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Abstract

A framework is developed for examining the price and welfare effects of the introduction of genetically modified (GM) crops. In the short run, non-GM grain generally becomes another niche product. However, more profound market effects are observed under some reasonable parameterizations. In the long run, consumer and producer welfare are usually greater after the introduction of GM technology. Nevertheless, in all instances some consumers and some producers lose. When identity preservation is expensive and cost savings are relatively small, both producer and consumer welfare are lower after introducing GM technology. Interestingly, this outcome is obtained even though all agents are individually rational.

Key words: asymmetric demand, consumer response, genetically modified (GM) crops, market response, non-GM crops, price signals, welfare analysis.

RESPONSE TO AN ASYMMETRIC DEMAND FOR ATTRIBUTES: AN APPLICATION TO THE MARKET FOR GENETICALLY MODIFIED CROPS

The rapid adoption of genetically modified (GM) crop varieties by farmers in the United States, Canada, and Argentina in the late 1990s created an interest among some consumers in having continued access to non-modified varieties. This consumer response appears to have been strongest in the European Union (EU), but it created a worldwide reaction against GM grain among companies that process food for direct human consumption. The consumer response also created concern among firms that process grain for animal feed. The first example of a restriction on GM grain for animal feed occurred in South Korea in March of 2001. The EU has also begun consideration of an animal feed directive. The possibility that the EU might restrict imports of GM grain products in turn caused some U.S. grain processors to request non-GM grain. The apparent motivation for grain processors is to maintain access to the EU market for corn gluten, a valuable by-product of both the fuel and corn sugar industries. These trade and commercial developments are reviewed by Carlson, Marra, and Hubbell (1997); James (1997, 1998, 2000); Hubbell, Marra, and Carlson (2000); Lin, Chambers, and Harwood (2000); Ballenger, Bohman, and Gehlar (2000); and McCluskey (2000).

The market response to these developments will depend on the relative size of the supply and demand for GM and non-GM varieties. One interesting feature of the market is the asymmetry with which customers will respond to market conditions. If the non-GM output share exceeds the corresponding demand share, then there will be a relative surplus of non-GM crops. This means that a consumer who is indifferent between GM and non-GM crops will end up consuming some non-GM grain. Because this consumer will not be willing to pay a premium for non-GM grain, some non-GM grain will be sold at the same price as GM grain. The rest of the non-GM output will be sold at a premium that pays for the additional handling charges, much as occurs in existing niche markets.

If the non-GM output share is smaller than the respective demand share, then a consumer who would have preferred non-GM grain will end up purchasing GM grain. For this to occur, all GM grain would have to be discounted to make the marginal consumer indifferent about buying GM or non-GM grain. One additional complicating factor is that output and demand uncertainty at the beginning of any crop year makes it difficult to predict production and demand shares.

The purpose of this paper is to describe the equilibrium conditions for markets with both types of grain. We provide both an algebraic form of these conditions and a simplified version in graphical form. We then use these conditions and a set of reasonable parameters to describe the conditions under which premiums and discounts will emerge and to explain how the sizes of these differences are related to the causal factors. The first scenario assumes that supply is fixed and is useful for examining market response within a one-year period. The second scenario allows supplies to adjust to price signals.

The general framework presented here is directly applicable to other markets, such as tropical woods, tuna, pork, prison products, and diamonds, where some consumers are willing to pay premiums for certificates indicating that environmental, animal welfare, labor, and humanitarian standards were met in the production process. However, the parameters chosen for the simulations are specific to the U.S. corn market.

Scenario I: Fixed Supply

Immediately after harvest, the amount of GM and non-GM grain available for consumption during the year is fixed. Suppose that maintaining the identity of non-GM grain costs C per bushel, which creates a wedge between the price paid by consumers for identified non-GM grain (P_{no}^{D}) and the price received by producers for non-GM grain sold as such (P_{no}^{S}). Without identification, non-GM grain can be traded only as GM grain at the GM price P_{GM} ($P_{GM} \leq P_{no}^{S} = P_{no}^{D} - C$), which is the same for both producers and consumers.

Total grain demand is an aggregation of individual demands from heterogeneous consumers. More specifically, consumers of type δ ($0 \leq \delta \leq 1$) will substitute GM grain for non-GM grain as long as the price paid for the former (P_{GM}) is less than or equal to a fraction δ of the price paid for the latter (P_{no}^{D}). That is, δ is a discount factor that agents of type δ apply to GM grain relative to non-GM grain. For example, agents with δ = 0.85 will buy GM grain instead of non-GM grain only if they pay no more than 85 percent of the non-GM price for the former.

Aggregate total grain demand (whether GM or non-GM) by δ-type consumers is represented by

$$D_\delta = d_\delta(P_\delta), \tag{1}$$

where $P_\delta \equiv P_{no}^{D}$ if $P_{GM} \geq \delta\, P_{no}^{D}$, and $P_\delta \equiv \delta^{-1} P_{GM}$ if $P_{GM} < \delta\, P_{no}^{D}$. Demand function $d_\delta(\cdot)$ is assumed to satisfy standard regularity conditions (e.g., $\partial d_\delta/\partial P_\delta < 0$). Given equation (1), the demand schedules for GM grain and non-GM grain by δ-type consumers are equations (2) and (3), respectively:[1]

$$D_{\delta GM} = \begin{cases} d_\delta(\delta^{-1} P_{GM}) & \text{if } P_{GM} < \delta\, P_{no}^{D}, \\ d_\delta(\delta^{-1} P_{GM}) - D_{\delta no} & \text{if } P_{GM} = \delta\, P_{no}^{D}, \\ 0 & \text{if } P_{GM} > \delta\, P_{no}^{D}, \end{cases} \tag{2}$$

$$D_{\delta no} = \begin{cases} d_\delta(P_{no}^{D}) & \text{if } P_{GM} > \delta\, P_{no}^{D}, \\ d_\delta(P_{no}^{D}) - D_{\delta GM} & \text{if } P_{GM} = \delta\, P_{no}^{D}, \\ 0 & \text{if } P_{GM} < \delta\, P_{no}^{D}. \end{cases} \tag{3}$$

From these expressions, it is clear that δ-type agents will consume a total amount of grain (GM plus non-GM) equal to $d_\delta(P_{no}^{D}) = d_\delta(\delta^{-1} P_{GM})$ when $P_{GM} = \delta\, P_{no}^{D}$. However, in this instance they are indifferent about how much of that quantity is GM grain as opposed to non-GM grain. Hence, the specific amounts of GM and non-GM grain consumed by δ-type agents cannot be determined uniquely without information about supply.

Given fixed supplies of GM grain ($\bar{S}_{GM}$) and non-GM grain ($\bar{S}_{no}$), the market-clearing conditions consist of equations (4) and (5):[2]

$$\bar{S}_{GM} = D_{d^*GM} + \sum_{d>d^*} d_d\,(d^{-1} P^*_{GM}), \tag{4}$$

$$\bar{S}_{no} = D_{d^*no} + \sum_{d<d^*} d_d\,(P^{D*}_{no}), \tag{5}$$

where $\delta^* \equiv P^*_{GM} / P^{D*}_{no} \leq 1 - C / P^{D*}_{no}$ is the market-clearing consumer discount for GM grain.[3] Equations (4) and (5) can be used to solve for the market-clearing prices P^*_{GM} and P^{D*}_{no}, and the equilibrium producer price is obtained as $P^{S*}_{no} = P^{D*}_{no} - C$. In equilibrium, consumers with a discount factor strictly less (greater) than δ^* will only consume non-GM (GM) grain. Consumers of type δ^* will be indifferent about consumption of either kind of grain, so they will consume the amounts that balance the corresponding supplies.

For the purpose of performing welfare analysis, it is important to note that the area below $d_\delta(\cdot)$ in equation (1) can be used to measure the impact on the consumer surplus of δ-type agents due to changes in prices P_{GM}, P^D_{no}, or both simultaneously (i.e., price changes that may affect P_δ). Although, in general, consumer surplus changes do not provide an exact measure of the welfare changes experienced by a consumer, the former measure the latter exactly when the consumer's utility is quasilinear (Varian 1992, p. 163). Further, aggregate consumer surplus is an exact measure of aggregate consumer welfare for quasilinear utilities (Varian 1992, p. 169). For these reasons, we will employ quasilinear utilities as needed when addressing consumer welfare issues.

