Genetically Modified Crops and Product Differentiation:
Trade and Welfare Effects in the Soybean Complex

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Abstract. A partial equilibrium four-region world trade model for the soybean complex is developed in which Roundup Ready (RR) products are weakly inferior substitutes to conventional ones, RR seeds are priced at a premium, and costly segregation is necessary to separate conventional and biotech products. Solution of the calibrated model illustrates how incomplete adoption of RR technology arises in equilibrium. The United States, Argentina, Brazil and the Rest of the World (ROW) all gain from the introduction of RR soybeans, although some groups may lose. The impacts of RR production or import bans by the ROW or Brazil are analyzed. U.S. price support helps U.S. farmers, despite hurting the United States, and has the potential to improve world efficiency.

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Biotechnology innovations in agriculture represent a recent trend that is providing both dazzling opportunities and unexpected challenges. Genetically modified (GM) crops account for a major share of U.S. cultivation of soybeans, maize, and cotton, and a few countries, notably Argentina, Canada, and China, have followed the United States's lead. It is estimated that, in 2002, GM crops accounted for 145 million acres worldwide (James). But from the beginning, the biotechnology revolution in agriculture has been controversial (Nelson; Moschini; Pardey). Notably, consumer groups and the public at large have raised, especially in Europe, a vociferous opposition to the introduction of GM products in the food system. They have expressed concern about the safety of GM food and about the environmental impact of GM crops, among other things, and have demanded that consumers be given the "right to know" whether the food they buy contains GM products.[1] As a result, a number of countries are implementing mandatory labeling regulations aimed at providing exactly that choice. Such national policies necessarily interfere with trade (Sheldon). Indeed, the international trade implications of widely differing adoption of, and policy response to, GM crops are proving increasingly difficult to accommodate in an ever more globalized world characterized by commodity-based agricultural trade. Frustration with the current situation is underscored by the official complaint to the World Trade Organization (WTO) that the United States (supported by several other countries) launched against the European Union (EU) in May 2003.[2] Such unresolved issues call for a deeper economic analysis of some trade-related consequences of GM crop adoption, and this paper is an effort in exactly that direction.

The GM crops that have been most successful embody a single-gene transformation that makes the crop resistant either to a herbicide (e.g., Roundup Ready soybeans) or to a particular pest (e.g., Bt maize). As such, these improved crops represent a typical process innovation, increasing the efficiency of production but not supplying any new attribute that consumers value *per se*. In fact, because some consumers object to GM food, the introduction of GM crops actually is bringing to market a product that some consider inferior in quality to its traditional counterpart. This "induced" product differentiation is one of the hallmarks of the current market impact of GM products and has a number of economic implications that need to be addressed. In particular, costly identity preservation activities are necessary to ensure that GM and non-GM products are segregated along the production, marketing, processing, and distribution chain of the food system (Bullock and Desquilbet). Some models recently have attempted to incorporate differentiated final product demands and supply-side identity preservation. Whereas these models vary in their approaches and the issues they address, they share the common attribute of being specified at a very aggregate level and of not modeling closely enough the characteristics of the innovation being analyzed (e.g., Nielsen and Anderson; Nielsen, Thierfelder, and Robinson; Lence and Hayes). In particular, the GM crops that we are interested in have been developed by the private sector and are protected by intellectual property rights (IPRs), which give innovators a limited monopoly power that affects the pricing of GM seeds for farmers and cannot be ignored in assessing the welfare effect of innovations (Moschini and Lapan). Studies that overcome some of these limitations (Moschini, Lapan, and Sobolevsky; Falck-Zepeda, Traxler, and Nelson) still do not address the issue of induced product differentiation.

A few recent studies have addressed the implication of product differentiation and identity preservation. Desquilbet and Bullock study potential adoption of GM rapeseed with non-GM market segregation in Europe based on a calibrated two-country model in which differentiated market supply and demand functions are built up from the individual agent level. Lapan and Moschini (2001, 2004) also build a two-country partial equilibrium model of an agricultural industry to analyze some implications of the introduction of GM products. They model the GM crop as "weakly inferior" in quality to the non-GM one in the importing country that does not produce the GM crop and consider that country's ability to impose policies that limit its exposure to GM products. Fulton and Giannakas model GM product introduction in a closed economy in a vertical product differentiation framework, with emphasis on the welfare impacts of alternative labeling regimes. Furtan, Gray and Holzman study the impact of the potential introduction of GM wheat, with emphasis on the irreversibility aspects of such GM crop release. Whereas these studies take the analysis in a desired direction, the treatment is mostly theoretical and the need remains for quantitative estimates concerning the impact of GM innovations, especially in an open economy setting.

