeds), it must increase overall welfare. However, that does not mean that everyone gains from this expansion in GM acreage. Proposition 2 establishes that the foreign country is hurt—at least over some domain—through increased GM plantings in the United States. Note that this result occurs even though there are no market failures present (given that, at this point, IP is assumed to be costless) and it can occur even if Europe imports no GM product. As is now apparent, the result here is due to the terms-of-trade impact on the foreign country's primary imports (non-GM product). The increased acreage of GM crop must increase the price of non-GM output, and this must hurt importers who predominantly buy this product. It is interesting to note, however, that European farmers actually gain from increased GM plantings in the

[15] Proofs are relegated to a Reader's Appendix, available from the authors upon request.

[16] Recall that we assume the economic (marginal) cost of producing GM and non-GM seeds is the same.

United States. Also, note that Europe need not lose everywhere: when GM imports become important enough, Europe may benefit from the terms-of-trade changes.

The Impact of Costly Identity Preservation

As previously discussed, the introduction and adoption of a GM crop creates a situation whereby European consumers view GM and GM-free products as imperfect substitutes but cannot distinguish between the two products simply through taste or visual experience. To meet this differentiated demand, sellers must undertake a costly system of IP. Specifically, we assume that, if both GM and non-GM goods are produced in a given country, then establishing that a particular output is GM-free entails segregation and verification costs. If only the non-GM product is grown in a country, then verification costs are unnecessary. This framework implies that the introduction of GM production into a region involves an externality that imposes costs on the (verified) output of another good.

As in the prior section, if U.S. consumers consider the GM and GM-free goods to be perfect substitutes, there should be a range of GM plantings over which prices are independent of any *change* in the level of such plantings. However, because of the IP costs, the introduction of the GM product in the United States imposes costs on producing (and identifying) the GM-free product. Thus, if p^0 denotes the price of the (GM-free) product prior to the introduction of the GM good, we expect that the introduction of GM production in the United States will cause a discontinuous drop in (farm-level) prices in the United States and an increase in prices in Europe (where no IP costs are incurred on production). However, as long as U.S. GM production is less than U.S. consumption, increases in GM production will not affect prices. Beyond this critical level, we expect that increased GM production will cause the farm-level price of the GM-free good to increase relative to that of the GM product.

The formal analysis requires us to distinguish between the output produced with non-GM seeds in a region and the availability of *verified* non-GM product from that region. Thus, we use the notation $\{f, b\}$ to label the variables corresponding to the "verified GM-free" and "GM (or blend)" output, respectively, instead of the earlier notation of $\{g, n\}$. We do so to reflect, as described earlier, the extra step of verification that is required once the GM product is introduced. Thus, p^n and p^g now denote U.S. producer prices (farmgate prices), whereas p^f and p^b denote consumer prices. Clearly, $p^n \geq p^g$, because the non-GM product can always be sold without verification (to be marketed as part of the "blend" product), and $p^b \leq p^f$, because nobody strictly prefers the GM product (and the blend output is treated just like the GM product). Furthermore, if c denotes the unit segregation/verification cost, then $p^f = p^n + c$, and $p^g = p^b$. The absence of trade barriers (apart from IP costs) implies that $\bar{p}^f = p^f$ and $\bar{p}^b = p^b$. Since no GM product is grown in Europe, we assume that no IP costs are required for product grown in that region, and hence $\bar{p}^n = \bar{p}^f$ (of course, $\bar{p}^g$ is meaningless for this region).

With this introduction in place, we now analyze how IP costs affect the equilibrium and conclusions of the previous section. As an initial reference point, consider the free trade pre-GM equilibrium. Assume demands are given from the indirect utility functions defined earlier with the price of the GM good set high enough so its demand is zero ($p^b \geq p^f$ suffices). Because in the preinnovation equilibrium no GM good is produced, there are no verification costs, implying consumer and producer prices are equal, while free trade equates prices across the two countries. Thus, there is only one price, whose equilibrium level p^0 is determined by

$$(18) \qquad L\pi_p(p^0) + \bar{L}\bar{\pi}_p(p^0) - D^f(p^0) - \bar{D}^f(p^0) = 0$$

where $D^f(p) = -\upsilon'(p)$ and $\bar{D}^f(p) = -\bar{\phi}_f(p, p)$. As mentioned earlier, it is assumed that the United States is an exporter in this equilibrium, that is, $L\pi_p(p^0) > D(p^0)$.

