Who Pays the Costs of Non-GMO Segregation and Identity Preservation, and Who Is to Blame?

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ABSTRACT

The paper analyzes the welfare effects of the introduction of GMO technology into a market in which a fraction of consumers refuses to buy GMOs. Our theoretical model recognizes that segregation and identity preservation (IP) of non-GMOs may create costs for both IP producers and non-IP producers. Our results show how GMO-hating consumers may win or lose from the introduction of GMO technology. If IP creates costs for non-IP producers, indifferent consumers and GMO producers may be made worse off because others refuse to consume GMOs. If GMO rejection is strong, IP producers win when GMOs are introduced, even though they do not produce GMOs.

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Introduction

Many citizens worldwide fear that the consumption of genetically modified organisms (GMOs) is unhealthful, and that the growing of GMOs places the environment at unnecessary risk. But despite this opposition, many farmers in the world continue to grow GMOs. The combination of the reluctance of many to consume GMOs with the willingness of others to grow GMOs has brought about the emergence of dual markets for several agricultural grains and oilseeds. To satisfy consumer demand (and government policy), farmers, grain handlers, and food processors in many parts of the world are striving to segregate GMOs from non-GMOs while preserving their identities. (Henceforth we will denote non-GMO segregation and identity preservation simply by "IP.") In most cases, those who strongly desire to consume non-GM products have to pay price premiums to do so. These price premiums have engendered political resentment, as many of those who do not wish to consume GMOs feel that they are paying the costs of IP while those responsible for the creation and adoption of the technology reap economic benefits.

Yet, who benefits and who loses from the creation and adoption of GMO technology may not be quite so obvious. While non-GMO consumers may be paying a price premium, it is not clear that the price they pay is higher than the price they would have paid had GMOs never been introduced. Nor is it clear that they are the only group paying for IP costs. In this paper, our purpose is to explore the question of who pays the costs, who is to blame for the costs, and who reaps the benefits of maintaining a dual-market system of GMOs and non-GMOs.

To accomplish the purpose of our paper, we pay particular attention to the assumptions used to describe IP costs. For while changes in these assumptions clearly affect the results of the welfare analysis, different and sometimes contradictory assumptions about IP costs have appeared in economic studies. Most authors have assumed constant per-unit IP costs, entirely paid for by the producers/grain-handlers who actually perform the segregation and identity preservation (Mayer and Furtan, Saak and Hennessy, Lapan and Moschini, Lence and Hayes, Pekaric and Meilke, Golan and Kuchler, Sobolevsky et al.). Saak, as well as Nadolnyak and Sheldon, have pointed out that for the extra costs paid by IP producers may vary depending on the size of the IP channel. Only Giannakas and Fulton, without explicitly modeling it, have suggested that GMO producers/grain-handlers may bear some of the IP costs. Unfortunately, so far little attention has been paid to the consequences of these assumptions on the welfare effects of IP.

In the following section we contend that segregating GM and IP goods throughout the supply chain results in a loss in the flexibility with which grain can be produced, moved, and stored, and therefore creates costs for both non-IP and IP producers. The analytical supply and demand framework is presented in section three. Baseline results on the effects of adoption with total consumer acceptance are presented in section four. Section five considers the case of partial consumer rejection of GMOs. Also in section five we compare our welfare effects with the ones obtained under common assumptions about IP costs.

Characteristics of costs of segregation and identity preservation

Non-GMO segregation and identity preservation requires keeping non-GMOs intended for IP physically separated from GMOs along the supply chain. Maintaining this separation is achieved by dedicating moving, storing, and processing equipment to one of the two products, at least for a period of time. This dedication may result in higher costs due to capacity under-use, greater constraints to management as it must organize more complicated grain blending and grain flows, and additional transportation costs from handling or processing units that are dedicated to IP or to non-IP products separately. Therefore, the coexistence of IP and GMO products creates additional costs in the supply system by making it less flexible (Bullock and Desquilbet, 2002).

We propose that the costs of less flexibility are not borne by IP producers (a label we use to include farmers, handlers, and processors) alone, but are shared between IP and non-IP producers. More specifically, we expect that the larger is one of the two production channels, the larger will be the per-unit cost of production, handling, and processing in the other. Consider first a hypothetical situation in which IP products make up a small share of total supply. Then, only a small fraction of all handling and processing equipment ends up dedicated to the IP channel, and only during specified periods. Assume that the share of IP crops in total supply increases. Then, additional facilities will start to accept IP crops, or will accept them during wider periods of time. Therefore, IP producers will be able to move, store and process their goods with fewer constraints, and the per-unit cost of participating in the IP channel will decrease. Yet simultaneously, as the size of the IP channel grows, similar costs of participating in the regular channel will arise for non-IP producers, because they will be more constrained in moving, storing, and processing their products.

These costs of less flexibility depend on where other non-IP and IP farmers, handlers, and processors are located. In our non-spatial analytical framework, we account for them in a simple way, by assuming that they depend only on the share of the other good (IP or non-IP) in total production. More specifically, we let x_i denote the share of the IP good in total production (i.e. in IP plus non-IP production). Then, $1 - x_i$ denotes the share of the non-IP good in total production. For a given producer, we let the parameter g denote a per-acre production externality for the non-IP (also called "regular") good, and we let parameter e denote a per-unit production externality parameter for the IP good. Then, we assume that this producer faces a per-acre cost $g\, x_i$ if he produces the regular good, and a per-acre cost $e(1 - x_i)$ if he produces the IP good. The term $g\, x_i$ represents a negative production externality for a regular producer resulting from the existence of the IP supply channel. The term $e(1 - x_i)$ represents a negative production externality for an IP producer resulting from the existence of the regular supply channel. Our formulation assumes that these negative production externality costs increase linearly with the share of the other good in total production.

In addition to these costs of less flexibility, IP producers incur two other types of IP costs. First, sellers have to ensure buyers that products that are claimed as non-GM are non-GM indeed. Therefore, IP costs for IP producers also include costs of chemical tests, costs of drawing up contracts between buyers and sellers, and costs of monitoring contract abidance. Second, IP products must be kept from being mixed with GMOs. For cross-pollinated species, pollen from neighboring GM fields can fertilize plants in a non-

GM field and lead to the commingling of GM and non-GM grain. Preventing this cross-pollination may require costly measures, such as increasing distances between non-GM fields and GM fields, or harvesting border rows separately. All along the supply chain, maintaining high purity levels of IP products may create costs to clean equipment, or to dedicate equipment to IP products for long time periods to avoid having to clean it (Bullock and Desquilbet, 2002). These costs of IP are described by a per-acre cost parameter d in our model, which is incurred only by producers of the IP good.