In this study we present a model that closely represents the product differentiation that is induced by the GM crop innovation and explicitly models the ensuing need for costly identity preservation activities that are required to supply the pre-innovation (non-GM) product. In particular, we show how the induced differentiated demand can be specified consistently so as to allow welfare analysis. The model is applied to the world market for soybeans and soybean products (soybean oil and meal).[3] Specifically, we develop a four-region world trade model in which GM crops are produced in a market with differentiated demands and segregation costs. Two of the products (soybeans and soybean oil) are modeled as existing in two varieties: conventional and GM, the latter variety being produced using herbicide-resistant Roundup Ready (RR) technology.[4] The four regions of the model are the United States, Argentina, Brazil, and the Rest of the World (hereafter ROW). The United States is the world's largest soybean producer and exporter. The other main producing region is South America, where most of the cultivation takes place in Argentina and Brazil (table 1). These two countries took different paths with respect to adopting RR soybeans because of different government policies.[5] Hence, considering these two regions separately will allow some interesting policy simulation analyses.[6]

Although, in principle, demands in all four regions could be differentiated, for the purpose of the analysis, only ROW is modeled with differentiated demands. This captures the observation that most resistance to GM product innovation to date has materialized overseas and provides the opportunity for our model to consider how differing GM regulation and policies across countries affect market performance. The model allows for costly identity preservation, an endogenous adoption rate of the GM technology, and noncompetitively supplied GM seed by an innovator-monopolist residing in the United States. The model is calibrated such that, when solved under both spatial and vertical equilibrium conditions, it replicates observed data in a benchmark year. The model is then solved under a number of scenarios that allow us to study and quantify the effects of GM crop adoption under the induced product differentiation hypothesis.

In addition to studying the impact of the cost of keeping traditional and GM crop products segregated, in order to meet the induced differentiated demand, questions addressed by this paper include the direction of price changes and trade flows in GM and non-GM markets, the efficiency gains from the GM crop innovation, and the distribution of welfare effects across regions and across agents (consumers, producers, and the innovator-monopolist). Also, the model is used to study the impact of policies directly aimed at GM crops, such as GM production and/or import bans in regions (such as the EU) with differentiated consumer demand, and GM production bans in exporting regions (such as Brazil) that want to preserve privileged access to demand for the traditional product in importing countries. Finally, the restrictions on parameter values used at the calibration stage also are investigated through an extensive sensitivity analysis.

The Model

The soybean complex consists of three closely related products: soybeans, soybean oil, and soybean meal. Soybeans primarily are crushed to extract soybean oil and meal, which are actively traded internationally. The structural model that we develop requires the specification of demand and supply functions for the three products (possibly available in two varieties, GM and conventional) in each of the four regions, as well as equilibrium conditions (market clearing for every product in every region, spatial equilibrium across regions, and vertical equilibrium across segments of the soybean complex).

Demand

The demand side of the model requires specifying two separate demands in the post-innovation period in at least one region, for conventional and for GM varieties. Also, the model must allow for the pre-innovation demand with only the conventional variety, and for the post-innovation demand with only the (*de facto*) GM variety when no segregation technology is available. In addition, all these demands should arise from the same preference ordering if welfare calculations are to be meaningful. Furthermore, as emphasized in Lapan and Moschini (2004), in our setting it is important that demands satisfy the property that the GM product is a “weakly inferior” (not just an imperfect) substitute for the traditional one. The presumption here is that the GM soybean product does not have any additional attribute from the consumers' point of view such that, *ceteris paribus*, all consumers will weakly prefer the non-GM product. But whereas some consumers may be willing to pay strictly positive amounts to avoid the GM product, other consumers may be willing to pay very little or may be indifferent between the two products. Thus, the GM product will never command a price that exceeds that of the non-GM product.