Now consider the introduction of the GM product, which we assume is grown only in the United States. Under our IP cost assumptions, segregation and verification costs in Europe are required only for imports, and these costs essentially act like an import tariff in which the tariff revenue is dissipated. The ensuing analysis needs to distinguish two cases, which depend on whether or not the farmgate prices of non-GM and GM products are equal in the United States, which in turn depends on the $\hat{z}$ determined by the monopolist's pricing of GM seed. Because verification costs are absent in the foreign country, the price received by foreign farmers for the non-GM product will differ from that received by U.S. farmers.

It is useful to break the analysis into stages, and take $\hat{z}$ as given initially. As discussed earlier, for a given GM acreage, there are two possibilities: (a) at $p^n = p^g$ the supply of non-GM product exceeds European (excess) demand; or (b) at $p^n = p^g$ there is an excess demand for the GM-free product. In the first case, the U.S. farmgate prices for the two varieties will be the same, and consumer prices will differ only by the verification costs. In the second case, on the other hand, it must be that $p^n > p^g$. Turning to demand, recall that U.S. consumers are indifferent between the two varieties; thus, with verification costs, they will consume only the GM (or blend) product. An equilibrium in which U.S. farmgate prices are equal (i.e., $p^n = p^g$) occurs if

$$(19)\quad S^g(p^g, \hat{z}) + S^n(p^n, \hat{z}) + \bar{S}^n(\bar{p}^n) + \upsilon'(p^b) + \bar{\phi}_f(\bar{p}^f, \bar{p}^b) + \bar{\phi}_b(\bar{p}^f, \bar{p}^b) = 0$$

provided

$$(20)\quad \{S^n(p^n, \hat{z}) + \bar{S}^n(\bar{p}^n) + \bar{\phi}_f(\bar{p}^f, \bar{p}^b)\} \geq 0$$

where

$$(21)\quad \begin{aligned} p^f &= \bar{p}^f = \bar{p}^n = p^b + c \\ \bar{p}^b &= p^b = p^n = p^g. \end{aligned}$$

Equation (19) asserts the equality of supply and demand for all product, whereas (20) ensures that sufficient GM-free product is available to meet European demand. The pricing assumption in (21) reflects the verification costs on the U.S.-produced GM-free product, the absence of such costs on foreign production, and the assumed equality of farmgate prices in the United States. At $c = 0$, this is the equilibrium that exists prior to the introduction of the GM crop, provided that GM acreage is small.

Define the equilibrium price from (19)–(21) as $p^b(c)$. From these equations, we can determine the comparative statics effects (dp^b/dc) and (dp^f/dc). Given the assumption that the yield function is the same for the two varieties, and using Condition 1 (and the usual convexity properties of the profit function and indirect utility function), these comparative statics can be signed, yielding:

PROPOSITION 3. *If GM plantings are not too large (so that farmgate prices of both varieties are the same), then (a) U.S. farmgate prices decrease as verification costs increase, (b) EU farm prices rise, and (c) consumer prices for (verified) GM-free products increase.*

As verification costs increase, European imports of the GM-free product decrease both because its domestic output rises and because its demand for the GM-free product falls. If verification costs are high enough, Europe's imports of the GM-free product may cease. Depending on preferences, Europe might start importing the GM product as c increases because the consumer prices of the two varieties move in opposite directions. But clearly, increases in c will not lead to excess demand for the GM-free product. If we define $z^0(c)$ such that $\{S^n(p^n, z^0) + \bar{S}^n(p^n + c) + \bar{\phi}_f(p^n + c, p^n)\} = 0$ with $p^n = p^g$, then z^0 is a nondecreasing function of c. Hence, if the initial equilibrium at $c = 0$ is such that U.S. farm prices are the same for both varieties, then, given $\hat{z}$, the equilibrium will remain so as c increases.