Throughout the paper, we will consider that all IP producers bear identical costs of IP, and that all non-IP producers bear identical costs of IP (i.e. that parameters g, d and e are identical for all producers). It would be more realistic (yet more complicated) to model the costs of IP as heterogeneous among agents. For example, they could be small for a farmer located near an elevator willing to accept the type of crop that he produces, but dissuasive for a farmer located far away from an elevator willing to accept his production. If some elevators accepted a crop during periods other than harvest time, costs would be smaller for farmers possessing adequate on-farm storage capacity. For handlers and processors, strict tolerance levels can be attained more easily in facilities that have multiple paths (as opposed to a single path) of dump pits, legs, conveyor belts, etc, along which grain is moved. It is also easier to segregate IP crops in a facility with multiple small storage bins rather than a few large bins. Moreover, having different facilities in close proximity is an advantage for some handlers who may dedicate some locations to GMOs and others to non-GMOs. In the conclusions section we will discuss the implications of heterogeneity in the costs of IP.

Analytical framework

In order to analyze the aspects of non-GMO segregation and IP described above, we develop a one-country partial equilibrium supply and demand model allowing welfare analysis.[1] We assume that three different types of one good may be produced. The first type (indexed by n) originally sprouts from non-GM seed, but no steps are taken to prevent its possible commingling with a GM good. The second type (indexed by g) is produced from GM seed. The third type is indexed by i, and later is referred to simply as "the IP good". It is grown from non-GM seed, and special efforts are made to avoid commingling it with the GM good. We assume that since the non-GMO n has not been identity preserved, consumers have no way of telling it from the GMO g. So, consumers consider n and g to be the same product, which we call the regular good (indexed by r). Our notation is summarized in Table 1.

Producers

We consider one production sector, into which we aggregate farmers, handlers and processors. We assume the existence of a continuum of producers, each characterized by a set of parameters $\{a, b, g, d, e\}$. We assume that parameters a and b are continuously distributed with a joint probability density function $f(a,b)$ over the domain $\Psi_{ab} = \{(a, b): a \in [a_L, a_H], b \in [b_L, b_H]\}$. We assume that parameters g, d and e are identical for all producers. To maintain simplicity the assumed functional forms of our supply curves imply that each producer produces only one good in equilibrium (n, g, i or a, where the good indexed by a is an alternative crop). Each of the four goods is produced under competitive conditions with a Leontief technology, using a fixed factor owned by the producer and a set of variable inputs perfectly elastic in supply. For the purposes of illustration, we consider the case of a herbicide-resistant GM seed, used complementarily with the herbicide to which it is resistant. (Our model is easily applicable to analysis other types of GMOs, but we maintain the example of herbicide resistance for consistency throughout.) We assume that GMO adoption only affects weed-control inputs, with conventional herbicides being replaced by the herbicide to which the GM seed is resistant. We assume that the unit cost of this herbicide and of the technology fee paid to access to the GMO technology is equal to v, which we call the GMO technology and weeding cost. For simplicity, we assume that yield per acre of the regular good and the IP good do not differ, and we normalize this yield at one unit per acre.

We assume that the function showing profit per acre of good n takes the form:[2]

(1) $p^n(p_r, x_i; a, b, g) = p_r - a - b - gx_i$,

where p_r is the price of the regular good (the "regular price"), a is the per-acre conventional weed control cost, and b represents per-acre other costs of production.[3]

The functions showing per-acre profit from production of crops g and i, respectively, are

(2) $p^g(p_r, v, x_i; b, g) = p_r - v - b - gx_i$,

(3) $p^i(p_i, x_i; a, b, d, e) = p_i - a - b - d - e[1 - x_i]$,

where p_i is the price of the IP good (the "IP price").

We make the partial equilibrium assumption that the per-acre profit level obtained from the alternative crop is constant and equal to e for each producer:

(4) $p^a = e$.

The technology specified (see footnote 1) implies the producer always finds it optimal to grow only one crop, the one yielding the maximum profit level. The producer's maximum per-acre profit function is given by:

(5) $p^{\max}(p_r, p_i, v, x_i, e; a, b, g, d, e) = \text{Max}\left(p^{n}(.); p^{g}(.); p^{i}(.); e\right)$

For the duration of the paper, we suppress the argument *e*, which is kept constant in our model. The supply function for good $k = a, n, g, i$ is then defined by:

(6) $q_k^s(p_r, p_i, v, x_i; a, b, g, d, e) = \begin{cases} 1 & \text{if} \quad p^{\max}(.) = p^{k}(.) \\ 0 & \text{otherwise} \end{cases}.$

In the case in which more than one good-specific profit level is equal to the maximum profit level, we arbitrarily consider that the producer grows only one of the profit-maximizing goods, with good *i* being the most preferred, then *g*, then *n*, then *a*. In the fourth section, we consider more closely the case in which profits are equal for good *n* and good *i*. In the fourth and fifth sections we will specify aggregate supply functions for each of the situations that we study.

Consumers

We consider two attitudes of consumers towards GMOs: indifference or hatred. Indifferent consumers derive the same utility from the regular good and the IP good, while GMO-haters derive no utility from the regular good. We let q denote the proportion of GMO-haters in the population. Initially, we consider demand functions at the individual level. For simplicity, we assume that each consumer consumes either the regular good, the IP good, or neither; and consumes 0 or 1 unit of any of these goods. This type of assumption is common in the literature of vertical differentiation (see e.g. Mussa and Rosen, 1978). In addition, we neglect income effects. Two constant positive parameters s_r and s_i characterize each consumer's willingness to pay for the regular good and the IP good. For a consumer characterized by (s_r, s_i), Marshallian demand functions for goods r and i are assumed to take the form:

$$(7)\ q_r^d(p_r, p_i; s_r, s_i) = \begin{cases} 1 \text{ if } & s_r - p_r > s_i - p_i \text{ and } s_r - p_r \geq 0 \\ 0 \text{ if } & s_r - p_r < s_i - p_i \text{ or } s_r - p_r < 0 \end{cases},$$

$$(8)\ q_i^d(p_r, p_i; s_r, s_i) = \begin{cases} 1 \text{ if } & s_i - p_i > s_r - p_r \text{ and } s_i - p_i \geq 0 \\ 0 \text{ if } & s_i - p_i < s_r - p_r \text{ or } s_i - p_i < 0 \end{cases},$$

$$(9)\ q_{ri}^d(p_r, p_i; s_r, s_i) = 1 \quad \text{if} \quad s_r - p_r = s_i - p_i \geq 0,$$

where $q_{ri}^d(.)$ denotes the consumer's summed demand for good r and/or i.[4]