To implement the notion of "weakly inferior" substitutes, as in Fulton and Giannakas, a good starting point is the vertical product differentiation model with unit demand of Mussa and Rosen (see also Tirole, chapter 7), whereby one can postulate a population of consumers with heterogeneous preferences concerning GM and non-GM goods. Specifically, to generalize this framework to the case where consumers choose both the type of good and the quantity to consume, let preferences for consumers of type τ be represented by the quasilinear utility function,

$$(1) \qquad U = u\left(q_0 + \tau q_1\right) + y \qquad ,$$

where $u(.)$ is increasing and strictly concave, q_0 and q_1 denote physical consumption by the consumer of the non-GM and GM product, respectively, and y denotes the consumption of a *numéraire* good. The condition $\lim_{x\to 0} u'(x) = \infty$ ensures that the consumer will buy either the non-GM or the GM variety, and it is further assumed that income is sufficiently high so that an interior solution holds. The parameter $\tau \in [0,1]$ reflects the "weak inferiority" of the GM variety.

Given this structure, the demand by a consumer of type τ depends upon the relative prices of each variety. In particular, a consumer of type τ will buy the GM variety if and only if $p^1 \le \tau p^0$.[7] Thus, from (1) the individual demand curves can be written as:

$$q_0 = d\left(p^0\right) \text{ and } q_1 = 0 \qquad\qquad \text{for } \tau < \hat{\tau}$$

$$q_0 = 0 \text{ and } q_1 = \frac{1}{\tau} d\left(p^1/\tau\right) \qquad\qquad \text{for } \tau \ge \hat{\tau} \quad ,$$

where the individual demand function $d(.)$ satisfies $d^{-1}(.) = u'(.)$, and $\hat{\tau} \equiv Min\{(p^1/p^0),1\}$. Aggregate market demand functions can then be defined as:

$$Q^0\left(p^0, p^1\right) = \int_0^{\hat{\tau}} d\left(p^0\right) dF(\tau)$$

$$Q^1\left(p^0, p^1\right) = \int_{\hat{\tau}}^1 \frac{1}{\tau} d\left(p^1/\tau\right) dF(\tau)$$

where $F(\tau)$ denotes the distribution function of consumer types.

To make this framework operational, one needs to specify the utility function $u(.)$ and the distribution function of consumer types $F(\tau)$.[8] Note that the model-relevant properties that arise from the above specification are: (i) $\partial Q^0(p^0, p^1)/\partial p^1 = \partial Q^1(p^0, p^1)/\partial p^0 \geq 0$ (i.e, goods are substitutes), and (ii) $Q^1(p^0, p^1) = 0$ if $p^1 > p^0$ (i.e., the GM product is viewed as weakly inferior substitute for the traditional one). Because exact aggregation is possible with quasilinear preferences, we can alternatively think of $Q^0(p^0, p^1)$ and $Q^1(p^0, p^1)$ as arising from the choices of a representative consumer who demands both varieties, while maintaining the property that the GM product is a weakly inferior substitute for the traditional one. Following this approach, we adopt a linear specification for $Q^0(p^0, p^1)$ and $Q^1(p^0, p^1)$, and ensure the "weak inferiority" property by carefully defining the domain of the functions. Specifically, the demand functions for conventional and RR products are written as

$$\text{(2)} \quad \left.\begin{aligned} Q^0 &= a_0 - b_0 p^0 + c p^1 \\ Q^1 &= a_1 + c p^0 - b_1 p^1 \end{aligned}\right\} \quad if \quad p^0 > p^1$$

$$\text{(3)} \quad \left.\begin{aligned} Q^0 &\in \left[a_0 - (b_0 - c)p \ , \ (a_0 + a_1) - (b_0 + b_1 - 2c)p\right] \\ Q^1 &\in \left[0 \ , \ a_1 - (b_1 - c)p\right] \end{aligned}\right\} \quad if \quad p^0 = p^1 \equiv p$$

$$\text{(4)} \quad \left.\begin{aligned} Q^0 &= (a_0 + a_1) - (b_0 + b_1 - 2c)p^0 \\ Q^1 &= 0 \end{aligned}\right\} \quad if \quad p^0 < p^1 \quad ,$$

where all parameters are strictly positive.