Finally, consider the monopolist's optimization problem, and recall that its profits are given by (7). Define z^0 as in the previous section, such that with costless verification there will be no price difference between GM and non-GM products for $\hat{z} \leq z^0$.

LEMMA 1. *Assume the monopolist's profit function is concave in $\hat{z}$. If at z^0 it happens that*

$$[\eta'(z^0)\Theta(z^0) + \eta(z^0)\theta(z^0)] < 0$$

where $\Theta(z^0)\pi_p(p^0) = D(p^0)$, then the monopolist's optimal sales decision is unaffected by the verification costs.

Lemma 1 follows directly from Proposition 3, and from the fact that, as c increases, there remains sufficient excess supply of the non-GM product so that the foreign demand can be met. Thus, the residual U.S. production of non-GM product is sold in the home market at the same price as the GM product because U.S. consumers are indifferent between the GM and GM-free products. Furthermore, we have:

PROPOSITION 4. *Provided Europe imports some GM product, increases in verification costs hurt the United States, lower world welfare, but have a potentially ambiguous effect on Europe's welfare.*

U.S. welfare declines because it is a net exporter and the farm-gate price declines. World welfare declines because of increased verification costs. Europe's welfare decreases because of the effective cost increase for imports of the GM-free product (including verification costs), but it potentially benefits from the reduced price of the GM product, so the overall impact is ambiguous. Around $c = 0$, all parties are hurt.

Unlike the case of no verification costs, the mere introduction of GM products will affect producers and consumers even if $\hat{z} < z^0(c)$. Given verification costs, it is true that for $\hat{z} \in (0, z^0]$, equilibrium prices are unaffected by the level of $\hat{z}$ since some of the GM-free product is sold in the United States at the price of the GM product. However, the introduction of any GM product in the United States implies that verification costs become necessary in order to export the GM-free product, and hence there is a discontinuous drop in U.S. (and world) welfare with the introduction of the GM product. This situation is illustrated in figure 2. Given $\hat{z} \in (0, z^0)$, increases in GM plantings do not affect equilibrium prices or Europe's welfare.

PROPOSITION 5. *Assuming positive verification costs, and that the optimal level of GM sales for the monopolist is such that the GM and GM-free products sell at the same price in the United States, then (a) the introduction of the GM crop in the United States leads to a discontinuous drop in U.S. farm output prices and to an increase in the price of the GM-free product in the importing country; and (b) the introduction of GM production may lead to a decline in U.S. welfare.*

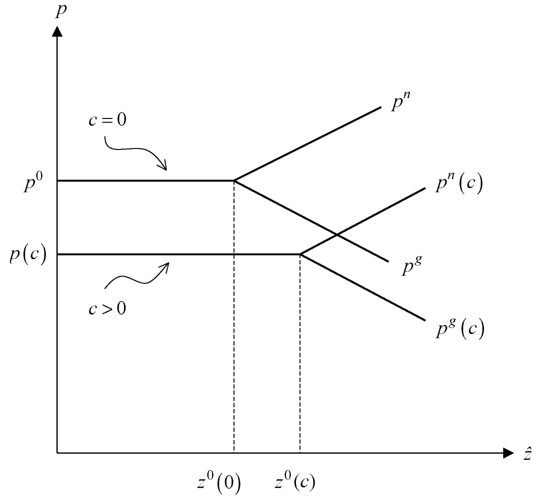

Figure 2. Identity preservation costs, acreage, and prices

Part (i) follows from the previous section and the immediately preceding discussion, where we have shown that, given $\hat{z} \leq z^0$, (*a*) if $c = 0$ then prices are independent of $\hat{z}$; whereas (*b*) given $\hat{z} \in (0, z^0)$, p^b is a declining function of *c*, while p^f is an increasing function of *c*. Part (ii) follows from the fact that the introduction of GM product leads to a decline in the U.S. terms of trade. If verification costs are small, then the gains will outweigh the losses; however, for large enough verification costs it is apparent that the introduction of the GM product may lower U.S. welfare.

GMO Regulation: Consumer Protection or Protectionism?