Let I denote the consumer's income. The implied indirect utility function is:

$$(10)\ V(p_r, p_i, I; s_r, s_i) = I + \text{Max}(s_r - p_r, s_i - p_i, 0).$$

For some positive number s, GMO-haters are characterized by $s_i = s$ and $s_r = 0$, while indifferent consumers are characterized by $s_i = s_r = s$. We assume that across the population s is distributed continuously with a probability density function $f_s(s)$. The aggregate demand function for good $k \in \{r, i\}$ is denoted $D_k(.)$ and is defined as the sum of individual demands for that good. We then have:[5]

$$(11)\ D_r(p_r, p_i, q) = \begin{cases} (1-q)D(p_r) & \text{if} \quad p_r < p_i \\ 0 & \text{if} \quad p_r > p_i \end{cases},$$

$$(12)\ D_i(p_r, p_i, q) = \begin{cases} qD(p_i) & \text{if} \quad p_r < p_i \\ D(p_i) & \text{if} \quad p_r > p_i \end{cases},$$

where

$$(13)\ D(p) = \int_p^{+\infty} f_s(s)\,ds \ .$$

When the regular price is equal to the IP price, indifferent consumers maximize utility by choosing either the IP good, the regular good, or both, while GMO-haters consume only the IP good. Therefore, we cannot define individual demand functions for the regular good and the IP good. But we know that quantities demanded of the regular good and the IP good, Q_r^d and Q_i^d, must satisfy:

(14) If $p_r = p_i$, then $Q_r^d + Q_i^d = D(p)$, $Q_i^d \geq q\, D(p)$, $Q_r^d \geq 0$, and $Q_i^d \geq 0$.

The introduction of GMO technology in the absence of hatred

In this section, we consider introduction of the GMO technology in the absence of hatred ($q = 0$). In such a situation's equilibrium, the IP good is neither supplied nor demanded. Therefore relevant per-acre profit functions are $p^n = p_r - a - b$, $p^g = p_r - v - b$ and $p^a = e$. Let Ψ_k denote the domain on which good $k = n$ or g is produced. The production domain and the supply function of good k are defined by:

(15) $\Psi_k(p_r, v) = \{(a,b) \in \Psi_{ab} : p^{\max}(p_r, v; a, b) = p^k\}$

(16) $S_k(p_r, v) = \int\int_{(a,b) \in \Psi_k(p_r, v)} f(a,b)\, db\, da$.

We then have:[6]

(17) $S_n(p_r, v) = \int_{a_L}^{Min(v, a_H, p_r - b_L - e)} \int_{b_L}^{Min(p_r - a - e, b_H)} f_{ab}(a,b)\, db\, da$,

(18) $S_g(p_r, v) = \int_{Max(a_L, v)}^{a_H} \int_{b_L}^{Min(p_r - v - e, b_H)} f_{ab}(a,b)\, db\, da$.

The equilibrium condition in the regular market is:

(19) $\Phi(p_r, v) = S_n(p_r, v) + S_g(p_r, v) - D(p_r) = 0$.

We model the absence of GMOs by letting v be equal to $v^{¥} > a_H$. (That is, the technology fee to grow the GMO crop plus the total herbicide cost is greater than the conventional weed-control costs of every farmer, so that it is not profitable for any farmer to adopt the GMO technology. In a sense, if the GMO had never been invented, its technology fee could be modeled as infinite.) We model the presence of GMOs by letting v be equal to $v^* \in (a_L, a_H)$. That is, we assume that the GMO technology and weed control cost paid by producers for access to the GMO and for the total herbicide is set higher than conventional weed control costs for some producers but lower than conventional weed-control costs for other producers. This would certainly be the case if the technology suppliers had market power; the technology fee would be set at a rate to give some but not all producers the incentive to pay the fee. In addition, we assume satisfaction of the following condition:

Condition A. $\Phi(v^* + b_L + e, v^*) < 0 < \Phi(v^* + b_H + e, v^*)$.

This condition ensures that when $v = v^*$, GM and non-GM equilibrium quantities are positive, and GM and non-GM supply functions are not constant in the neighborhood of the equilibrium. We then find the usual price and welfare effects resulting from the introduction of an innovation (see e.g. Alston et al., 1995), as stated in proposition 1.

Proposition 1.[7] *In the absence of hatred, introduction of GMO technology lowers the equilibrium regular price,* i.e., $p_r(v^*, 0) < p_r(v^¥, 0)$, where $p_r(v^¥, 0)$ denotes the equilibrium regular price in the absence of GMOs, $p_r(v^*, 0)$ denotes the equilibrium regular price in the presence of GMOs, $v^¥ > a_H$, and $v^* \in (a_L, a_H)$ satisfies condition A.

Corollary of proposition 1. *In the absence of hatred, all consumers gain from the introduction of GMO technology. Producers whose profit-maximizing choice is not to* *adopt GMO technology lose from its introduction. Among those producers whose profit-maximizing choice is to adopt GMO technology, those with "high conventional weed control costs" win from its introduction, while those with "low conventional weed control costs" lose.*

The intuition behind Proposition 1 and its corollary is straightforward. The technological change decreases production costs for GMO-adopters, shifts industry supply out, and thus decreases the equilibrium price. Since in this case no consumers hate GMOs, all consumers are made better off by the price drop. Non-adopters lose from this price drop since their production costs are left unchanged when the new technology is introduced. The simultaneous lowering of costs and price makes the effect of the technological change on adopters to be dependent on the degree to which costs are driven down, which will be different for different adopters. The higher are an adopter's conventional weed control costs, the more that adopter's costs are reduced by the new technology, and the more that adopter will win (or the less that adopter will lose) from the introduction of GMO technology.

The introduction of GMO technology in the presence of hatred, with identical IP cost parameters for all producers

Henceforth, we assume that consumers who hate GMOs make up some positive fraction of the population (i.e., that $q > 0$) and that IP cost parameters g, d and e are positive. Thus far the literature about non-GMO IP has considered most commonly that IP costs are constant and arise for IP producers only (i.e., that $g = e = 0$). In the following we simulate this particular case by letting g and e go to zero at the limit. We also simulate the more general case of $g > 0$, $e > 0$.

Supply functions

Individual producers are assumed capable of producing four different goods: n, g, i and a. The crop-specific per-acre profit functions for goods n, g, i, and a take the form $p^n = p_r - a - b - g\, x_i$, $p^g = p_r - v - b - g\, x_i$, $p^i = p_i - a - b - d - e(1 - x_i)$ and $p^a = e$. The production domain and the supply function for good $k = n, g, i$ is defined by:

(20) $\Psi_k(p_r, p_i, v, x_i) = \{(a, b) \in \Psi_{ab} : p^{\max}(p_r, p_i, v, x_i; a, b) = p^k\}$

(21) $S_k(p_r, p_i, v, x_i) = \int\int_{(a,b) \in \Psi_k(p_r, p_i, v, x_i)} f(a, b)\, db\, da$.

We define a function $E(x_i)$ to represent the per-acre cost difference between producers who grow the non-GM good and do segregate and preserve its identity and those who grow the non-GM good but do not segregate it and preserve its identity. This cost difference is not just d, the direct cost of IP, but also the difference in externality costs. (We will refer to $E(x_i)$ as the per-acre "difference in full IP costs.")

(22) $E(x_i) = d + e\,(1 - x_i) - g\, x_i$.