Several observations are in order. First, the symmetry condition is maintained, such that this demand system is integrable into well-defined (quasilinear) preferences, a condition that will become important when making welfare evaluations. Next, the total demand that is implied by this structure is

$$Q^T = (a_0 + a_1) - (b_0 - c)p^0 - (b_1 - c)p^1 . \tag{5}$$

Given the condition $b_0 > c$ and $b_1 > c$,[9] which we shall assume, total demand is decreasing in either price. Also note that, at $p^0 = p^1$, equation (2) gives $Q^1 = a_1 - (b_1 - c)p^0$ [in the domain $p^0 \le a_1/(b_1 - c)$]. Thus, this specification is consistent with a positive mass of consumers being perfectly indifferent between good 0 and good 1 at $p^1 = p^0$ (but with $p^0 < p^1$, demand for Q^1 vanishes).

The specification in equation (4), which applies in the domain $p^0 < p^1$, also represents market demand before the introduction of RR products. That is, the before-innovation situation is equivalent to the new technology being available but only at a prohibitive price, i.e., above p^0. When the new technology is adopted but the RR and conventional varieties are not separated in the supply chain, the effective demand for the conventional product is assumed to be zero. In other words, the assumption is that consumers treat co-mingled product as equivalent to GM product.[10] Hence, this case is equivalent to the situation where the price of the GM-free product is prohibitively high, i.e., above the “choke” price $\overline{p}^0 \equiv (a_0 + cp^1)/b_0$. Therefore, the post-innovation demand without identity preservation is written as

$$\left.\begin{aligned} Q^0 &= 0 \\ Q^1 &= a_1 + \frac{ca_0}{b_0} - \left(b_1 - \frac{c^2}{b_0}\right)p^1 \end{aligned}\right\} \; if \quad p^0 \ge \overline{p}^0 . \tag{6}$$

Note that the conditions $b_0 > c$ and $b_1 > c$ ensure that this demand is downward sloping. The complete specification of the demand system (2)–(4) for all prices in $\mathbb{R}^2_+$ is represented in figure 1. Finally, for regions and/or products with undifferentiated demand, the specification used is also linear and written as

$$Q^U(p) = a - bp \quad . \tag{7}$$

Supply

We use an extended version of the parsimonious specification for soybean production and supply developed in Moschini, Lapan, and Sobolevsky, which accounts for the main features of soybean production practices, reflects the nature of biotechnology innovation in the soybean industry, and is suitable for calibration purposes. In its original form, this specification assumes homogeneous soybean farmers who have the choice of growing conventional or RR soybeans or both,[11] who do not segregate the two varieties during the production process and therefore receive the same price for either variety. The aggregate soybean supply function is written as $Y_B = L \cdot y$, where Y_B is total production consisting of a mix of conventional and RR soybeans, L is land allocated to soybeans (which depends on the profitability of this crop), and y denotes yield (production per hectare).[12] But with differentiated products and identity preservation costs, farmers may obtain different prices in equilibrium. To account for this, we need to represent explicitly the cost of segregating conventional and GM products.

Separation of non-GM soybeans and soybean products requires extensive segregation activities to ensure "identity preservation" (Lin, Chambers, and Harwood; Bullock and Desquilbet). This activity includes separation of non-GM beans at all levels of production and along the supply chain (from planting through harvest, storage, and transportation) and testing for GM content at various points in the marketing system. These costs are modeled by a constant unit segregation cost $\varphi > 0$ which applies if, and only if, the region in question produces both varieties. This unit segregation cost arises between the production level (at the farm gate) and the point of domestic user demand (or, equivalently, the exporting point for goods to be shipped to foreign markets). The parameter φ thus represents a wedge between the producer and the home demand price or, if the product is not consumed at home, the importing region's demand price minus transportation costs.

With segregation costs, the profit functions per hectare for each variety of soybeans in each region are written as

(8) $$\pi^0 = A + \frac{G}{1+\eta}\left(p_B^0 - \varphi\right)^{1+\eta} - \delta w$$

(9) $$\pi^1 = A + \alpha + \frac{(1+\beta)G}{1+\eta}(p_B^1)^{1+\eta} - \delta w(1+\mu) \quad ,$$

where p_B^0 is the (demand) price of conventional soybeans (so that the farm-level price in the conventional soybean market is $p_B^0 - \varphi$) and p_B^1 is the market price of RR soybeans. By Hotelling's lemma, this specification implies that the yield functions are $y^0 = (p_B^0 - \varphi)^\eta G$ for the conventional technology and $y^1 = (1+\beta)(p_B^1)^\eta G$ for the RR technology. The interpretation of the parameters involved is as follows: δ is the (constant) amount of seed per unit of land, w is the price of soybean seed, μ is the markup (which reflects the technology fee) on the RR seed price charged by the innovator-monopolist who developed the RR technology, η is the elasticity of yield with respect to the soybean price, α is the (additive) coefficient of unit profit increase due to the RR technology, β is the coefficient of yield change due to the RR technology, and A and G are parameters subsuming all other input prices (presumed constant).