A Graphical Analysis with Two Polar Types of Consumers

It is helpful to analyze graphically a simplified version of the model. Consider the extreme case of only two consumer types; namely, consumers who are unwilling to consume GM grain at any price (i.e., $\delta = 0$) and consumers who are completely indifferent about GM and non-GM grain (i.e., $\delta = 1$). Assume further that their total demands for grain are given by $D_0 = d(P^D_{no})$, and by

$$D_1 = \begin{cases} d(P_{GM}) & \text{if } P_{GM} < P^D_{no}, \\ d(P^D_{no}) & \text{if } P_{GM} \geq P^D_{no}, \end{cases} \tag{6}$$

respectively. That is, the two types of consumers have the same $d(\cdot)$ function.[4] To avoid cluttering the graphs, assume zero identification costs (i.e., $C = 0$), so that $P_{no}^{D} = P_{no}^{S} = P_{no}$. Demand for GM grain by consumers of type $\delta = 0$ is zero ($D_{0GM} = 0$). Figure 1 depicts demand for GM grain from consumers of type $\delta = 1$ (D_{1GM}), along with a hypothetical fixed supply of GM grain (S_{GM}). When prices of non-GM grain are high ($P_{no} \geq \underline{P}$), all of the consumption by type-1 agents consists of GM grain only. The solid line in Figure 1 gives their demand schedule. For example, for the GM supply level shown, $D_1 = D_{1GM} = S_{GM}$ and the corresponding price for GM grain is $P_{GM} = P < P_{no}$ ($\geq \underline{P}$). But for lower prices of non-GM grain, say, $P_{no} = \underline{\underline{P}}$, the quantity of GM grain demanded at prices above $P_{GM} = \underline{\underline{P}}$ is zero, so that the dashed line depicts the GM demand schedule. Given a GM supply of S_{GM}, the GM price is $P_{GM} = \underline{\underline{P}} = P_{no}$ (i.e., there is no discount for GM grain), and total grain consumption by type-1 agents equals $\underline{\underline{Q}}$, of which S_{GM} consists of GM grain and the remainder ($\underline{\underline{Q}} - S_{GM}$) is non-GM grain.

The consumer surplus of type-1 agents (i.e., the area below $d_1(\cdot)$ in (1)) can also be read in Figure 1. To see this, note that total grain demand by type-1 consumers (1) is the same as their demand for GM grain when $P_{no} \geq \underline{P}$ (i.e., $D_1 = D_{1GM}$ given $P_{no} \geq \underline{P}$). Hence,

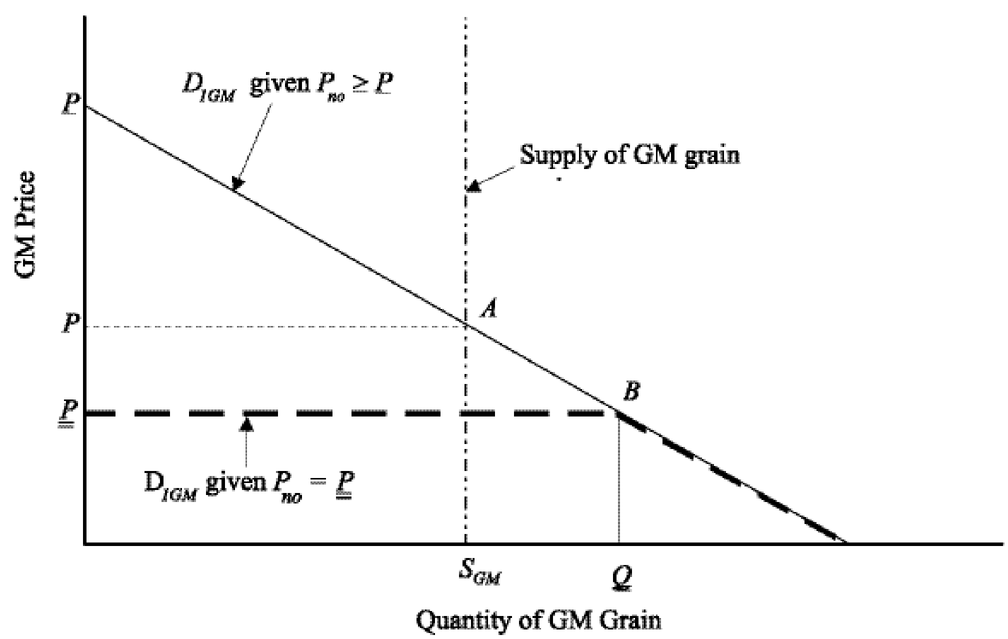


FIGURE 1. Demand for genetically modified grain by consumers of type 1 (D_{1GM})

the area under the curve D_{1GM} for $P_{no} \geq \underline{P}$ measures the consumer surplus of type-1 agents.[5] For example, type-1 consumers' surplus when $P_1 = P$ is given by the triangle $\underline{P}AP$. Similarly, area $PAB\underline{\underline{P}}$ measures the change in type-1 consumers' surplus due to a change in P_1 from P to $\underline{\underline{P}}$.

In equilibrium, either there is some discounting ($\delta^* \equiv P^*_{GM} / P^*_{no} < 1$) or there is no discounting whatsoever ($\delta^* \equiv P^*_{GM} / P^*_{no} = 1$). Consider the discounting equilibrium first. If $\delta^* < 1$, market equilibrium conditions (4) and (5) become (7) and (8), respectively:

$$\underline{S}_{GM} = d_1(P^*_{GM}), \tag{7}$$

$$\underline{S}_{no} = d_0(P^*_{no}), \tag{8}$$

where $P^*_{GM} < P^*_{no}$. Figure 2 illustrates this market equilibrium. The distance between the two vertical axes is equal to the total grain supply, $\underline{S}_{GM} + \underline{S}_{no}$. The left-hand-side vertical axis measures GM prices, against which demand for GM grain by type-1 consumers is shown. Analogously, the right-hand-side axis measures non-GM prices, and demand for non-GM grain by type-0 consumers is depicted against it.

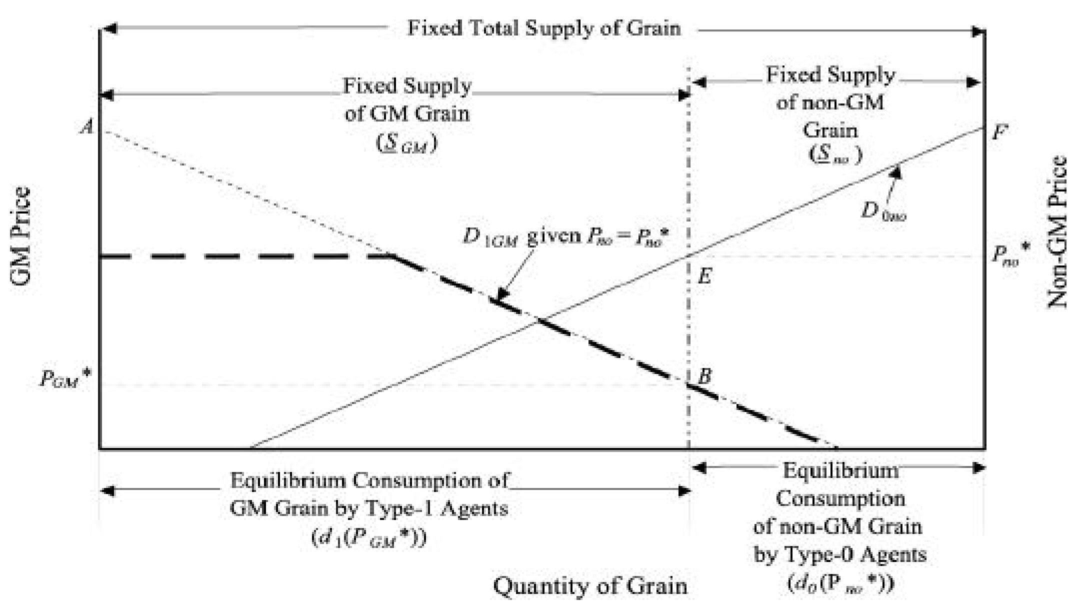


FIGURE 2. Market equilibrium with a large, fixed supply of genetically modified grain relative to non-genetically modified grain

The equilibrium displayed in Figure 2 is characterized by a large supply of GM grain relative to the non-GM supply. Because relative GM supplies are large and only type-1 agents are willing to consume such grain, the equilibrium GM price (P^*_{GM}) must be low to clear the market as required by equation (7). In equilibrium, the discount for GM grain arises because if such a discount did not exist (i.e., $P_{no} = P^*_{GM}$), demand for non-GM grain by type-0 consumers would exceed the supply of non-GM grain (i.e., $d_0(P_{no} = P^*_{GM}) > \underline{S}_{no}$) and would fail to meet equilibrium condition (8). The latter condition is met only if the discount factor equals $\delta^* \equiv P^*_{GM} / P^*_{no} < 1$. In equilibrium, the consumer surplus of type-1 agents is depicted by the triangle ABP^*_{GM} , whereas the consumer surplus of type-2 agents is given by the smaller triangle EFP^*_{no} .

In the no-discount equilibrium ($\delta^* \equiv P^*_{GM} / P^*_{no} = 1$), market equilibrium conditions (4) and (5) turn out to be conditions (9) and (10), respectively:

$$\underline{S}_{GM} = d_1(P^*) - D_{1no}, \tag{9}$$

$$\underline{S}_{no} = D_{1no} + d_0(P^*), \tag{10}$$

where $P^* = P^*_{GM} = P^*_{no}$. Figure 3 illustrates this scenario, which differs from the situation shown in Figure 2 only in that the fixed supply of non-GM grain is large relative to the fixed supply of GM grain. In particular, total grain supply is identical in both figures.

The relatively plentiful non-GM supply illustrated in Figure 3 implies that, even at a low non-GM price such as P^*_{no} , there is non-GM grain left over by type-0 agents that has to be absorbed by type-1 consumers ($\underline{S}_{no} - d_0(P^*) > 0$). But because type-1 agents are not willing to pay any premium for such grain, in equilibrium the non-GM price cannot exceed the GM price (i.e., $P^*_{no} = P^*_{GM} = P^*$). Hence, no GM discount is observed in equilibrium (i.e., $\delta^* \equiv P^*_{GM} / P^*_{no} = 1$). Type-1 agents consume all of the GM supply ($D_{1GM} = \underline{S}_{GM}$) plus the fraction of non-GM supply not consumed by type-0 agents ($D_{1no} = (\underline{S}_{no} - d_0(P^*)$). In equilibrium, the consumer surpluses of type-0 agents and type-1 agents are represented by triangles ABP^*_{GM} and BFP^*_{no}, respectively.