We can conclude from the per-acre profit functions that when the price premium equals to the difference in full IP costs, $p_i - p_r = E(x_i)$, any producer's per-acre profit from good n equals his per-acre profit from good i ($p^i = p^n$ for every producer). For those producers who obtain higher per-acre profits from good n or i than from good g or a, the profit-maximization problem does not have a unique solution determining how much of goods n or i should be produced. But we can define the sum of the total quantities supplied of good i and good n. This supply function is defined in equation (23) (where we use a bar to denote supply functions under the assumptions of this section, and where

$S_n(.)$ is defined in equation 17):[8]

(23) $\bar{S}_{ni}(p_r, p_r + E(x_i), v, x_i) \equiv S_n(p_r - gx_i, v)$.

Quantities supplied of the non-GM non-IP good and of the non-GM IP good, Q_n^s and Q_i^s, must then satisfy:

(24) If $p_i - p_r = E(x_i)$, then $Q_n^s + Q_i^s = \bar{S}_{ni}(p_r, p_r + E(x_i), v, x_i)$, $Q_n^s \geq 0$, $Q_i^s \geq 0$.

When $p_i - p_r \neq E(x_i)$, supply functions for goods i and n are defined separately as

$$(25)\ \begin{cases} \bar{S}_i(p_r, p_i, v, x_i) = 0 \text{ if } p_i - p_r < E(x_i) \\ \bar{S}_i(p_r, p_i, v, x_i) \equiv S_n(p_i - d - e(1 - x_i), v + p_i - p_r - E(x_i)) \text{ if } p_i - p_r > E(x_i) \end{cases}$$

$$(26)\ \begin{cases} \bar{S}_n(p_r, p_i, v, x_i) \equiv S_n(p_r - gx_i, v) \text{ if } p_i - p_r < E(x_i) \\ \bar{S}_n(p_r, p_i, v, x_i) = 0 \text{ if } p_i - p_r > E(x_i) \end{cases}$$

Finally, the supply function of good g is defined as

$$(27)\ \begin{cases} \bar{S}_g(p_r, p_i, v, x_i) \equiv S_g(p_r - gx_i, v) \text{ if } p_i - p_r \leq E(x_i) \\ \bar{S}_g(p_r, p_i, v, x_i) \equiv S_g(p_r - gx_i, v + p_i - p_r - E(x_i)) \text{ if } p_i - p_r > E(x_i) \end{cases}$$

Description of equilibria

Definition. Given v and q, an ordered triplet $(p_r, p_i, x_i) \in \Re_+^2 \times [0, 1]$ is an *equilibrium triplet* if there exists $(Q_n^s, Q_i^s, Q_r^d, Q_i^d) \in \Re_+^4$ for which equilibrium equations (28) to (30) all hold:

(28) $\bar{S}_g(p_r, p_i, v, x_i) + Q_n^s = Q_r^d$,

(29) $Q_i^s = Q_i^d$,

(30) $x_i = \dfrac{Q_i^d}{Q_r^d + Q_i^d}$,

and additionally if the following hold: (a) on the supply side: $Q_n^s = \bar{S}_n(p_r, p_i, v, x_i)$ and

$Q_i^s = \bar{S}_i(p_r, p_i, v, x_i)$ whenever $p_i - p_r \neq E(x_i)$; $Q_n^s + Q_i^s = \bar{S}_{ni}(p_r, p_i, v, x_i)$ whenever $p_i - p_r = E(x_i)$; (b) on the demand side: $Q_r^d = D_r(p_r, p_i, q)$ and $Q_i^d = D_i(p_r, p_i, q)$, whenever $p_i \neq p_r$; and $Q_r^d + Q_i^d = D(p_r)$ whenever $p_i = p_r$.

According to our definition, equilibrium prices allow the markets of the regular good and the IP good to clear, and in equilibrium the value of x_i is equal to the quantity of the IP good demanded by consumers divided by the sum of the quantities of the IP good and the regular good demanded by consumers.

In Propositions 2 and 3, we examine the conditions under which the GMO and the IP good are both produced in positive quantities in the equilibrium of our model.

Condition B. $D(p_r(v^*, 0) + d + e) > 0$.

Proposition 2. *If the parameters characterizing full IP costs for IP producers are "not too high", as long as some fraction of the population hates GMOs, a market for the segregated and identity-preserved non-GMO good will arise.* That is, letting $v = v^*$ and $q > 0$ and letting condition B hold, then there is no equilibrium triplet (p_r, p_i, x_i) such that $p_i - p_r < E(x_i)$, and in equilibrium a positive quantity of the IP good is supplied and demanded.

Condition B holds if the parameters characterizing full IP costs for IP producers, d and e, are "not too high".[9] From Proposition 2, this condition implies that the IP equilibrium quantity is positive in any equilibrium of our model: the equilibrium price of the IP good is always low enough to have some consumers demand the IP good.

Condition C. $g < a_H - v^* + d$ and $g < p_r(v^*, 0) - v^* - b_L - e$.

Proposition 3. *If the parameter characterizing full IP costs for regular producers is "not too high", even though some fraction of the population hates GMOs, a market for the GMO will arise.* More formally, assume that $v = v^*$ and $q > 0$. If condition C holds, then there is no equilibrium triplet (p_r, p_i, x_i) such that $p_i < p_r$, and in equilibrium a positive quantity of the GM good is supplied and demanded.

Condition C holds if g is "not too high", and therefore if the externality cost for regular producers, $g\,x_i$, is "not too high". Then, a market for the GMO will exist, and in equilibrium the IP price will be at least as high as the regular price. (Otherwise, some producers would be ready to produce the GMO, but indifferent consumers would prefer to consume the cheaper IP good rather than the regular good.)

In Propositions 4 and 5, we examine the conditions under which there is no IP price premium (i.e. $p_i = p_r$) in the equilibrium of our model. For this purpose, we define:

(31) $\tilde{x}_i = \dfrac{d+e}{g+e}$.

It is immediate to see that full IP costs for regular producers, $g\,x_i$, are identical to full IP costs for IP producers, $d + e\,(1 - x_i)$, if and only if the share of the IP good in total consumption, x_i, is equal to the value $\tilde{x}_i$ defined in equation (31). For any $x_i < \tilde{x}_i$, full IP costs for regular producers are lower than full IP costs for IP producers. Respectively, for any $x_i > \tilde{x}_i$, full IP costs for regular producers are higher than full IP costs for IP producers.

Proposition 4. *As long as full IP costs are lower for regular producers than for IP producers, there is no equilibrium without an IP price premium.* More formally, assume that $v = v^*$ and $q > 0$. If condition B holds, then there is no equilibrium triplet (p, p, x_i) such that $x_i < \tilde{x}_i$.

Corollary to Proposition 4. If $g < d$ and if condition B holds, then there is no equilibrium triplet (p, p, x_i).