The relationship between π^0 and π^1 determines which technology is adopted by farmers. Specifically, the equilibrium in which both soybean varieties are produced requires that farmers are indifferent between the two technologies, i.e., $\pi^0 = \pi^1$. The total supply of land to the soybean industry in each region is written as a function of land rents, $L(\bar{\pi})$, where $\bar{\pi} = \max\{\pi^0, \pi^1\}$. Specifically, the land supply function is written in the constant elasticity form $L(\bar{\pi}) = \lambda\bar{\pi}^\theta$, where θ is the elasticity of land supply with respect to soybean profit per hectare, and λ is a scale parameter. The region's adoption rate $\rho \in [0,1]$ or, equivalently, the land allocation between conventional and RR soybeans, is endogenously determined in equilibrium. But for a given ρ, RR and conventional soybeans will have ρL and $(1-\rho)L$

hectares of land allocated to them, respectively, and thus aggregate supply of each soybean variety in each region can be written in equilibrium as

$$(10)\qquad Y_B^0 = \lambda\left[A + \frac{G}{1+\eta}(p_B^0 - \varphi)^{1+\eta} - \delta w\right]^{\theta}(1-\rho)(p_B^0 - \varphi)^{\eta} G$$

$$(11)\qquad Y_B^1 = \lambda\left[A + \alpha + \frac{(1+\beta)G}{1+\eta}(p_B^1)^{1+\eta} - \delta w(1+\mu)\right]^{\theta}\rho(1+\beta)(p_B^1)^{\eta} G\ .$$

U.S. Price Support Policies

The supply equations (10) and (11) were obtained under the assumption of no government intervention. But in the soybean sector, a major support program has been available to U.S. producers since 1996 through nonrecourse marketing assistance loans and loan deficiency payments (LDPs) (USDA 1998). Essentially, LDPs establish an effective floor for the soybean price at the farm level. It turns out that, whereas the 1996 and 1997 soybean crops did not benefit from LDPs, soybean prices got as low as \$150/mt in the following years, well below the national average loan rate of \$193/mt that remained fixed at that level until 2002. Only in the summer of 2002 did soybean prices recover to exceed the loan rate. Thus, LDPs have played a significant role in the U.S. soybean industry in recent years, and may continue to do so again in the future.

A number of studies, summarized in Alston and Martin, explain how price-distorting policies may affect the size and distribution of welfare changes because of innovation. In such a setting there is even the possibility of immiserizing technical change, as in Bhagwati, who demonstrates that growth may be welfare reducing because of various trade policy distortions and terms-of-trade effects. Thus, in the policy analysis that we present, it is important to account for the effects of price support through LDPs. A relevant feature of the U.S. price support program in our setting is that it does not distinguish between conventional and RR soybeans (i.e., it provides the same floor price for either variety). To integrate such effects into our model, let p_{LDP} denote the average price offered by price support programs, such that in the supply equations (10) and (11) the farm-level conventional soybean price $(p_B^0 - \varphi)$ is replaced by $\max\{p_{LDP}, p_B^0 - \varphi\}$, and the GM soybean price p_B^1 is replaced by $\max\{p_{LDP}, p_B^1\}$.

Trade and Market Equilibrium

In our model, the world is divided into four regions: the United States (U), Brazil (Z), Argentina (A), and the ROW (R). Such regional division of the world allows the model to specifically describe individual economic characteristics of the main players in the soybean complex and to emphasize the existing differences among them. The model allows us to study whether different regions are affected differently by the introduction of RR technology and to model region-specific policy actions of interest and estimate their economic impact on each region separately.

Trade takes place at all levels of the soybeans complex: in soybeans (B), soybean oil (O), and soybean meal (M). Any region can be involved in trading any product of any variety, and there are no *a priori* restrictions on the direction of trade. The spatial relationship among prices in different regions is established using constant price differentials defined for each pair of regions for each product, each variety, and each possible direction of trade flow. These spatial price differentials essentially represent transportation costs but may also incorporate the effects of the existing import policies (Meilke and Swidinsky).