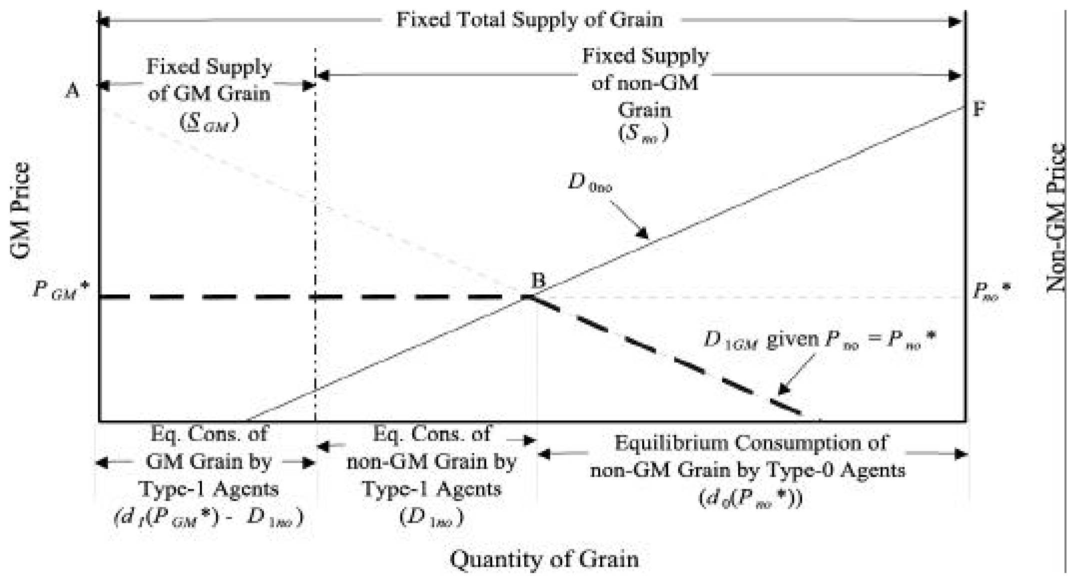


FIGURE 3. Market equilibrium with a small, fixed supply of genetically modified grain relative to non-genetically modified grain

In summary, assuming fixed supply and polar consumer types, the GM discount in equilibrium behaves in an intuitive fashion. Discounts for GM grain are observed when non-GM supply is small relative to GM supply. The GM discount falls as the supply share of non-GM increases and eventually becomes zero for sufficiently large non-GM supply shares. Analysis of Figures 2 and 3 also reveals that, for given fixed supplies of GM and non-GM grain, the GM discount will either increase or remain unchanged at zero if demand from type-0 consumers increases and/or if demand from type-1 consumers decreases. In contrast, the response of the GM discount to an increase in total grain supply holding constant the GM share is ambiguous, as it depends on the specific shapes of the demand functions of type-0 and type-1 consumers.

The consumer surplus of type-0 (type-1) agents increases (decreases) as the relative non-GM supply increases, up to the point where the relative supply of non-GM grain is so large that in equilibrium some of the latter is acquired by type-1 agents. Beyond that point, additions to the share of non-GM supplies do not affect the consumer surplus of either type-0 agents or type-1 agents. In general, increasing the relative supply of GM grain versus non-GM grain may increase or decrease total consumer surplus (i.e., the sum of type-0 and type-1 consumer surpluses), depending on the specific characteristics of type-0 and type-1 demand schedules.

We can analyze the situation under identification costs, as was done previously, but this time we use a derived demand instead of the original demand for type-0 consumers. In Figures 2 and 3, the derived demand would appear below the original demand curve D_{0no}, at a vertical distance equal to the identification cost. The most interesting result from such an analysis is that in the Figure 3 scenario, only part of the non-GM grain is identified in equilibrium. The reason for this is that in such a scenario, some of the non-GM grain is acquired by type-1 consumers, who do not care about whether the grain is GM or not. Therefore, type-1 consumers pay P_{GM}^{*} to buy GM grain as well as unidentified non-GM grain. Type-0 consumers buy only identified non-GM grain at a price of $P_{no}^{D*} = P_{GM}^{*} + C$, and suppliers receive P_{GM}^{*} for all of the grain sold, regardless of whether the latter is GM or not.

Scenario II: Flexible Supply

We analyze the more realistic scenario with flexible supply by modeling a production sector in a manner analogous to the demand framework already discussed. In particular, we assume that producers of type σ ($0 < \sigma \leq 1$) can produce GM grain at a fraction σ of the cost of producing non-GM grain.[6] That is, type-σ producers will prefer to plant a GM crop instead of a non-GM crop if $P_{GM} > \sigma\ P_{no}^{S}$, and vice versa. Aggregate total (i.e., GM plus non-GM) grain supply by type-σ producers is denoted by

$$S_{\sigma} = s_{\sigma}(P_{\sigma}), \tag{11}$$

where $P_{\sigma} \equiv P_{no}^{S}$ if $P_{GM} \leq \sigma\ P_{no}^{S}$, and $P_{\sigma} \equiv \sigma^{-1} P_{GM}$ if $P_{GM} > \sigma\ P_{no}^{S}$. We also assume that supply function $s_{\sigma}(\cdot)$ is well behaved (e.g., $\partial s_{\sigma}/\partial P_{\sigma} > 0$). Based on equation (11), the supply schedules for GM grain and non-GM grain corresponding to σ-type producers are equations (12) and (13), respectively:

$$S_{\sigma GM} = \begin{cases} s_s\,(s^{-1} P_{GM}) & \text{if } P_{GM} > s\ P^S_{no}, \\ s_s\,(s^{-1} P_{GM}) - S_{s\,no} & \text{if } P_{GM} = s\ P^S_{no}, \\ 0 & \text{if } P_{GM} < s\ P^S_{no}, \end{cases} \tag{12}$$

$$S_{\sigma no} = \begin{cases} s_s\,(P^S_{no}) & \text{if } P_{GM} < s\ P^S_{no}, \\ s_s\,(P^S_{no}) - S_{s\,GM} & \text{if } P_{GM} = s\ P^S_{no}, \\ 0 & \text{if } P_{GM} > s\ P^S_{no}. \end{cases} \tag{13}$$

A Graphical Example

For illustrative purposes, Figure 4 shows the total supply schedules (11) by firms of types $\sigma = 1$ and $\sigma = \underline{\sigma} < 1$. To facilitate the discussion, Figure 4 is drawn assuming that the total supply functions are identical for the two kinds of firms (i.e., $s_1(\cdot) = s_{\underline{\sigma}}(\cdot) = s(\cdot)$).[7]

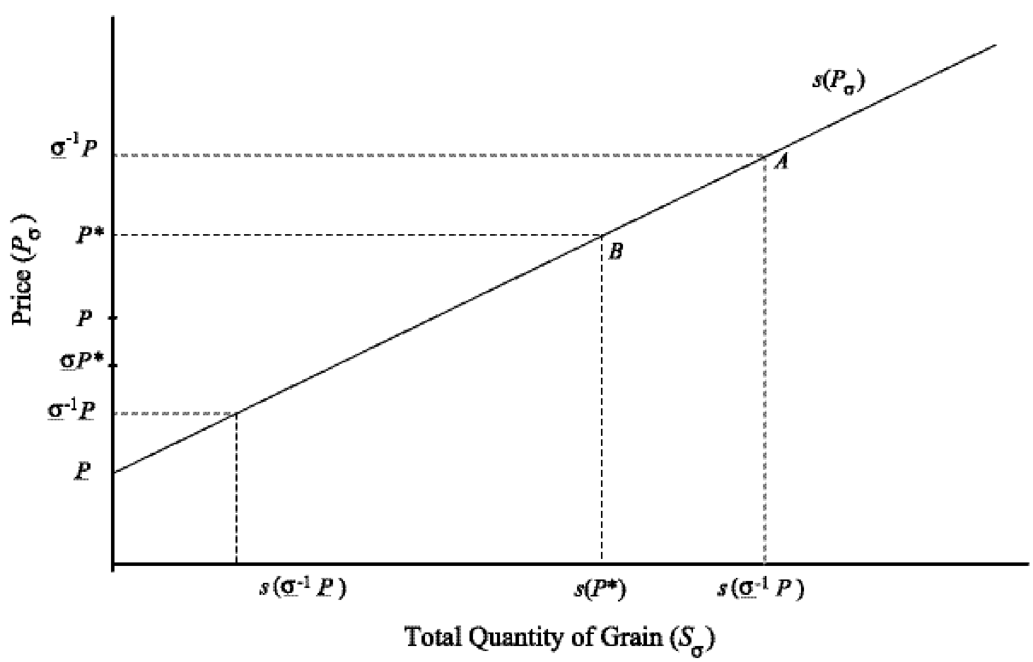


FIGURE 4. Total supply of grain by producers of types s = 1 (S_1) and s = $\underline{s}$ < 1 ($S_{\underline{s}}$)