If full IP costs for regular producers are lower than full IP costs for IP producers and if there is no IP price premium, all non-GMO producers obtain higher profits if they do not to identity-preserve their good. Therefore, there is no IP production. This cannot be equilibrium from Proposition 2. If g is smaller than d, $\tilde{x}_i$ is higher than 1. Since in any equilibrium of our model x_i must be between 0 and 1, there is no equilibrium without an IP price premium if g is smaller than d.

Condition D. Assume that if $g \geq d$, then the two following conditions hold:

D.1. $S_n(p_r(v^*, 0)) < \tilde{x}_i D(p_r(v^*, 0) + g\ \tilde{x}_i)$

D.2. Given $p \in \Re_+$ and $x_i \in [\tilde{x}_i, 1]$, we have that: $D(p) >$

$$Max[(g+e)(S_{g1}-S_{g2})-e(1-x_i)D'(p),(g+e)S_{n2}-gx_iD'(p),(g+e)((1-x_i)S_{n2}-x_iS_{g2}],$$

where S_{gk} is the derivative of $S_g(p - g\, x_i, v^* - E(x_i))$ with respect to its k^{th} argument and S_{nk} is the derivative of $S_n(p_i - d - e\,(1 - x_i), v^* - E(x_i))$ with respect to its k^{th} argument, for k = 1, 2. From (17) and (18), $S_{n1} \geq 0$, $S_{g1} \geq 0$, $S_{n2} \geq 0$, $S_{g2} \leq 0$.

Proposition 5. Assume that $v = v^*$, $q > 0$ and $g \geq d$. Equilibria in which there is no IP premium (i.e. $p_i = p_r = p$) are characterized as follows.

a. If full IP costs are identical for regular producers and for IP producers ($x_i = \tilde{x}_i$), (p, p, $\tilde{x}_i$) is an equilibrium triplet iff $\bar{S}_g(p, p, v^*, \tilde{x}_i) + \bar{S}_{ni}(p, p, v^*, \tilde{x}_i) = D(p)$, $\bar{S}_{ni}(p, p, v^*, \tilde{x}_i) \geq \tilde{x}_i D(p)$ and $q \leq \tilde{x}_i$.

b. If full IP costs are higher for regular producers than for IP producers ($x_i > \tilde{x}_i$), (p, p, x_i) is an equilibrium triplet iff $\bar{S}_g(p, p, v^*, x_i) = (1 - x_i) D(p)$, $\bar{S}_i(p, p, v^*, x_i) = x_i D(p)$ and $q \leq x_i \leq 1$.

c. *If the IP full cost parameters* g, d *and* e *are "not too high," even when full IP costs for regular producers are higher or equal to full IP costs for IP producers, there is no equilibrium without an IP price premium.* More formally, if condition D.1 holds, then there is no equilibrium triplet of the type described in Proposition 5a. And if condition D.2 holds, the absence of an equilibrium triplet of the type described in Proposition 5a implies the absence of an equilibrium triplet of the type described in Proposition 5b.

Proposition 5 describes equilibria in which there is no premium for IP production ($p_i = p_r = p$). In equilibrium, by definition of the equilibrium value of x_i, the IP consumption, Q_i^d, must be equal to $x_i D(p)$, and the regular consumption, Q_r^d, must be equal to $(1 - x_i) D(p)$. Because the price of the IP good and the price of the regular good are the same, all indifferent consumers derive the same utility from consuming any of these two goods. GMO-haters, as for them, derive no utility from consuming the regular good. Then in equilibrium all regular consumption comes from indifferent consumers, while IP consumption may come from both indifferent consumers and GMO-haters. Therefore, in equilibrium the IP consumption by GMO-haters, $q D(p)$, has to be smaller or equal to the total IP consumption, Q_i^d.

If full IP costs are identical for regular producers and for IP producers ($x_i = \tilde{x}_i$), all non-GMO producers are indifferent between supplying good *n* and good *i*. In equilibrium, total supply of the GM and non-GM goods must equal to total demand for the IP and regular goods, and the non-GM supply, $\bar{S}_{ni}(p, p, v, x_i)$, must at least cover the IP consumption, Q_i^d (Proposition 5a).

If full IP costs are higher for IP producers than for regular producers ($x_i > \tilde{x}_i$), then all the non-GM good is identity-preserved. Therefore the IP consumption must equal the IP production and the regular consumption must equal the GM production in equilibrium (Proposition 5b).

From Proposition 5c, these equilibria where there is no IP price premium cannot arise if condition D holds. This condition holds if the full IP cost parameters g, d and e are "not too high" (it necessarily holds when these parameters are close to zero).[10] This condition is quite technical, but basically the intuition is the following. Assume that this condition holds. Assume that there is no IP price premium. Then in equilibrium the share of the IP good in total production would be low, so that actually the full costs of IP for regular producers would be lower than the full costs of IP for IP producers.

Propositions 2 to 5 imply that as long as the IP full cost parameters g, d and e are "not too high," in any equilibrium the IP price will be higher than the regular price and the IP price premium ($p_i - p_r$) will be at least as great as the difference in full IP costs ($E(x_i)$). Proposition 6 describes such equilibria.

Condition E. Given $q \in (0,1)$ and given a price pair $(p_r, p_i) \in \Re_+^2$, if x_i satisfies

$x_i = \dfrac{q\ D(p_i)}{(1-q)D(p_r) + q\ D(p_i)}$, then we have that:

$$(1-q)D(p_r) + qD(p_i) > Max[-gx_i(1-q)D'(p_r) - e(1-x_i)qD'(p_i)$$
$$-(g+e)(1-x_i)qD'(p_i), -(g+e)x_i(1-q)D'(p_r)],$$

where $D'(p)$ is the price-derivative of $D(p)$ and is negative from equation (13).

Proposition 6. Assume that $v = v^*$ and $q > 0$.

a. Given $p_i > p_r$ and $p_i - p_r = E(x_i)$, (p_r, p_i, x_i) is an equilibrium triplet iff

$\bar{S}_g(p_r, p_i, v^*, x_i) + \bar{S}_{ni}(p_r, p_i, v^*, x_i) = (1 - q)\ D(p_r) + q\ D(p_i)$, $\bar{S}_{ni}(p_r, p_i, v^*, x_i) \geq q\ D(p_i)$

and $x_i = \dfrac{q\ D(p_i)}{(1-q)D(p_r) + q\ D(p_i)}$.

b. Given $p_i > p_r$ and $p_i - p_r > E(x_i)$, (p_r, p_i, x_i) is an equilibrium triplet iff

$\bar{S}_g(p_r, p_i, v^*, x_i) = (1 - q)\ D(p_r)$, $\bar{S}_i(p_r, p_i, v^*, x_i) = q\ D(p_i)$,

and $x_i = \dfrac{q\ D(p_i)}{(1-q)D(p_r) + q\ D(p_i)}$.

c. Assume that condition E holds and that

(*) $\qquad x_i = \dfrac{q\ D(p_i)}{(1-q)D(p_r) + q\ D(p_i)}$.