Equilibrium Conditions

We assume that crushing one unit of soybeans produces γ_O units of oil and γ_M units of meal, and that unit crushing costs (crushing margins) are constant and equal to m_i (where the subscript *i* indexes the region). Then, the spatial market equilibrium conditions for the three-good, four-region model previously outlined are as follows:

$$(12) \qquad \sum_{i=U,A,Z,R} Q_{B,i}^0(p_{B,i}^0, p_{B,i}^1) + \frac{1}{\gamma_O}\left(\sum_{i=U,A,Z,R} Q_{O,i}^0(p_{O,i}^0, p_{O,i}^0)\right) = \sum_{i=U,A,Z,R} Y_{B,i}^0(p_{B,i}^0, \rho_i)$$

$$(13) \qquad Q_{B,i}^0(p_{B,i}^0, p_{B,i}^1) + \frac{1}{\gamma_O} Q_{O,i}^0(p_{O,i}^0, p_{O,i}^1) = Y_{B,i}^0(p_{B,i}^0, \rho_i), \qquad i \in I_0$$

(14) $$\sum_{i=U,A,Z,R} Q^1_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} \sum_{i=U,A,Z,R} Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) = \sum_{i=U,A,Z,R} Y^1_{B,i}(p^1_{B,i}, \rho_i)$$

(15) $$Q^1_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) = Y^1_{B,i}(p^1_{B,i}, \rho_i), \qquad i \in I_1$$

(16) $$\frac{1}{\gamma_M}\left(\sum_{i=U,A,Z,R} Q_{M,i}(p_{M,i})\right) = \frac{1}{\gamma_O}\left(\sum_{i=U,A,Z,R} Q^0_{O,i}(p^0_{O,i}, p^1_{O,i}) + \sum_{i=U,A,Z,R} Q^1_{O,i}(p^0_{O,i}, p^1_{O,i})\right)$$

(17) $$p^0_{B,i} + m_i = \gamma_M p_{M,i} + \gamma_O p^0_{O,i}, \qquad i \in I'_0$$

(18) $$p^1_{B,i} + m_i = \gamma_M p_{M,i} + \gamma_O p^1_{O,i}, \qquad i \in I'_1$$

(19) $$\begin{array}{lll} \pi^0_i(p^0_{B,i}) = \pi^1_i(p^1_{B,i}) & if \quad \rho_i \in (0,1) & \\ \pi^0_i(p^0_{B,i}) \ge \pi^1_i(p^1_{B,i}) & if \quad \rho_i = 0 & i = U, A, Z, R \\ \pi^0_i(p^0_{B,i}) \le \pi^1_i(p^1_{B,i}) & if \quad \rho_i = 1 & \end{array}$$

(20) $$\left|p^0_{B,i} - p^0_{B,j}\right| \le t^0_{B,ij}, \quad i,j = U, A, Z, R,\ i \ne j$$

(21) $$\left|p^1_{B,i} - p^1_{B,j}\right| \le t^1_{B,ij}, \quad i,j = U, A, Z, R,\ i \ne j$$

(22) $$\left|p^0_{O,i} - p^0_{O,j}\right| \le t^0_{O,ij}, \quad i,j = U, A, Z, R,\ i \ne j$$

(23) $$\left|p^1_{O,i} - p^1_{O,j}\right| \le t^1_{O,ij}, \quad i,j = U, A, Z, R,\ i \ne j$$

(24) $$\left|p_{M,i} - p_{M,j}\right| \le t_{M,ij}, \quad i,j = U, A, Z, R,\ i \ne j$$

Equations (12) and (14) are market clearing equations requiring that the total world soybean demand for direct use and processing equals world supply in each variety. Market clearing conditions for regions that do not trade soybeans and oil, if such regions exist, are represented by equation (13) (for conventional products) and equation (15) (for RR products). Thus, the subset $I_0 \subset \{U, A, Z, R\}$ contains the indices of nontrading regions for conventional products, and the subset $I_1 \subset \{U, A, Z, R\}$ contains the indices of nontrading regions for RR products. Also, given (12), the number of elements in I_0 should not exceed three, and the same applies to I_1. Equation (16) ensures that the soybean equivalents of oil and meal demands are the same, in aggregate. Equations (17) and (18) ensure that soybean processors of either variety receive a constant crushing margin m_i to cover their costs. Because of the existence of spatial price linkages among trading regions, each of these equations should be applied only to a single trading partner and all non-trading regions (if such regions exist in equilibrium). Thus, I_0' is the set of indices of one trading region and all nontrading regions for conventional products, and I_1' is the set of indices of one trading region and all nontrading regions for RR products.