For example, consider the scenario where $P^S_{no} = P^*$ and $P_{GM} = P$, such that $P < P^* < \underline{\sigma}^{-1} P$. In this instance, type-1 firms have $P_1 = P^*$ and produce a total amount equal to $s(P^*)$, all of which is non-GM grain (i.e., $S_1 = S_{1no} = s(P^*)$ and $S_{1GM} = 0$). In contrast, type-$\underline{\sigma}$ firms have $P_{\underline{\sigma}} = \underline{\sigma}^{-1} P > P^*$ and produce a total amount $s(\underline{\sigma}^{-1} P) > s(P^*)$, of which all consists of GM grain (i.e., $S_{\underline{\sigma}} = S_{\underline{\sigma}GM} = s(\underline{\sigma}^{-1} P)$ and $S_{\underline{\sigma}no} = 0$). The producer surplus of type-1 firms is given by the triangle $P^*B\underline{P}$, whereas type-$\underline{\sigma}$ producer surplus is the larger triangle $\underline{\sigma}^{-1}PA\underline{P}$. It follows that a reduction in the cost of producing GM crops from $\sigma = 1$ to $\sigma = \underline{\sigma}$ while maintaining P^S_{no} and P_{GM} constant at P^* and P, respectively, increases producer surplus by the trapezoid $\underline{\sigma}^{-1}PABP^*$.

Starting from $P_{GM} = P$, a *ceteris paribus* GM price decrease leaves type-1 producers unaffected, as it was unprofitable for them to grow GM crops to begin with. However, such a price decrease will induce a reduction in the (GM) output of type-$\underline{\sigma}$ firms, as long as $P_{GM} > \underline{\sigma}\, P^*$. At $P_{GM} = \underline{\sigma}\, P^*$, type-$\underline{\sigma}$ producers switch to non-GM crops. For larger GM price reductions (i.e., $P_{GM} < \underline{\sigma}\, P^*$), type-$\underline{\sigma}$ firms produce $s(P^*)$ of non-GM and none of the GM crops, regardless of how much P_{GM} drops below $\underline{\sigma}\, P^*$.

Because of their lower cost of growing GM crops, type-$\underline{\sigma}$ firms have a clear advantage over type-1 producers. This may be better appreciated by considering the situation where $P^S_{no} < \underline{P}$ and $P_{GM} = \underline{P}$. In this instance, it is unprofitable for type-1 firms to plant either GM or non-GM crops, whereas type-$\underline{\sigma}$ firms supply the amount $s(\underline{\sigma}^{-1}\, \underline{P})$ of GM grain.

Market Equilibrium with Flexible Supply

In the presence of flexible supplies (12) and (13), the market-clearing conditions analogous to (4) and (5) are (14) and (15), respectively:[8]

$$S_{s^*GM} + \sum_{s<s^*} s_s\,(s^{-1} P^*_{GM}) = D_{d^*GM} + \sum_{d>d^*} d_d\,(d^{-1} P^*_{GM})\,, \tag{14}$$

$$S_{s^*no} + \sum_{s>s^*} s_s\,(P^{S*}_{no}) = D_{d^*no} + \sum_{d<d^*} d_d\,(P^{D*}_{no})\,. \tag{15}$$

These two equations plus the non-GM price equation $P_{no}^{D*} = P_{no}^{S*} + C$ (and the definitions of δ^* and σ^*) provide the required information to solve for the three unknown equilibrium prices P_{no}^{S*}, P_{no}^{D*}, and P_{GM}^{*}. In equilibrium, only those producers with a relative advantage at growing GM crops will supply GM grain. Such producers are characterized by $\sigma < P_{GM}^{*} / P_{no}^{S*} = \sigma^*$. Firms with $\sigma > P_{GM}^{*} / P_{no}^{S*} = \sigma^*$ will only supply non-GM grain, as their cost savings from planting GM crops are not enough to offset the price differential in favor of non-GM grain.

Welfare Analysis

Total welfare effects (ΔW) are measured as the sum of the total change in producers' surplus (ΔPS) and the total change in consumers' surplus (ΔCS). To illustrate, suppose that we want to quantify the impact on producers' surplus caused by a technological innovation (e.g., a reduction in the cost of producing GM grain across all firms). Because the innovation induces a change in supply schedules, let $s_s^0(\cdot)$ and $s_s^1(\cdot)$ be the supply functions for the initial and final set of type-σ producers, respectively. Then,

$$\Delta PS \equiv \left[\sum_s \int_{\underline{B}_s^1}^{P_s^1} s_s^1(x)\,dx \right] - \left[\sum_s \int_{\underline{B}_s^0}^{P_s^0} s_s^0(x)\,dx \right], \tag{16}$$

where P_s^0 (P_s^1) denotes the type-σ price corresponding to the initial (final) equilibrium prices P_{no}^{S0} and P_{GM}^{0} (P_{no}^{S1} and P_{GM}^{1}), $\underline{B}_s^0$ ($\underline{B}_s^1$) is the lower bound for the domain of $s_s^0(\cdot)$ ($s_s^1(\cdot)$), and x is an integration dummy. The first and second terms within brackets denote the final and initial total producers' surpluses, respectively. Total producers' surpluses are obtained by adding up across all types of firms their corresponding surpluses, which are represented by the integrals.

In a similar manner, total change in consumers' surplus (ΔCS) is calculated as follows:

$$\Delta CS \equiv \left[\sum_d \int_{P_d^1}^{\overline{B}_d^1} d_d^1(x)\,dx \right] - \left[\sum_d \int_{P_d^0}^{\overline{B}_d^0} d_d^0(x)\,dx \right], \tag{17}$$

where $\overline{B}_d^0$ ($\overline{B}_d^1$) is the upper bound for the domain of $d_d^0(\cdot)$ ($d_d^1(\cdot)$), and the remaining notation is analogous to the notation used in equation (16). In the special situation where all of the demand schedules remain unchanged (i.e., $d_d^0(\cdot) = d_d^1(\cdot) = d_\delta(\cdot)$ for all δ), as would be the case for the technological innovation example, equation (17) simplifies to $\Delta CS = \sum_d \int_{P_d^1}^{P_d^0} d_d(x)\,dx$.

Model Calibration

To perform quantitative analysis, we must specify demand and supply functions (1) and (11), respectively. For this purpose, we adopt the following isoelastic demand schedule:

$$d_\delta(P_\delta) = \kappa_D(\delta)\; P_d^{-e_d}\,, \tag{18}$$

where $\kappa_D(\delta)$ denotes a demand scaling function, and ε_δ is the constant demand elasticity corresponding to type-δ consumers. Scaling function $\kappa_D(\delta)$ is the aggregate amount demanded by type-δ agents when they face price $P_\delta = 1$, i.e., $\kappa_D(\delta) = d_\delta(1)$.

Given demand elasticities (ε_δ) and observable data, it is straightforward to recover $\kappa_D(\delta)$ from equation (18). That is, $\kappa_D(\delta) = \underline{\underline{D}}_\delta \times \underline{\underline{P}}_d^{e_d}$, where $\underline{\underline{D}}_\delta$ and $\underline{\underline{P}}_\delta$ denote grain consumed and price faced by type-δ consumers, respectively, during the period used for calibration. But $\underline{\underline{D}}_\delta = \underline{\underline{m}}_\delta \times \underline{\underline{D}}$, where $\underline{\underline{m}}_\delta \equiv \underline{\underline{D}}_\delta / \underline{\underline{D}}$ represents the market share of type-δ consumers and $\underline{\underline{D}} \equiv \sum_d \underline{\underline{D}}_d$ is total grain consumption during the calibration period. Hence, $\kappa_D(\delta)$ may be estimated from equation (19), as well:

$$\kappa_D(\delta) = \underline{\underline{m}}_\delta \times \underline{\underline{D}} \times \underline{\underline{P}}_d^{e_d}\,. \tag{19}$$

Expression (19) is employed here to calculate $\kappa_D(\delta)$ because market shares are easier to interpret than are absolute quantities. More importantly, equation (19) facilitates performing sensitivity analysis when market shares $\underline{\underline{m}}_\delta$ are not well known. This is true because market shares must satisfy the properties of a probability distribution, i.e., $\underline{\underline{m}}_\delta \geq 0$ and $\sum_d \underline{\underline{m}}_d = 1$. Therefore, a simple accuracy check consists of verifying that any postulated set of market shares satisfies such properties. Further, equation (19) allows us to resort to alternative parameterizations of well-known families of probability density functions to conduct sensitivity analysis regarding $\underline{\underline{m}}_\delta$.

Supply functions (11) are also postulated to be isoelastic, i.e., $s_\sigma(P_\sigma) = \kappa_S(\sigma)\ P_s^{e_s}$, where $\kappa_S(\sigma)$ represents a supply scaling function and ε_σ is the constant supply elasticity corresponding to type-σ producers. Supply scaling function $\kappa_S(\sigma)$ may be recovered analogously to equation (19). That is, $\kappa_S(\sigma) = \underline{\underline{m}}_\sigma \times \underline{\underline{S}} \times \underline{\underline{P}}_s^{-e_s}$, where $\underline{\underline{m}}_\sigma \equiv \underline{\underline{S}}_\sigma / \underline{\underline{S}}$ denotes the market share of type-σ producers, $\underline{\underline{S}}_\sigma$ is aggregate production by type-σ firms, $\underline{\underline{S}} \equiv \sum_s \underline{\underline{S}}_s$ represents total grain production, and $\underline{\underline{P}}_\sigma$ is the price faced by type-σ producers, all corresponding to the period used for calibration.