Given $p_i - p_r = E(x_i)$, (*) implicitly defines $x_i = f(p_r, q)$. Then we can define equilibrium supply functions $\hat{S}_g(p_r, v^*, q) \equiv \bar{S}_g(p_r, p_r + E(f(p_r, q)), v^*, f(p_r, q))$ and $\hat{S}_{ni}(p_r, v^*, q) \equiv \bar{S}_{ni}(p_r, p_r + E(f(p_r, q)), v^*, f(p_r, q))$. Both functions are non-decreasing in p_r.

Given $p_i - p_r > E(x_i)$, (*) implicitly defines $x_i = g(p_r, p_i, q)$. Then we can define equilibrium supply functions $\tilde{S}_g(p_r, p_i, v^*, q) \equiv \bar{S}_g(p_r, p_i, v^*, g(p_r, p_i, q))$ and $\tilde{S}_i(p_r, p_i, v^*, q) \equiv \bar{S}_i(p_r, p_i, v^*, g(p_r, p_i, q))$. $\tilde{S}_g(.)$ is non-decreasing in p_r and non-increasing in p_i, and

$\tilde{S}_i(.)$ is non-increasing in p_r and non-decreasing in p_i.

Proposition 6a describes equilibria in which the IP premium exactly covers the difference in full IP costs (p_i - $p_r = E(x_i)$). This causes all non-GMO producers to be indifferent between supplying the non-GM non-IP good and the non-GM IP good. In these types of equilibria the production of the non-GM good exceeds the demand for the IP good by GMO-haters. Some of the non-GM good is then sold as an IP good to GMO-haters. The rest of the non-GM good is sold as a regular product to indifferent consumers.

Proposition 6b describes equilibria in which the IP premium exceeds the difference in full IP costs (p_i - $p_r > E(x_i)$). In such equilibria all non-GMO production is also identity-preserved, and demanded only by GMO-haters, while indifferent consumers consume only the GM good.

From Proposition 6c, condition E ensures the "good behavior" of equilibrium supply functions obtained by constraining x_i to be equal to its equilibrium value: given p_i - $p_r = E(x_i)$, the GM and the non-GM supply function are both price increasing; given p_i - $p_r > E(x_i)$, the GM and the IP supply function are both increasing in their own price and decreasing in the price of the other good. Basically, condition E holds if the externality cost parameters g and e are "not too high" (it necessarily holds when $g = e = 0$). This condition will be useful in the comparative statics analysis below, because it is a sufficient condition for the stability of equilibria of the type described in Proposition 4.

Price and welfare effects

Condition F. $d < p_r(v^*, 0) - v^* - b_L - e$.

Proposition 7. Let v be equal to v^*. Assume that conditions A to F hold.

a. There is a unique number $q^* \in (0, Min(\tilde{x}_i, 1))$ and a unique accompanying equilibrium triplet (p_r^*, p_i^*, x_i^*) of the type described in proposition 6a satisfying $\bar{S}_{ni}(p_r^*, p_i^*, v^*, x_i^*) = q^* D(p_i^*)$.

b. Let q^* be defined as in Proposition 7a. Any q^L satisfying $0 < q^L < q^*$ is accompanied by a unique equilibrium triplet. This equilibrium triplet is of the type described in proposition 4a and satisfies $\bar{S}_{ni}(p_r, p_i, v, x_i) > q\, D(p_i)$. In addition, for any q^H satisfying $q^* < q^H = 1$, any accompanying equilibrium must be of the type described in proposition 6b.

With a small amount of hatred ($q < q^*$), in equilibrium the IP premium ($p_i - p_r$) just covers the difference in full IP costs ($E(x_i)$), because then the production of the non-GM good exceeds the demand for the IP good by GMO-haters. With much hatred ($q > q^*$), the premium for IP is greater than the difference in full IP costs for IP and regular producers ($p_i - p_r > E(x_i)$), because some producers with high conventional weed control costs (that is $a > v$) have to be willing to leave the GMO sector (that is, give up the low cost v and instead bear a) and go into the IP sector.

Proposition 8 gives the price effects of the introduction of the GMO technology in the presence of hatred, or the introduction of the hatred in the presence of GMOs. The corollary to Proposition 8 gives welfare changes of individual producers and consumers following from the introduction of GMO technology or hatred.

Proposition 8. Let v be equal to v^*. Assume that conditions A to F hold. For $z_k = p_r, p_i, x_i$, we let $z_k(v^*, q)$ denote the equilibrium value of z_k. For any $q \in (0, 1)$ we then have: $p_r(v^*, q) - g\, x_i(v^*, q) < p_r(v^*, 0) < p_i(v^*, q)$. Other relative price levels depend on the model's parameterization.

Corollary of proposition 8

a. Effects of the introduction of GMO technology, given hatred.

- If there are no IP costs for regular producers, then indifferent consumers are all helped. Otherwise, indifferent consumers are either all hurt or all helped, depending on the model parameterization.
- GMO-haters are either all hurt or all helped, depending on the model parameterization.
- GMO producers characterized by "high conventional weed costs" are helped, while GMO producers characterized by "low conventional weed costs" are hurt.
- Given a small amount hatred, all those who are non-GMO producers in the presence of hatred are hurt. Given much hatred, all these producers are either hurt or helped depending on model parameterization.

b. Effects of the introduction of hatred, given GMO technology.

- Assume that regular producers bear none of the cost caused by less efficiency in the grain production and handling system. Then consumers who remain indifferent to GMOs and non-GMOs are helped when other consumers begin to hate GMOs.
- Assume that regular producers do bear some of the cost caused by less efficiency in the grain production and handling system. Then, depending on the model

parameterization, indifferent consumers are either all hurt or all helped when other consumers begin to hate GMOs.

- GMO-haters pay more than they would pay if everybody accepted GMOs.
- Those who are GMO producers in the presence of hatred are all hurt
- Those who are non-GMO producers in the presence of hatred are all hurt by the introduction of a small amount of hatred, while they are either all hurt or all helped by the introduction of much hatred, depending on the model parameterization.