As discussed earlier, one of the responses to the development and adoption of GM crops has been the imposition of an increasingly elaborate set of regulations aimed at the marketing of GM products. For example, such "regulation" may require importers of GM products to keep enhanced records about the origin of production of the imports (i.e., traceability), even if they are not labeled GM-free. Indeed, that seems to be a feature of the current EU labeling and traceability system, discussed earlier, and perhaps it highlights the most important economic implications of "mandatory" labeling requirements relative to "voluntary" ones. Imposing such regulation-based costs on GM product marketing will lower GM imports into Europe, and a sufficiently high cost will be equivalent to a ban on imports. (If these administrative costs for GM products equal the verification costs for GM-free products, then, given equality of prices in the United States, this fee will be prohibitive with respect to GM imports.)

Let t denote the per-unit cost these regulations impose on GM imports, and assume $t < c$. Given equality of price in the United States, European prices for GM-free and GM products will be $\bar{p}^f = p^n + c$, $\bar{p}^b = p^b + t$, respectively, where $p^b = p^g = p^n$. Using these relations, equilibrium prices are determined from (19), provided the restriction on net supply of the GM-free product holds. Totally differentiating yields the comparative statics effects (dp^b/dt) and $(d\bar{p}^b/dt)$. Given the identity of U.S. prices for the two varieties, $(d\bar{p}^f/dt) = (dp^b/dt)$. Under the assumption that the demand for each good is more sensitive to its own price (Condition 1), we have $(d\bar{p}^b/dt) > 0 > (dp^b/dt)$. It then follows:

PROPOSITION 6. *Assume the monopolist's decision on GM acreage is such that, in the United States, $p^g = p^n$. Also assume there are verification costs of c per unit on GM-free goods shipped from the United States to Europe. Then European regulations on the imported GM product that raise real-handling costs will (a) lower the price of U.S. output, and thus lower U.S. welfare; (b) raise the net cost to Europe of the imported GM product but lower the cost to Europe of the imported GM-free product; and thus (c) may increase European welfare.*

It is worth noting that the costs represented by t operate like a tariff on the GM product but with the tariff revenue dissipated through the regulatory costs (similar to the case of tariffs with rent-seeking behavior). Thus, whereas the trade barrier on GM products worsens Europe's terms of trade for GM imports, it improves Europe's terms-of-trade for the GM-free product. Consequently, if Europe imports mainly the GM-free product, the overall impact on Europe can be beneficial. The effects of GM regulations here are modeled as real costs due not to technology but to burdensome administrative rules, and hence these rules must reduce economic efficiency (i.e., the United States must lose more than Europe gains). The regulations do not correct an externality, provided that any GM goods are still produced in the United States; they merely serve as a (wasteful) device to manipulate the terms of trade. From Proposition 6 we also have the following result (see also Giannakas and Fulton; Crespi and Marette):

COROLLARY 1. *A European "standard" that prohibits the sale of GM products in Europe may raise European welfare.*

Note that, unlike the standards literature where domestic standards are used as a strategic device to protect a local firm from a foreign competitor (who may appropriate local monopoly rents) (e.g., Fischer and Serra), there is no strategic game involved in this argument. Rather, the standard here serves as an indirect way to improve the terms of trade.

We turn now to the case in which the U.S. prices of GM and GM-free products differ. The U.S. price of the GM-free product will rise above the GM price when, at equal prices, exporting the entire U.S. GM-free crop is insufficient to meet European (excess) demand, given the arbitrage conditions. Equilibrium prices for this case, and the critical threshold for GM plantings are determined by:

$$S^g(p^g,\hat{z}) + S^n(p^n,\hat{z}) + \bar{S}^n(\bar{p}^n) + \upsilon'(p^b) + \bar{\Phi}_f(\bar{p}^f,\bar{p}^b) + \bar{\Phi}_b(\bar{p}^f,\bar{p}^b) = 0 \tag{22}$$

$$S^n(p^n,\hat{z}) + \bar{S}^n(\bar{p}^n) + \bar{\Phi}_f(\bar{p}^f,\bar{p}^b) = 0 \tag{23}$$

$$\begin{aligned} \bar{p}^f &= \bar{p}^n = p^n + c \\ \bar{p}^b &= p^b + t \\ p^b &= p^g \\ p^n &\geq p^g. \end{aligned} \tag{24}$$