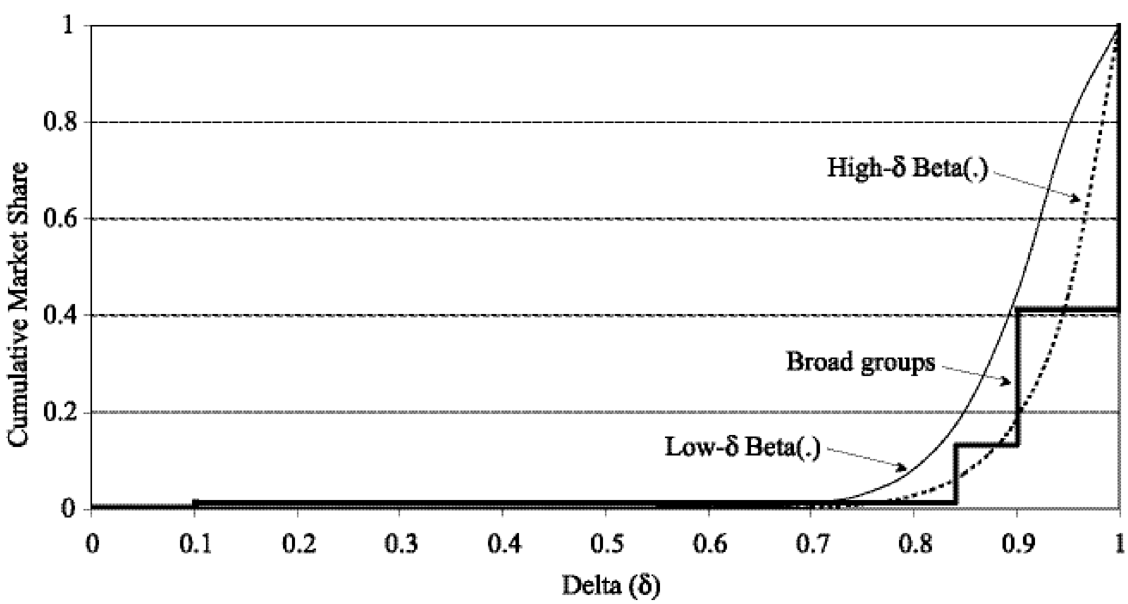
Short-Run Results and Discussion

In the short run, market prices will depend on the available supplies of GM and non-GM grain and on consumer preferences. Consumer preferences can be described based on the discounts (δ) at which they are indifferent about GM and non-GM grain and the market share associated with each consumer type ($\underline{\underline{m}}_\delta$).

Available data on consumer preferences categorize consumers into broad homogenous groups. For example, livestock feeders consume the bulk of the corn output, and all of these consumers are currently viewed as being indifferent about the two types of grain (i.e., $\delta = 1$). Companies that purchase corn for food and for export markets prefer non-GM grain, and these markets have a discount for GM corn. The corn-processing industry is also a major consumer and it, too, is viewed as being homogenous with a preference for non-GM grain, due to the desire to sell corn gluten to the EU. Finally, there is a small group of consumers who, for ethical or philosophical reasons, refuses to consume GM grain at any price (i.e., $\delta \to 0$).

In reality, slight differences in preferences are likely to exist within the broad groups of consumers. For example, some livestock feeders may in fact be concerned about market access for livestock producers, and this subset of producers will have $\delta < 1$. These preference differences within the broad groups would be missed if we used only the available data on market shares and deltas. To address this issue, a beta cumulative distribution function (cdf) is fitted to the existing aggregate data as shown in Figure 5.[9] The thick line shows the delta values for each broad group on the horizontal axis and the cumulative market shares on the vertical axis.[10] Next, the parameters of a beta cdf that fitted approximately through the center points of the group-specific market shares are obtained. The curve labeled high-δ Beta(·) in Figure 5 shows this beta cdf for the corn market data taken from the 1999 crop year. For example, this beta cdf shows that 18.5 percent of the consumers had a discount factor of $\delta \leq 0.9$. The use of this continuous cdf allows us to approximate the preference differences within the groups and gets around the lumpiness introduced by the industry data.

It is relatively easy to introduce a change in consumer preferences using the beta cdf. The curve labeled low-δ Beta(·) shows how preferences might respond if additional controversy arose about GM foods. For example, in the spring of 2000, a GM variety of corn called Starlink was approved in the United States for animal use but not for food use. This variety was allowed into the U.S. bulk handling system after the fall 2000



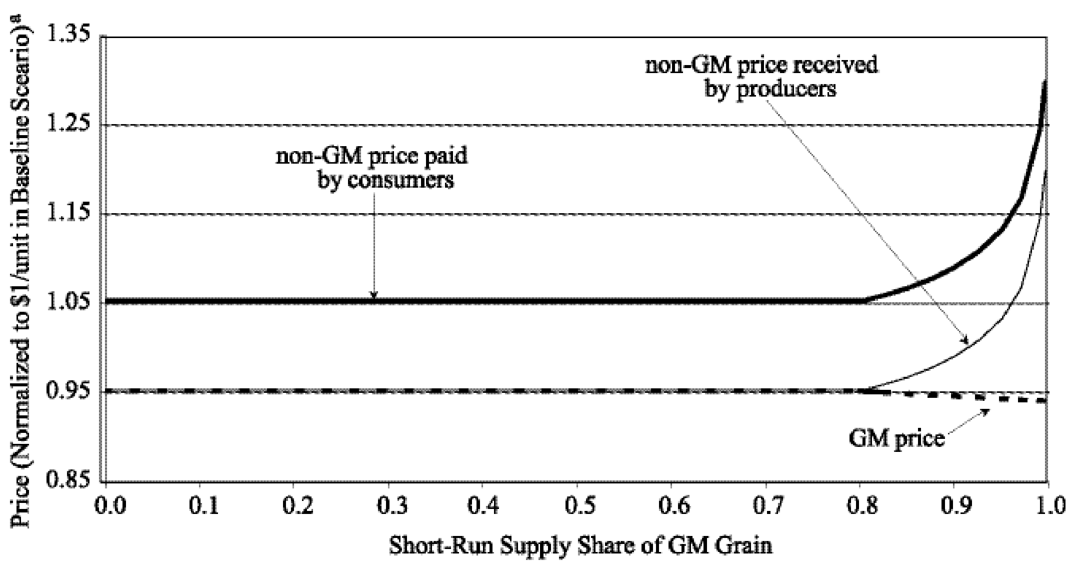
Note: High- and low-δ Beta(.) denote the Beta(x|16,1,0,1) and Beta(x|20,2.3,0,1) cdfs, respectively.

FIGURE 5. Distribution of consumer types

harvest and created controversy when it was found in certain food products such as taco shells and corn chips. Consumer scares of this type will influence different market segments in different ways. In this situation, the GM discount of those who consume corn as food might increase appreciably, while the GM discount of the processing sector might remain constant. As shown in Figure 5, the beta cdf is flexible enough to allow for different relative effects of this type.[11]

Market Impacts

Figure 6 shows the impact on market prices of changes in the available supply of GM and non-GM grain. The data in the figure are based on the consumer preferences depicted by the curve high-δ Beta(·) above. The horizontal axis measures the percentage of the short-run supply that consists of GM grain. For example, a value of 0.9 on this axis means that 90 percent of the grain supply is GM and that 10 percent is non-GM. Note that these percentages need not be related to the proportions of GM and non-GM crops planted. This is true because farmers and grain storers will typically co-mingle GM and non-GM grain unless there is an incentive not to do so. In addition, GM crops can potentially pollinate non-GM crops, again reducing available non-GM supplies.



[a]Baseline scenario consists of a zero supply of GM grain, so that $P_{no} = P_{GM} = 1$.