First, we consider the effects of GMOs and hatred on GMO-haters. Segregation and identity preservation are costly procedures, and parts of these costs are passed along to those who refuse to consume GMOs. Therefore, given GMO technology, GMO-haters necessarily pay more than they would pay if everybody accepted GMOs ($p_r(v^*, 0) < p_i(v^*, q)$). However, given hatred, the introduction of GMOs may increase or decrease the price paid by GMO-haters: $p_r(v^¥, 0)$ may be higher or lower than $p_i(v^*, q)$. In other words, GMO-haters may end up paying more or less than if GMO technology had never appeared. This indeterminate effect results from two opposing effects. First, costs of IP are partially transmitted to GMO-haters (which tends to make $p_i(v^*, q)$ higher than $p_r(v^¥, 0)$). Second, as the GMO technology is introduced, those who were formally the non-GMO producers characterized by the highest conventional weed control costs become GMO producers. As a result, those who are left to produce the non-GM good are the former non-GMO producers characterized by the smallest weed control costs. As this cut in weed control costs tends to make $p_i(v^*, q)$ smaller than $p_r(v^¥, 0)$. . *Therefore, our model suggests that the complaints of anti-GMO consumers and activists that they are* *made worse off by the appearance of the GMO technology may be legitimate or illegitimate.*

We now consider the effects of GMO technology and GMO-hatred on indifferent consumers. Consider the introduction of hatred given that GMO technology is available. First, assume that there are no IP costs for regular producers ($g = 0$). This assumption about IP costs is the most common one in current models of IP (see Introduction). As hatred is introduced, the regular demand function shifts in, because some consumers turn to the IP market. In equilibrium, the regular price then decreases ($p_r(v^*, q) < p_r(v^*, 0)$). Since $p_r(v^*, 0) < p_r(v^{¥}, 0)$, in this case, indifferent consumers necessarily win from the introduction of GMOs, and the presence of GMO-haters makes them win even more. Now, assume that there are IP costs for regular producers ($g > 0$). In this case, regular producers bear part of the IP cost, but another part is transmitted to indifferent consumers. As a result, the relative levels of $p_r(v^*, 0)$ and $p_r(v^*, q)$ are indeterminate, and the relative levels of $p_r(v^{¥}, 0)$ and $p_r(v^*, q)$ are indeterminate as well. Therefore, those whose tastes make no distinction between GMOs and non-GMOs may end up paying a higher price for their food than they otherwise would have, because demands for segregation and identity preservation by anti-GMO consumers can make the entire supply system less efficient. Part of the cost of this inefficiency is passed along in the form of higher food prices to the indifferent consumers. *So, just as GMO-hating consumers may blame the higher prices they pay on the corporations that introduced GMO technology, indifferent consumers may also have to pay higher prices, and be able to blame it on GMO-hating consumers.*

Now, we consider the effects of GMO technology and GMO-hatred on producers of various kinds. GMO producers necessarily lose from the introduction of hatred ($p_r(v^*, q) - g\, x_i(v^*, q) < p_r(v^*, 0)$). Also, GMO producers characterized with low cost savings from GMO adoption lose from the introduction of GMOs in the presence of hatred. However, given hatred, GMO producers characterized with high cost savings from GMO adoption win from the introduction of GMOs. Non-GMO producers are worse off when GMOs are introduced into a market with a small amount of hatred ($p_i(v^*, q^L) - d - e\ (1 - x_i(v^*, q^L)) < p_r(v^*, 0) < p_r(v^¥, 0)$). As the amount of hatred increases, encouraging additional producers to turn to the IP market may require an increase in the IP price. As a result IP producers may win or lose from the introduction of a high amount of hatred: ($p_i(v^*, q^H) - d - e\ (1 - x_i(v^*, q^H))$ may be lower or higher than $p_r(v^*, 0)$).

Marion: I think we need a table showing who wins/who loses in different circumstances. I'll try to come up with such a table.

Conclusions

We have developed a model of segregation and identity preservation of non-GM products, recognizing that IP costs may arise for both IP and non-IP producers and may vary depending on the relative sizes of the two production channels. We study welfare effects of the introduction of GMOs with partial consumer rejection. Our model predicts that whether consumers who reject GMOs are made better or worse off by their introduction. Another important result of our model is that even indifferent consumers may be made worse off by the introduction of GMOs provided that there exist other consumers who reject GMOs. This result contrasts with the result obtained under the literature's most common assumption, which is that non-GMO segregation and IP are not costly for non-IP producers. This result has important implications for real-world situations, notably if we consider the potential large-scale introduction of GMOs in regions where they face strong consumer rejection like the European Union. For the implication is that even people who are perfectly happy to consume GMOs may be made worse off by their introduction into the market place—even if there are no true ill-effects from GMO consumption *per se*.

An aspect that we have not studied in our model is that IP costs may be heterogeneous between producers - an assumption that we believe to be more realistic than our assumption of identical IP cost parameters for all producers. If IP costs are different from one producer to the other, different GMO producers and different non-GMO producers will be affected in different ways by the introduction of GMOs. Notably, producers who are the most efficient at identity-preserving their good may end up better off than they were in the pre-GMO situation, even when few consumers reject GMOs (while all IP producers necessarily lose in an equivalent situation in our model). This result also has important implications for real-world situations, notably for the current situation in the United States, where producers are facing GMO rejection in export markets. Currently, the export demand for IP products is lower than the non-GM production in the U.S. Any IP model that assumes homogeneous costs of IP would suggest that these IP producers obtain lower profit levels than would have been the case if GMOs had not been introduced. The assumption of heterogeneity in IP costs would permit recognition that some IP producers may win from the introduction of GMOs, even with a small amount of hatred, and even though they are not themselves producing

GMOs.

Various aspects not considered in our study merit further investigation. A first question relates to the behavior of innovators selling the GMO technology when IP is introduced. In our model, the price set by innovators for the GMO technology is exogenous. in actuality, innovators strategically adapt their prices in the presence of GMO rejection (Lapan and Moschini). Another question of interest is the potential role of public intervention, such as taxes on GMO producers or subsidies to non-GMO producers, to alter the welfare effects following from consumer rejection of GMOs. These questions are particularly important in the current political climate, in which some politicians have opined that all additional costs resulting from segregation and IP should be made to be borne by users of GMOs.[11] Our model widens the road for further empirical investigation of the welfare effects of policy changes affecting GMOs and related markets. Of particular interest would be an empirical analysis of the two real-world situations mentioned in our paper (the U.S.'s situation of exporting the IP goods to countries facing large-scale GMO refusal, and the EU's situation of potential adoption of GMOs where a large share of domestic consumers refuse GMOs.)

References

Alston, J.M., Norton, G.W., and P.G. Pardey. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. CAB International, Oxon, UK, New York, USA, 1998.

Bullock D.S., and M. Desquilbet. "The economics of non-GMO segregation and identity preservation." *Food Policy* 27(February 2002): 81-99.

Bullock, D.S., and E.I. Nitsi. "Roundup Ready Soybean Technology and Farm Production Costs: Measuring the Incentive to Adopt." *American Behavioral Scientist*, 44(*** 2001):1283-1301.

Fernandez-Cornejo, J., and W.D. McBride. *Adoption of Bioengineered Crops*. USDA ERS Agricultural Economic Report No. 810, May 2002.

Giannakas, K., and M. Fulton. "Consumption Effects of Genetic Modification: What if Consumers Are Right?." *Agricultural Economics*, 27(*** 2002), 97-109.

Golan E., and F. Kuchler. "Labeling biotech foods: implications for consumer welfare and trade." Presented at International Agricultural Trade Research Consortium Symposium, Montreal, Canada, June 26-27 2000.