The equilibrium conditions in (22) and (23) determine $p^n(c,t,\hat{z})$ and $p^g(c,t,\hat{z})$, with European prices determined through the stated arbitrage conditions. For future reference, define $z^0(c,t)$ such that $p^n(c,t,z^0(c,t)) = p^g(c,\ t,\ z^0(c,t))$. For $\hat{z} < z^0(c,t)$, $p^n = p^g$, and the preceding results apply. For $\hat{z} > z^0(c,t)$, $p^n > p^g$, as is assumed in this subsection. We will return to the case $\hat{z} = z^0(c,t)$ later. Given $\hat{z}$, the comparative statics of prices can be determined. In particular, we find:

LEMMA 2. *From equations* (22)–(24) *we find* $(\partial p^n/\partial\hat{z}) > 0$ *and* $(\partial p^n/\partial\hat{z}) > (\partial p^g/\partial\hat{z})$*, although the sign of* $(\partial p^g/\partial\hat{z})$ *is indeterminate. Furthermore,* $(\partial p^n/\partial c) < 0, (\partial\bar{p}^f/\partial c) > 0$, $(\partial p^g/\partial c) = (\partial\bar{p}^b/\partial c) > 0$*; and,* $(\partial p^n/\partial t) = (\partial\bar{p}^f/\partial t) > 0$, $(\partial p^g/\partial t) < 0, (\partial\bar{p}^b/\partial t) = [1 + (\partial p^g/\partial t)] > 0$.

Given $\hat{z}$, the incidences of the IP and regulation costs c and t act as one would expect both on own price and on the price of the substitute good. Thus, given $\hat{z}$, an increase in the unit verification costs c lowers the U.S. price of the GM-free product but raises the price of the GM product as European demand shifts; the European price of both varieties increases.[17] Similarly, given $\hat{z}$, an increase in administrative costs on the GM products (i.e., an increase in t) will lower the U.S. price of GM product but will raise the U.S. price of the GM-free variety while raising both prices in Europe. Thus, given (c,t), under the maintained demand assumption, an increase in $\hat{z}$ (the amount of the

[17] In the United States there is no substitution in demand by assumption, and no substitution in supply, given $\hat{z}$. If Europe does not consume the GM product, the increase in c will not affect the price of the GM product, given $\hat{z}$. Of course, in either case, the monopolist is likely to adjust his optimal $\hat{z}$ in response to these exogenous shifts in transaction costs.

GM acreage cultivated) increases the price of non-GM product but has a potentially ambiguous impact on the price of the GM product as total production in this industry declines (this cannot happen around $p^n = p^g$, where realized yields are equal across varieties). Because it must be that $(\partial p^n/\partial \hat{z}) > (\partial p^g/\partial \hat{z})$, European welfare will be reduced by this increased GM acreage if European imports of GM-free soybeans are at least as large as those of GM product. Thus, it is apparent that Europe has an interest in adopting policies that could reduce the amount of acreage allocated to GM crops.

Similarly, given $\hat{z}$, an increase in European regulations on GMO imports (an increase in t) increases European prices for both varieties and thus must hurt Europe (as there is no tariff revenue), while it is conceivable that the United States benefits from this policy. Naturally, if $\hat{z}$ adjusts, then the qualitative results could change. Thus, consider how changes in c or t affect the monopolist's *optimal* acreage decision. In doing so, we must consider three possibilities: (*a*) $\hat{z} > z^0(c, t)$ so that $p^n(c, t, \hat{z}) > p^g(c, t, \hat{z})$; (*b*) $\hat{z} < z^0(c, t)$ so that $p^n = p^g$; and (*c*) $\hat{z} = z^0(c, t)$. Note that the latter case is more than a mere singularity because the monopolist's marginal revenue curve is discontinuous at that point. Specifically, from the monopolist's profit function in (7) we have:

$$(25)\quad \frac{d\Pi^M}{d\hat{z}} = \begin{cases} [\eta'(\hat{z})\Theta(\hat{z}) + \eta(\hat{z})\theta(\hat{z})], & \text{for } \hat{z} < z^0 \\ \left[\pi_p(p^g)\dfrac{\partial p^g}{\partial \hat{z}} + \eta'(\hat{z}) - \pi_p(p^n) \times \dfrac{\partial p^n}{\partial \hat{z}}\right]\Theta(\hat{z}) + [\pi(p^g) + \eta(\hat{z}) - \pi(p^n)]\theta(\hat{z}), & \text{for } \hat{z} > z^0. \end{cases}$$