FIGURE 6. Prices of genetically modified and non-genetically modified grain, assuming high-δ Beta(·) cdf

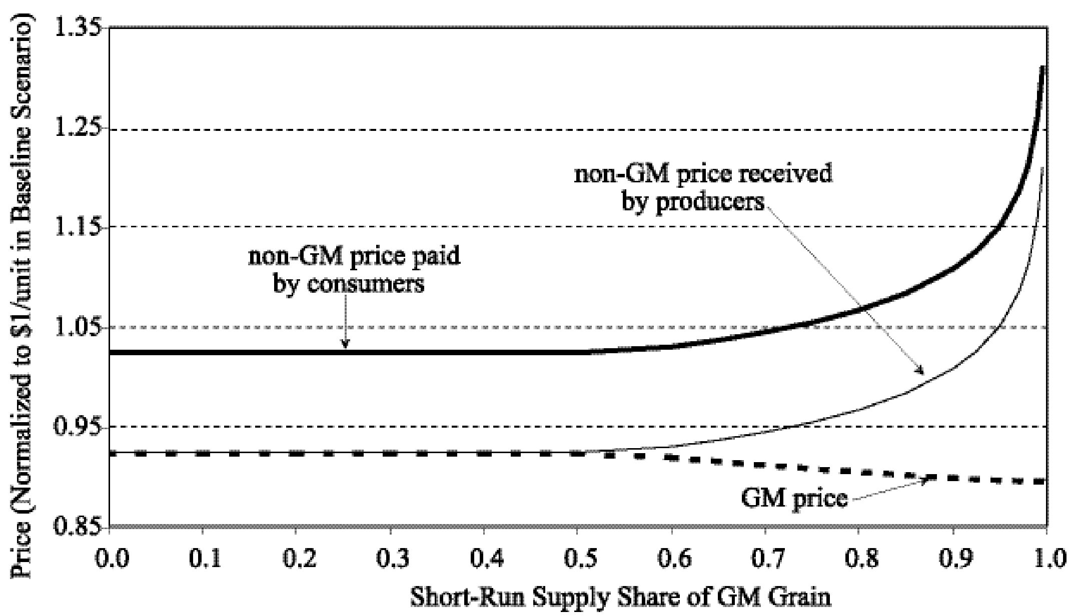
The data in Figure 6 assume a \$0.20/bu cost associated with handling a differentiated grain. This cost is approximate and is based on Miranowski et al. 1999. Costs include those associated with inefficient use of elevator space, additional paperwork arising from certification, and small-batch transportation. This cost corresponds to a 10 percent price differential in the normalized prices. Whenever consumers are willing to pay these additional handling fees, non-GM grain is made available at a premium that equals these additional handling costs. This drives a wedge between the non-GM price paid by consumers and the non-GM price received by farmers.

With the high-δ Beta($\cdot$) consumer preferences used in Figure 6, the farm-level prices of GM and non-GM grains are identical so long as the short-run supply share of GM grain does not exceed 80 percent. These results might seem surprising given that most consumers prefer non-GM grain (see the high-δ Beta($\cdot$) curve in Figure 5). The reason for this result is that consumers must be willing to pay a premium that exceeds handling charges before impacts will be seen in farm-level prices. For example, if the available supplies of GM grain equal 70 percent, then those consumers who are willing to pay a premium for non-GM grain will do so and non-GM grain will be treated as a niche market. At the farm level, some non-GM grain will enter this niche market and some will enter the bulk market. Farmers who segregate non-GM grain for this niche market will receive a premium that compensates them for additional handling charges but will otherwise receive that same price for GM and non-GM grain. This scenario represents the actual market structure observed in the 1999 crop year.

A different market structure emerges when the supplies of non-GM grain become very tight. This is shown in the results to the right of the 80 percent point in Figure 6. Here, the non-GM grain supplies are so low that there is not enough to supply those consumers who are willing to pay a premium that equals or exceeds handling charges. Some of the consumers in this group will need to be enticed into buying GM grain, and this can only occur if GM grain is discounted at the farm level. For example, if the available supply of GM grain is 90 percent, then market equilibrium occurs where non-GM grain sells at a premium of 15.1 percent (= 1.089/0.946) (see Figure 6). Given a 15.1 percent discount, these consumers are now willing to consume a GM commodity grain in lieu of the more expensive alternative. Because this equilibrium discount exceeds the 10 percent handling charge, a discount must also emerge at the farm level. All GM grain must sell at the same discounted price at the farm level, because there is no way to charge different prices based on end uses in a bulk commodity system.

The situation just described is not representative of a typical niche market because the underlying bulk commodity market is also affected.[12] Those farmers who initially own the 90 percent market share of GM grain will try to sell it at a non-discounted price. But for markets to clear, consumers who have 0.869 (= 1/1.151) $\leq \delta \leq$ 0.9 must eventually be induced to purchase this GM grain. Thus, GM grain will be bought and sold until all GM grain sells at a discounted price and markets clear.

Figure 7 repeats the analysis shown in Figure 6 but with a different representation of consumer preferences. The consumer preferences modeled in Figure 7 are from the low-δ Beta(·) cdf depicted in Figure 5. In Figure 7, available supplies of GM grain need only exceed 50 percent of the market for the farm-level differential between GM and non-GM prices to occur. This farm-level discount grows rapidly and exceeds 10 percent of the GM price when the supply share of GM grain exceeds 89 percent. Farmers who own non-GM grain get a premium in excess of identification costs. Those who own GM grain need to



[a]Baseline scenario consists of a zero supply of GM grain, so that $P_{no} = P_{GM} = 1$.

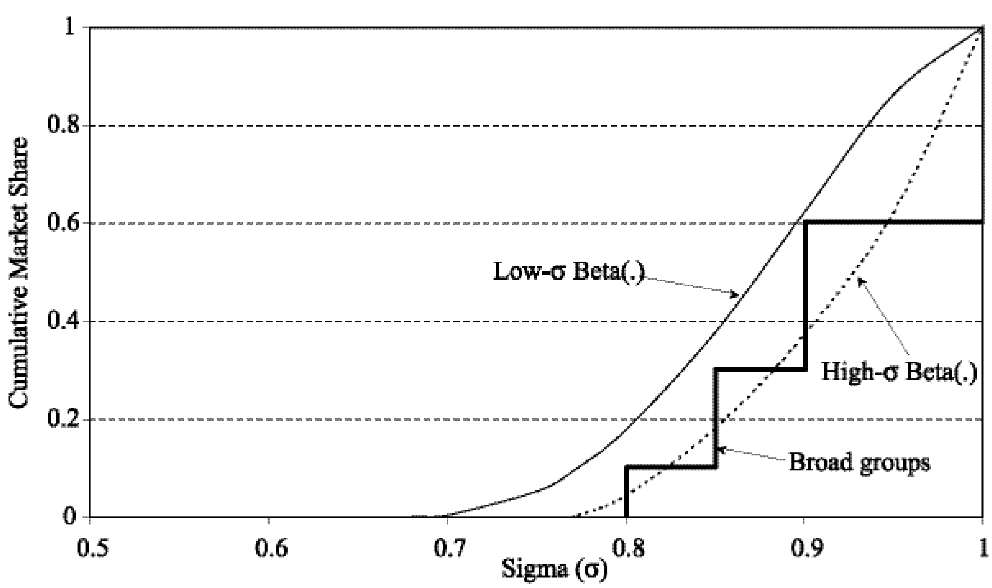
FIGURE 7. Prices of genetically modified and non-genetically modified grain, assuming low-d Beta(·) cdf

discount their product in order to sell to the marginal (high δ) consumer. These farmers would be unwilling to plant GM grain in the following year unless the cost advantage of GM exceeded the farm-level discount schedule.

Long-Run Results and Discussion: The Impact of Introducing Genetic Modification Technology

The short-term results presented above are driven by consumer preferences, because supply is held fixed. In the long-run results discussed here, supply is allowed to adjust to the introduction of GM technologies. Therefore, the nature of the technology innovation on the supply side needs to be described. In the baseline scenario, GM technologies are not available, so only non-GM grain is produced.

The introduction of GM technologies reduces the per bushel production cost, and this cost reduction varies across producers, as shown in Figure 8. The discrete cdf represents our best assessment of the production cost differences across broad producer groups for the 2000 crop year and are based in part on data from Duffy and Smith (2000) and the U.S. Department of Agriculture, Economic Research Service (USDA-ERS 2000).



Note: High- and low-σ Beta(.) denote the Beta(x|1.4,0.8,0.77,1) and Beta(x|2.5,1.7,0.68,1) cdfs, respectively.

FIGURE 8. Distribution of producer types

The variation in cost reduction across producers is motivated by differences in soil types, weed infestations, insect pressure, and the ability to absorb information about new technologies. Two supply scenarios are considered. The curve labeled high-σ Beta(·) is the beta cdf fitted to the broad-group data. The high-σ Beta(·) curve shows that no farmer achieves more than a 25 percent cost reduction from GM grain. About 5 percent of producers obtain more than a 20 percent cost reduction, and about 20 percent of producers get more than a 15 percent cost reduction. The low-σ Beta(·) curve shows a greater incentive to adopt, with almost 40 percent of producers getting a cost reduction of 15 percent or greater. Both curves show a significant group of producers who obtain very little cost reduction from the GM technology.

Table 1 presents results for 20 different scenarios, chosen to reflect various market conditions. These scenarios include the following: much consumer concern (low δ) and little consumer concern (high δ); a small cost reduction (high σ) and a large cost reduction (low σ); with supply elasticities at the high end and the low end of those reported in the literature (0.6 and 0.3, respectively); with demand elasticities of –0.3 and –0.6; and with identification costs of 10 percent and 20 percent of the baseline market price, which is calibrated to equal 1. Because baseline quantity is also calibrated to equal 1, baseline total expenditures (which equal total revenues) equal 1 as well.