Equation (19) describes the farmers' incentive compatibility constraints. Production of both conventional and RR soybeans in the same region takes place only when the respective unit profits are the same, i.e., when farmers are indifferent about which variety to produce; otherwise only the more profitable variety is produced. Equations (20) through (24) define the spatial configuration of prices. The four-region spatial model in equilibrium will have a maximum of three trade flows in each product variety. In the case of the soybean complex and the chosen regional division of the world, there are three specific trade flows that are most likely to prevail in any conceivable equilibrium. Currently, trade takes place between the United States and the ROW, between Brazil and the ROW, and between Argentina and the ROW, but whether that will hold with differentiated markets is to be determined by equilibrium. Price differentials (transportation costs), assumed symmetric for each pair of regions, are denoted by $t_{m,ij}^{k}$.[13] Whenever trade between two regions in a particular product variety exists, the corresponding inequality becomes an equality.

As mentioned earlier, the model assumes that the soybean and soybean oil demands in the ROW are the only differentiated demands in the system, while U.S., Argentine, and Brazilian consumers remain indifferent to what variety of soybeans, oil, or meal they consume. In a nontrivial differentiated equilibrium with no production or import bans (i.e., the one in which both varieties are produced and consumed), it follows that the demands in (12)–(24) must satisfy

$$Q^0_{B,i}(p^0_{B,i},p^1_{B,i}) \equiv 0,\ i = U, A, Z$$

$$Q^0_{O,i}(p^0_{O,i},p^1_{O,i}) \equiv 0,\ i = U, A, Z$$

$$(25) \qquad Q^1_{B,i}(p^0_{B,i},p^1_{B,i}) \equiv Q^U_{B,i}(p^1_{B,i}),\ i = U, A, Z$$

$$Q^1_{O,i}(p^0_{O,i},p^1_{O,i}) \equiv Q^U_{O,i}(p^1_{B,i}),\ i = U, A, Z$$

$$Q_{M,i}(p_{M,i}) \equiv Q^U_{M,i}(p_{M,i}),\ i = U, A, Z, R\ .$$

Were we to assume that all four regions have differentiated demands in soybeans and soybean oil, only the last of the five identities in (25) would apply.

The existence and uniqueness of equilibrium is guaranteed by the standard shape of demand and supply functions (Samuelson). But because we are assuming that a region producing only conventional soybeans pays no segregation cost, we are introducing a discontinuity that can affect the uniqueness property of equilibrium. A limitation of the equilibrium system (12)–(24) is that it does not allow recovery of all individual trade flows, i.e., distinct exports/imports of soybeans, soybean oil, and soybean meal. This feature ultimately is due to the assumption of constant-returns-to-scale (and no capacity constraints) for the crushing technology in all regions of the world, which makes the interregional distribution of crush undetermined in equilibrium. The meaningful trade flow that can be recovered from equilibrium is the factor content of trade, in the form of the excess supply of soybeans (in each variety) remaining after subtracting domestic soybean demand and the soybean equivalent of domestic oil demand from the domestic supply of beans:

$$(26) \qquad ES^j_{B,i} = Y^j_{B,i} - Q^j_{B,i} - \frac{1}{\gamma_O} Q^j_{O,i} \quad i = U, A, Z, R;\ \ j = 0,1\ .$$

We can call $ES^j_{B,i}$ the soybean-equivalent net exports. However, because trade in soybean products does not necessarily follow the fixed proportions of the crushing technology, this measure must be supplemented by a residual, which here is defined as the residual meal net export:

(27) $$ES_{M,i} = \frac{1}{\gamma_O}\left(Q^0_{O,i} + Q^1_{O,i}\right)\gamma_M - Q_{M,i} \quad i = U, A, Z, R\,.$$

Solution Algorithm

The task is that of solving a spatial four-region, three-good equilibrium model. The solution of spatial equilibrium models can be traced back to Samuelson, who showed that in the partial-equilibrium (one-commodity) context, the problem of finding a competitive equilibrium among spatially separated markets could be converted into a maximum problem. He suggested that this problem could be solved by trial and error, or by a systematic procedure of varying export shipments in the direction of increasing social welfare. Takayama and Judge extended Samuelson's work to a multiple-commodity competitive equilibrium and, under the additional assumption of linear regional demand and supply functions, reduced spatial equilibrium to a quadratic programming problem solvable with available simplex methods. Attempts to extend this framework to nonlinear demand and supply specifications have been less successful, as discussed in Takayama and Labys.