Lapan H., and G. Moschini (2002). "Innovation and trade with endogeneous market failure: the case of genetically modified products." Working Paper 02-WP 302, Center for Agricultural and Rural Development, Ames, Iowa, USA.

Lence S., and D. Hayes (2001). "Response to an asymmetric demand for attributes: an application to the market for genetically modified crops." *NCR-134 Conference on Applied Commodity Price Analysis, Forecasting and Market Risk Management*, St Louis, Missouri, USA.

Mayer, H., and W.H. Furtan (1999). "Economics of transgenic herbicide-tolerant canola: The case of Western Canada." *Food Policy* 24: 431-442.

Nadolnyak, D.A., and I.M. Sheldon (2002). "A model of diffusion of genetically modified crop technology in concentrated agricultural processing markets - the case of soybeans." *6th ICABR conference "Biotechnology, science and modern agriculture: a new industry at the dawn of the century*", Ravello, Italy.

Pekaric-Falak, I., Meilke, K.D., and K. Huff, (2001). "The trade effects of Bt corn." Canadian Agri-Food Trade Research Network.

Saak, A.E. (2002). "Identity preservation and false labeling in the food supply chain." Working Paper 02-WP 295. Ames, Iowa, Center for Agricultural and Rural Development.

Saak, A.E., and D.A. Hennessy. "Planting decisions and uncertain consumer acceptance of genetically modified crop varieties." *Amer. J. Agr. Econ.* 84(May 2002):***.

Table 1. Notation

Indexes	
a	alternative crop
g	GM good
n	non-GM non-IP good
r	regular good (*g* and *n*)
i	IP good
Exogenous parameters	
v	GMO technology and weed control cost
q	proportion of GMO-haters
Parameters for producers	
a	unit weed control cost for the non-GM good
b	unit other production costs, excluding the externality cost
g	externality parameter of segregation costs for regular producers
d	constant IP costs for IP producers
e	externality parameter of segregation costs for IP producers
e	unit profit on the alternative crop
x_i	share of the IP good in total production
$g x_i$	full IP costs for regular producers
$d + e(1- x_i)$	full IP costs for IP producers
$E(x_i)$	difference in full IP costs between IP and regular producers
Parameters for consumers	
s_r	willingness to pay for the regular good

s_i willingness to pay for the IP good

End Notes

[1] In this paper we use a one-country model in order to limit the number of variables. However, we would obtain similar welfare effects in a multi-country situation.

[2] The profit function given in (1) is derived from a Leontief production function of the type: $Y_n = Min\{b_0\, y_{0n} / x_i,\ b_1\ y_{1n},...,\ b_m\ y_{mn},\ F_n\}$, where b_j is a parameter and y_{jn} is the quantity of variable input j, for $j \in \{0,..., m\}$, and where F_n is the amount of fixed factor that the farmer devotes to crop n. Input 0 is needed only when x_i is strictly positive, and the larger is x_i, the higher is the quantity of this input necessary to produce the amount Y_n. Input 1 is herbicide. Let v_j denote the price of variable input j (kept constant in our model). Then it can be shown that $a = v_1 / b_1, b = \sum_{j=2}^{m} (v_j / b_m)$ and $g = v_0 / b_0$.

[3] Several studies underline that economic benefits from adopting GMOs vary widely between farmers (Bullock and Nitsi; Fernandez-Cornejo and McBride). One main reason is that different farmers face different weed situations, or different insect pressures, so that pesticide cost reductions or yield changes following from GMO adoption vary among them. In our model we assume heterogeneity in potential pesticide cost reductions, i.e. heterogeneity in parameter a.

[4] The implied utility function is given by: $u(q_r, q_i, q_z; s_r, s_i) = (s_r q_r + s_i q_i)/(q_r + q_i) + q_z$ if $q_r + q_i \geq 1$, $u(q_r, q_i, q_z; s_r, s_i) = s_r q_r + s_i q_i + q_z$ otherwise, where z is the numeraire and q_j is the quantity of good j. This utility function implies that each consumer reaches the satiation level after consuming one unit of the regular or the IP good.

[5] Our specification implies that as long as $p_r < p_i$, cross-price elasticities of demand functions for goods *r* and *i* are equal to zero. This assumption simplifies the comparative statics analysis. This framework could be extended to consider that some consumers view the IP good as superior to the regular good, yet are ready to consume the regular good if it is inexpensive enough relative the IP good.

[6] Production domains are given by: $\Psi_n(p_r,v) = \{(a,b) \in \Psi_{ab} : a < v,\ p_r - a - b \geq e\}$, and $\Psi_g(p_r,v) = \{(a,b) \in \Psi_{ab} : v \leq a,\ p_r - v - b \geq e\}$.

[7] Proofs of the propositions are lengthy, and have been omitted from the paper to save space. Proofs are available from the authors.

[8] Production domains are given by: $\Psi_{ni}(p_r, p_r + E(x_i), v, x_i) = \{(a, b) \in \Psi_{ab}: a \leq v, p_r - g x_i - a - b \geq e\}$; $\Psi_i(p_r, p_i, v, x_i) = \varnothing$ if $p_i - p_r < E(x_i)$, $\Psi_i(p_r, p_i, v, x_i) = \{(a, b) \in \Psi_{ab}: a \leq v + p_i - p_r - E(x_i), p_i - d - e(1 - x_i) - a - b \geq e\}$ if $p_i - p_r > E(x_i)$; $\Psi_n(p_r, p_i, v, x_i) = \{(a, b) \in \Psi_{ab}: a \leq v, p_r - g x_i - a - b \geq e\}$ if $p_i - p_r < E(x_i)$, $\Psi_n(p_r, p_i, v, x_i) = \varnothing$ if $p_i - p_r > E(x_i)$; $\Psi_g(p_r, p_i, v, x_i) = \{(a, b) \in \Psi_{ab}: a > v + \text{Max}(p_i - p_r - E(x_i), 0), p_r - g x_i - v - b \geq e\}$.

[9] From Proposition 1, $D(p_r(v^*, 0))$ is the equilibrium regular quantity demanded when GMOs are introduced in the absence of hatred. This quantity is positive. Since $D(p_r(v^*, 0) + d + e)$ decreases as $d + e$ increases, this quantity will be non-zero as long as $d + e$ is "not too high".

[10] If $g = d$ then condition 5.1 is given by: $S_n(p_r(v^*, 0)) < D(p_r(v^*, 0) + g)$. If $g = 0$ this condition necessarily holds. It can be easily checked that $\tilde{x}_i D(p_r(v^*, 0) + g \tilde{x}_i)$ decreases as g increases. Therefore, condition 5.1 holds if g is sufficiently small. And condition 5.2

holds if $g = e = 0$ and if these parameters are sufficiently small.

[11] The German minister of agriculture, supported by its Austrian and Italian homologues, made a declaration in this sense in June 2002 (Agra-Europe, l'agence d'information agro-économique Bruxelles-Paris, Agra-Presse n°2867, July 2002).