Scenario 1 represents a situation with a lot of consumer concern and a large production cost advantage for GM grain. Elasticities in this scenario are small, implying that both supply and demand are relatively unresponsive. The identity cost in scenario 1 is 10 percent of the baseline market price. Reading across the first row of numbers in Table 1, the results for this scenario show that GM grain captures an 81 percent market share. At 1.0074, total grain production (GM plus non-GM) is slightly higher (0.74 percent) than in the baseline. The GM price is 11.6 percent lower than the baseline price of non-GM grain, reflecting lower production costs. The non-GM farm price is also lower than in the baseline, reflecting increased competition from inexpensive GM grain as well as the need for non-GM producers to bear some of the costs associated with identity preservation. The non-GM wholesale price is higher relative to the baseline. This is true because non-GM consumers must pay a portion of the identification cost and because

TABLE 1. Long-run effects from introducing genetic modification technology

	Ident.	Elasticity		Market Share[a]		Equil. Supply		GM	Non-GM Price		Surplus Change				
Scen.	Cost	Sup.	Dem.	Sup.	Dem.	GM	Total	Price	Farm	Wholesale	Prod.	Cons.	d*	Indiff.[b]	s*
1	0.1	0.3	–0.3	Low *s*	Low *d*	0.8147	1.0074	0.8841	0.9435	1.0435	0.0278	0.0231	0.847	0.884	0.937
2	0.1	0.3	–0.6	Low *s*	Low *d*	0.8176	1.0099	0.8917	0.9514	1.0514	0.0371	0.0149	0.848	0.892	0.937
3	0.2	0.3	–0.6	Low *s*	Low *d*	0.9396	1.0076	0.8882	0.9179	1.1179	0.0292	0.0102	0.794	0.888	0.968
4	0.1	0.6	–0.3	Low *s*	Low *d*	0.8202	1.0100	0.8763	0.9355	1.0355	0.0197	0.0315	0.846	0.876	0.937
5	0.1	0.6	–0.6	Low *s*	Low *d*	0.8252	1.0152	0.8838	0.9434	1.0434	0.0286	0.0238	0.847	0.884	0.937
6	0.1	0.3	–0.3	Low *s*	High *d*	0.9127	1.0134	0.9047	0.9436	1.0436	0.0489	0.0426	0.867	0.905	0.959
7	0.1	0.3	–0.6	Low *s*	High *d*	0.9172	1.0180	0.9185	0.9578	1.0578	0.0655	0.0281	0.868	0.918	0.959
8	0.2	0.3	–0.6	Low *s*	High *d*	0.9865	1.0168	0.9163	0.9346	1.1346	0.0616	0.0258	0.808	0.916	0.980
9	0.1	0.6	–0.3	Low *s*	High *d*	0.9196	1.0180	0.8909	0.9293	1.0293	0.0338	0.0573	0.866	0.891	0.959
10	0.1	0.6	–0.6	Low *s*	High *d*	0.9281	1.0273	0.9044	0.9434	1.0434	0.0499	0.0435	0.867	0.904	0.959
11	0.1	0.3	–0.3	High *s*	Low *d*	0.7117	1.0006	0.9102	0.9441	1.0441	0.0042	0.0013	0.872	0.910	0.964
12	0.1	0.3	–0.6	High *s*	Low *d*	0.7140	1.0009	0.9111	0.9448	1.0448	0.0055	0.0003	0.872	0.911	0.964
13	0.2	0.3	–0.6	High *s*	Low *d*	0.8995	0.9973	0.9052	0.9134	1.1134	–0.0061	–0.0065	0.813	0.905	0.991
14	0.1	0.6	–0.3	High *s*	Low *d*	0.7142	1.0010	0.9090	0.9434	1.0434	0.0036	0.0024	0.871	0.909	0.964
15	0.1	0.6	–0.6	High *s*	Low *d*	0.7167	1.0015	0.9100	0.9440	1.0440	0.0046	0.0017	0.872	0.910	0.964
16	0.1	0.3	–0.3	High *s*	High *d*	0.8532	1.0059	0.9304	0.9454	1.0454	0.0222	0.0186	0.890	0.930	0.984
17	0.1	0.3	–0.6	High *s*	High *d*	0.8557	1.0079	0.9367	0.9516	1.0516	0.0295	0.0119	0.891	0.937	0.984
18	0.2	0.3	–0.6	High *s*	High *d*	0.9964	1.0063	0.9329	0.9356	1.1356	0.0241	0.0086	0.822	0.933	0.997
19	0.1	0.6	–0.3	High *s*	High *d*	0.8569	1.0080	0.9239	0.9390	1.0390	0.0157	0.0254	0.889	0.924	0.984
20	0.1	0.6	–0.6	High *s*	High *d*	0.8615	1.0121	0.9302	0.9452	1.0452	0.0227	0.0191	0.890	0.930	0.984

Notes: The baseline scenario assumes that GM grains cannot be produced and is calibrated so that equilibrium supply and equilibrium non-GM prices (both at the farm and at the wholesale levels) equal 1. The table reports the effect of introducing GM crops with cost savings represented by the low- and high-σ market shares.

[a] The low- and high-σ (δ) scenarios are represented by the Beta(x| 2.5,1.7,0.68,1) and Beta(x| 1.4,0.8,0.77,1) [Beta(x| 20,2.3,0,1) and Beta(x| 16,1,0,1)] cdfs, respectively.

[b] "Indifference" is the δ of consumers (σ of producers) whose welfare is unchanged by the introduction of the GM technology. Consumers with δ > (<) "Indifference" experience a welfare gain (loss). Similarly, producers with σ < (>) "Indifference" experience a welfare gain (loss).

non-GM grain prices must remain high relative to GM grain to induce producers to plant non-GM grain.

All scenarios exhibit an increase in the wholesale price of non-GM grain relative to the baseline. This price increase suggests that some consumers will be worse off after the introduction of this technology. However, total producer and consumer surplus (shown in columns 12 and 13 of Table 1) increase. These measures of surplus are relative to baseline expenditures (and revenues) of 1. In scenario 1, the gain in consumer surplus is 2.31 percent of baseline expenditures and the gain in total producer surplus equals 2.78 percent of baseline revenues. The column labeled δ^* (σ^*) shows the discount level for the agent who is indifferent about consuming (producing) GM and non-GM corn under the market prices associated with this scenario. Discount level δ^* (σ^*) reflects the percentage difference between the GM price and the wholesale (farm-level) non-GM price.

As mentioned previously, some consumers will experience an increase in welfare and others will experience a reduction in welfare. The δ of the consumer who is indifferent about the introduction of the GM technology is reported in the "indifference" column of Table 1. This consumer will have the same level of surplus after introducing GMs as in the (pre-GM) baseline. All consumers with d less than this critical value will be worse off after the introduction of GM technology. These consumers have a relatively strong preference for non-GM grain. Those who dislike GM grain the most (i.e., those with $\delta < \delta^*$) will continue to consume non-GM grain after the introduction of the GM crops, whereas those who are not as adamantly against GM grain (i.e., those with $\delta^* \leq \delta <$ "indifference") will switch to consume GM grain. In scenario 1 with a GM price of 0.884, consumers in this second subgroup ($0.847 < \delta < 0.884$) would have consumed non-GM grain if its price had stayed at 1 after introducing GM technology. However, the non-GM price increase (from 1 to 1.0435) caused by the latter induced such consumers to switch and buy GM grain.

Note that the δ level of the consumer who is indifferent between a particular scenario and the baseline is exactly equal to the GM price for that scenario. This makes sense. For example, in scenario 1, consumers can get GM grain at an 11.6 percent discount with respect to the non-GM price in the baseline scenario. Hence, consumers with $\delta = 0.884$

are neither worse off nor better off after the introduction. Consumers with $\delta > 0.884$ will gain, because they would have bought GM at prices higher than 0.884 if GM had been available in the baseline. In scenario 1, such consumers can buy GM grain at a lower price than they had been willing to pay in the baseline.

For producers, the simulations can be interpreted as a "technology innovation" respective to the baseline, which allows firms to produce at lower cost but such that cost savings differ across firms. Producers with the greatest cost reductions benefit and producers with the smallest cost reduction are worse off. In scenario 1, producers who can achieve cost savings from GM production of more than 11.6 percent (i.e., $\sigma <$ "indifference") gain because their costs fall by more than the price of GM grain. Those producers whose costs fall by less than 11.6 percent (i.e., $\sigma >$ "indifference") lose because the market price of grain falls. Producers with s = "indifference" are indifferent about producing non-GM at a price of 1 (i.e., the baseline price) and producing GM at a price of 0.884.

The last column in the table shows σ^*, the σ of the producer who is indifferent about producing GM and non-GM grain under the market prices shown for each scenario. Note that all producers with $\sigma < \sigma^*$ (= 0.937) plant GM, but only those with $\sigma <$ "indifference" (= 0.884) benefit compared to the baseline. For example, in scenario 1, a producer with $\sigma = \sigma^* = 0.937$ is indifferent about producing GM and non-GM. However, since the non-GM farm price is 0.9435, it is obvious that this producer is worse off now than in the baseline when the non-GM price was 1.

Scenarios 11 through 15 all have a relatively large amount of consumer concern and a relatively small production cost advantage. In these scenarios, the changes in producer and consumer surplus are very small, and in scenario 13 they are negative. What happens in scenario 13 is that most farmers switch over to GM grain production (GM output share is 90 percent) and thus bulk handling facilities are used for GM grain. A significant group of consumers continues to purchase non-GM grain, and to do so they must pay high costs (assumed equal to 20 percent) associated with identity preservation. These identity preservation costs did not exist in the baseline, and in this particular scenario the additional costs associated with this second system are greater than the production cost advantages associated with the GM technology. The results for this scenario seem counterintuitive in that a group of individually rational agents has adopted a technology that collectively makes them worse off. This kind of result suggests that it is worthwhile to look more closely at the individual welfare effects for this particular scenario.