As shown earlier, under the maintained demand assumptions, $(\partial p^n/\partial \hat{z}) > 0$, and $(\partial p^n/\partial \hat{z}) > (\partial p^g/\partial \hat{z})$. Also, $\pi_p(p^n) \geq \pi_p(p^g)$, and $\lim_{\hat{z}\to z^0}[\pi_p(p^n) - \pi_p(p^g)] = 0$. Thus, it follows that

$$(26)\quad \lim_{\hat{z}\to(z^0)^+}(\partial\Pi^M/\partial\hat{z}) < \lim_{\hat{z}\to(z^0)^-}(\partial\Pi^M/\partial\hat{z}).$$

In other words, the monopolist's marginal revenue curve is discontinuous at z^0, with a discrete downward jump at that point.

This discontinuity in the marginal revenue curve is illustrated in figure 3. The curve ABD shows the inverse demand curve for GM seeds, which is the difference in profits on the marginal land. Along segment AB, $p^n = p^g$, and the demand curve is negatively sloped only because the cost savings due to GM production decline as $\hat{z}$ increases (if all land were identical, the demand curve would be horizontal over this domain). However, along segment BD ($\hat{z} > z^0$), GM output is sufficiently large (non-GM output is sufficiently small) so that the U.S. farm price of non-GM output exceeds that of GM output. The negative slope of the demand curve along BD reflects not only the change in cost savings on the marginal land but also the change in output prices. Even if all land were homogenous, the demand curve would be negatively sloped over this domain. Thus, the demand curve is continuous but has a kink, at B. The marginal revenue curve is represented by AB′CD′, with the discontinuity in the marginal revenue curve at z^0 (the vertical segment B′C) reflecting the kink in the demand curve. The monopolist's optimal decision depends, of course, upon where the marginal revenue curve crosses the horizontal axis. While any of the three cases could occur, the figure represents the case in which the discontinuity in the marginal revenue curve encompasses the horizontal axis. Clearly, the possibility of the monopolist's optimal decision being z^0 is more than a singularity.

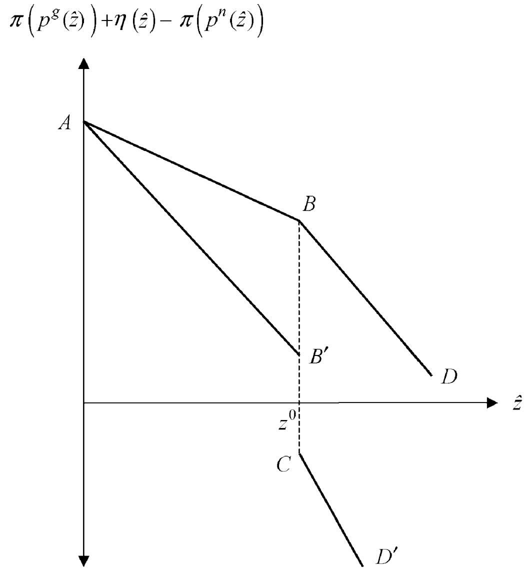

Figure 3. Marginal revenue and innovator's acreage choice

Given Lemma 1, it is clear that, if the monopolist's optimal choice $\hat{z}$ is in the domain $\hat{z} < z^0(c, t)$, then (marginal) changes in c or t will not affect acreage allocations. On the other hand, for the case in which $\hat{z} \geq z^0(c, t)$, the optimal decision will be affected by these parameters. As noted previously, there is a positive probability that the monopolist's optimal decision will be to choose GM acreage so that the prices of the two varieties are "just" equal, that is, $\hat{z} = z^0(c, t)$. The impact on price and GM acreage for this case is readily demonstrated.[18] Specifically, we find:

$$(27)\quad \begin{aligned} &(dp(c,t)/dc) \in (-1, 0) \\ &(dp(c,t)/dt) \in (-1, 0) \\ &(dz^0(c,t)/dc) > 0 \\ &(dz^0(c,t)/dt) < 0, \end{aligned}$$

where $p^n = p^g = p$, whereas European prices are such that $\bar{p}^f = (p + c)$ and $\bar{p}^b = (p + t)$. These results reflect the endogeneity of GM acreage to the stated variables. Hence, we have the following:

PROPOSITION 7. *Assuming it is optimal for the monopolist to choose acreage such that the GM and non-GM varieties in the United States have just the same output price, then an increase in the IP cost c leads to (a) more acreage allocated to GM crops; (b) lower U.S. prices for both goods; (c) higher European prices for GM-free imports, but lower prices for GM imports; (d) lower overall efficiency and lower welfare in the United States; (e) lower welfare in Europe if its primary imports are GM-free; but (f) an increase in the monopolist's profits. Similarly, an increase in the GM regulation cost t imposed on imports of the GM product leads to (a) less acreage allocated to the GM product; (b) lower U.S. prices for both goods; (c) higher European prices for GM imports but lower prices for GM-free imports; (d) lower overall efficiency and lower welfare in the United States; (e) potentially higher welfare in Europe, especially if GM-free imports exceed GM imports; and (f) a decline in monopoly profits.*

Conclusion

In this article, we have developed a model of an innovation that is produced and marketed by a home-country monopolist, is adopted by a competitive sector, and leads to tradable final products that are considered weakly inferior in quality by consumers in the foreign country. This stylized model fits the most important features of the current generation of agricultural GM products, and it allows us to investigate how the introduction of GM crops affects economic efficiency and the distribution of welfare across importers and exporters. We also have considered how policies limiting, or regulating, imports of GM products will affect welfare in importing and exporting countries. We have explicitly accounted for the externality that the introduction of GM crops has on preexisting non-GM products and have studied the role of segregation and verification costs in influencing the welfare effects associated with the introduction of these new products. The analysis of the article has been predicated on the assumption that consumers may rationally prefer, at least weakly, GM-free goods to GM goods.

Within this framework, we have shown that the introduction of GM products can lower welfare, because of the cost externality that arises if there are verification costs involved in certifying that a product is GM-free. Even if there is an overall welfare gain, the importing country (if it is the one that has the preference for the GM-free good) is likely to be harmed by the introduction of the GM product. Moreover, we have shown that regulations on trade in GM products will redistribute income among trading nations and may benefit the importing country. Some forms of such regulations may be thought of as imposing artificial costs on trade in GM products—thus possibly reducing overall economic efficiency—and will harm the importing country if the regulations have no impact on planting decisions. However, by inducing the monopolist to reduce the amount of GM seeds sold, regulations restricting imports of GM products can benefit the importing nation by lowering the price of GMO-free goods. Thus, it may be difficult to determine whether these regulations are motivated by an attempt to "protect consumers" or simply "to protect."

The foregoing results provide useful insights into the roots of the ongoing trade problems concerning GMOs, including the WTO case pitting the United States against the EU. In addition, our results provide a basis for evaluating policies that are emerging to deal with the unique problems brought about by the first generation of GM products. Recall that, within the context of our model, verification costs allow consumers to distinguish (and be able to choose) between GM and GM-free goods. But such costs only need to be incurred by the product wanting to claim "GM-free" status, and this

[18] The case in which $\hat{z} > z^0(c, t)$ yields similar results, subject to some additional qualifications. See Lapan and Moschini (2001) for more details.

verification can be delivered by a voluntary labeling system. The additional requirements of a "mandatory" labeling system can be interpreted as merely administrative burdens imposed on GM-trade. Extrapolating from our model to a multicountry setting, we note that both the verification costs and these administrative costs could induce some exporters to ban production of GM products. This seems most likely in producing regions, such as South America, which typically do not retain the monopoly rents from GM-seed sales.

[Received February 2003; accepted August 2003.]

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