For scenario 13, the GM price is 0.9052 of the non-GM baseline price. Those producers who have a production cost advantage of more than 9.5 percent benefit from the GM technology. This is 40 percent of producers, as shown in Figure 8. However, a significant group (60 percent) of producers does not experience this critical reduction in production costs. Because identification costs are high in scenario 13, the farm price of non-GM grain is also low at 0.9134. Producers with $\sigma > 0.905$ must therefore accept a major reduction in output price, and the welfare loss for this group (3.27 percent of total baseline revenues) is greater than the welfare gain for those producers who did experience a large cost reduction (2.67 percent of the total baseline revenues).

Many of those consumers who do switch to GM grain in scenario 13 do so because the price of GM grain is almost 19 percent lower than the wholesale price of non-GM grain. However, many of these consumers have a weak preference for non-GM grain and so they do not obtain the full benefit associated with the reduction in GM prices. A significant group of consumers continues to consume non-GM grain despite the large price differential. Consumers who at a GM price of 0.9052 would have preferred to buy non-GM grain if its price had stayed at the baseline level of 1 (i.e., consumers with $\delta < 0.905$) suffer a welfare loss of 2.78 percent of total baseline expenditures. Consumers who would have bought GM grain if it had been offered to them in the baseline at a price of 0.905 or higher experience a welfare gain equal to 2.13 percent of total baseline expenditures. Because the losses of the former outweigh the gains of the latter, consumers as a whole experience a loss from the introduction of GM grains. In scenario 13, the identification cost acts like a tax or distortion, and the negative effects of this distortion are felt by producers who receive lower prices and by consumers who either pay the tax or consume a GM product despite a weak preference for non-GM grain.

Conclusions

Grain marketing and handling facilities have evolved to minimize handling and production costs and are not set up to offer consumers a choice among various product lines. This system has evolved because in the past, few consumers were willing to pay the premiums associated with a differentiated system. Those consumers who have been willing to pay for differentiated grains have participated in small, high-cost niche markets.

The development and commercialization of GM grains has created some unusual and difficult problems for those involved in the bulk commodity markets. At first, very few consumers expressed any concern about the technology. This lack of concern coupled with a strong incentive for farmers to adopt allowed GM grain to capture most of the market. With this majority market share has come access to the bulk handling system that had formerly been utilized for non-GM grains. Soon after GM grains became the standard in U.S. markets, a significant amount of consumer concern emerged. This concern is greatest in food and export markets but has been expressed also by grain processors who export by-products to the EU. The market share of these concerned groups is less than 50 percent.

This paper develops a framework for examining the price and welfare effects of these developments. Results are presented for the short run where supplies are fixed and for the long run when supply is allowed to adapt to market conditions.

The short-term results show that in most cases, non-GM grain becomes another niche product. However, there are some reasonable parameterizations that show a more profound market effect. This situation can occur when the proportion of consumers who are willing to pay a premium in excess of handling costs for non-GM grain is greater than the share of non-GM grain available. In years when these circumstances exist, the farm price of all GM grain will be discounted so that some GM grain is purchased by consumers who prefer non-GM grain. In years when these circumstances do not exist, farm prices of GM and non-GM grain will be identical because the marginal consumer will be indifferent between the two types of grain.

The long-run results show that in almost all circumstances, consumer and producer welfare is greater after the introduction of GM technology. However, in all instances some consumers and some producers will lose. Consumers with a strong preference for non-GM grain will lose because they must pay farmers a premium to encourage them to grow non-GM grain and pay the handling charges associated with identity preservation. Farmers who do not obtain a substantial cost reduction from producing GM grain will also lose because market prices will reflect the cost savings available to those who obtain a greater cost advantage. There are circumstances where both producer welfare and consumer welfare are lower after introducing GM technology. This can occur when identity preservation is expensive and cost savings are relatively small. Interestingly, this outcome is obtained even though all agents are individually rational.

Endnotes

1. The postulated demand (1) is consistent with modern consumer behavior theory (Becker 1971; Lancaster 1971), which treats goods as inputs that are used with time and human capital to produce commodities that directly enter a consumer's utility function. For example, the postulated demand schedules are consistent with utility-maximizing agents who derive utility from consumption of non-GM grain but derive no utility from consumption of GM grain. However, type-δ agents can transform GM grain into non-GM grain at a cost of $(1/\delta - 1)\, P_{GM}$ per unit. This transformation can only be performed for self-consumption purposes (i.e., its produce cannot be marketed) (see, e.g., Chap. 10 in Deaton and Muellbauer 1980). Because the net cost of transforming one unit of GM grain into one unit of non-GM grain is $1/\delta\, P_{GM}$, agents of type δ will either buy non-GM grain directly if $P_{no}^{D} < 1/\delta\, P_{GM}$; buy GM grain and transform it if $P_{no}^{D} > 1/\delta\, P_{GM}$; or be indifferent as to the two ways of getting non-GM grain if $P_{no}^{D} = 1/\delta\, P_{GM}$.

2. Expressions (4) and (5) should involve integrals instead of summations if δ types follow a continuous distribution.

3. The inequality condition on δ^{*} follows from the relationship $P_{GM} \leq P_{no}^{S} = P_{no}^{D} - C$. Suppliers would be irrational if this condition were violated, since $P_{GM} > P_{no}^{S}$ means that suppliers sell non-GM grain as identified non-GM grain for P_{no}^{S} dollars, instead of selling it as unidentified GM grain for P_{GM} ($> P_{no}^{S}$) dollars.

4. This implies that if only non-GM grain were available, each of the two types of consumers would consume half of the total supply of (non-GM) grain.

5. This assertion applies only to consumers with $\delta = 1$. In general, the consumer surplus of type-δ agents ($0 \leq \delta \leq 1$) is measured by the area under the total demand schedule $d_{\delta}(P_{\delta})$.

6. Note that the model is quite general because costs are measured based on per bushel of grain produced, not on a per acre basis. For example, the model includes the cases where GM grain can be produced at lower per bushel cost because of either higher GM yields per acre than non-GM crops, given the same production costs per acre, or lower GM production costs per acre, but the same yields per acre as non-GM crops.

7. This assumption implies that both types of firms are identical at producing non-GM grain, because $P_1 = P_{\sigma} = P_{no}^{S}$ for sufficiently low P_{GM}, in which case $S_{1no} = S_1 = S_{\sigma} = S_{\sigma no}$. As discussed later, however, actual output may be different for the two types of firms because P_1 need not be equal to P_{σ} in general.

8. As mentioned in connection with equations (4) and (5), equations (14) and (15) should involve integrals rather than summations if firms' distributions are continuous rather than discrete.

9. The beta cdf is given by Beta(x| α, β, x_{min}, x_{max}) $\equiv \Gamma(\alpha + \beta)\ (x - x_{min})^{\alpha-1}\ (x_{max} - x)^{\beta-1}/[\Gamma(\alpha)\ \Gamma(\beta)\ (x_{max} - x_{min})^{\alpha+\beta-1}]$ for $x_{min} \leq x \leq x_{max}$, where $\Gamma(\cdot)$ is the gamma function.

10. The model assumes four types of corn consumers. The first type is strongly opposed to GM food for religious, philosophical, or food safety reasons and has $\delta = 0.1$. This group consumes 1 percent of the annual production. Some members of this group are located in the U.S. and some are located outside of the U.S. A second group consists of firms that produce ethanol and high-fructose corn syrup, and the by-product corn gluten feed. This group has a market share of 12 percent. Firms in this group have an economic incentive to avoid GM grains if there is a discount for gluten from GM grain. This discount will emerge if the EU bans imports of GM animal feeds. This discount can be estimated by comparing the value of gluten feed for delivery to the EU with the value of the same product retained for feeding in the U.S. This discount will vary depending on the relative prices of feed grains in the U.S. and the EU and the proportion of total production that is exported. If the EU bans importation of GM animal feeds, processors sell gluten on U.S. rather than on EU markets. Gluten for delivery to the EU sells at \$100/ton, whereas GM gluten for domestic consumption sells at the 1999 price of \$50/ton (USDA-ERS, *Feed Outlook*, various). Each bushel of corn processed yields 13.2 pounds of gluten, and a reduction in the gluten price of \$0.025/lb (\$50/tn) corresponds to a discount of \$0.33/bu, or 16.5 percent, assuming that corn is worth \$2.00/bu. Hence, the second group is assumed to have $\delta = 0.84$. The third group consists of firms that process food for domestic consumers not identified in the first two groups and those who purchase grain for export. These firms know that some of their consumers will have a preference for non-GM food, and they find it easier to switch all of their production over to non-GM crops rather than to maintain two separate production systems. Exports accounted for 21 percent of production in 1999 and food for domestic consumption accounted for 7.9 percent (FAPRI 2000). However, since some of those consuming food belong to the first category above, the market share of this second group is set at 28 percent. This group is assumed to have $\delta = 0.9$. The fourth and last group consists of those who feed corn to domestic livestock in the U.S., which is assumed to have $\delta = 1$ and takes the remainder market share (i.e., 59 percent).

11. Of course, other cdfs may be needed to realistically represent other scenarios.

12. Under these market conditions, three prices are relevant. These are the wholesale price of non-GM grain, the farm price of non-GM grain, and the farm price of GM grain. Under the niche market structure we have described above, only two prices are relevant, the wholesale non-GM price and the farm price of all grain.

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