In view of the above, we elected to solve directly the system of nonlinear equations (12)–(24) defining the spatial equilibrium conditions by using numerical techniques implemented by user-written programs coded in GAUSS.[14] Obviously, the equations defining the system to be solved must be binding, but in our case the number of binding equations in (12)–(24) is not determined *a priori*. There are two sources of ambiguity: the number of trade flows in each commodity, and the possible specialization in production of a particular soybean variety in each region.[15] Our algorithm looks for an equilibrium by repeatedly solving the fluctuating-in-size binding portion of the system (12)–(24) over all of the following combinations: (*a*) each region specializes in conventional soybeans, in RR soybeans, or does not specialize; (*b*) there is no trade in RR beans/oil; (*c*) there is only one RR trade flow involving a pair of regions, in either direction, for all possible region pairs; (*d*) there are two RR trade flows, in all possible combinations of directions, excluding (for arbitrage reasons) cases when the same region is both exporter and importer of the same product(s); (*e*) there are three RR trade flows, in all possible combinations of directions, excluding (for arbitrage reasons) cases when the same region is both exporter and importer of the same product(s). The solution—when found—is checked against the remaining non-binding equations of the system (12)–(24).

Calibration

The parameters of the model are calibrated such as to replicate prices and quantities in the soybean complex for the crop year 1998–99, the most recent complete year when the analysis was undertaken. Production and utilization data are given in table 1. Additional data on the history of world adoption rates for RR soybeans, as well as prices for various soybean products in the main world markets, are reported in Sobolevsky, Moschini, and Lapan. Based on that, the benchmark U.S. prices for soybeans, oil, and meal were set to \$176, \$441, and \$145 per mt, respectively. In the United States in 1998–99, the soybean price at the producer level differed from \$176/mt because of LDPs. The spatial price differentials (transfer costs) were set at the levels used in Moschini, Lapan, and Sobolevsky, extended to account for South America being broken down into two regions.[16] See table 2 for individual transportation costs.

Calibration of demand parameters requires assigning values to the parameters (a_0, a_1, b_0, b_1, c) so as to retrieve the benchmark quantity and price data. As is typical in this setting, a range of parameter values is admissible, depending on elasticity assumptions. But here, elasticity assumptions are difficult because the benchmark equilibrium is a pooled one (without segregation), whereas the demand system we wish to calibrate distinguishes between GM and non-GM goods. To proceed, we follow the strategy whereby the five parameters of interest are identified by the (observed) benchmark price and (pooled) quantity demanded ($\hat{p}$ and $\hat{Q}$), by the own-price elasticity of undifferentiated demand $\hat{\varepsilon}^{UU}$, by the own-price elasticity of conventional demand $\hat{\varepsilon}^{00}$, by the fraction $\hat{\sigma} \in (0,1)$ of demand that is "indifferent" between GM and non-GM at prices $p^0 = p^1 = \hat{p}$, and by the fraction $\hat{k} \geq 1$ by which total demand would increase if the new product were to become available at price $p^1 = \hat{p}$. More specifically, because no significant segregation took place in the reference year 1998–99, we can assume, as discussed earlier, that in this reference year $Q^0 = 0$ and $Q^1 = a_1 + c\overline{p}^0 - b_1 p^1$. Hence, for the observed total quantity demanded $\hat{Q}$ and price $\hat{p}$, it must be that

$$\hat{Q} = a_1 + \frac{ca_0}{b_0} - \left(b_1 - \frac{c^2}{b_0} \right) \hat{p} \; . \tag{28}$$

If p^0 were to fall from the choke level $\overline{p}^0$ to $p^0 = p^1 = \hat{p}$, total demand (the sum of differentiated demands) increases such that we write

$$a_0 + a_1 - \left(b_0 + b_1 - 2c \right) \hat{p} = \hat{k}\hat{Q} \, , \tag{29}$$

but a fraction of the total demand is indifferent at those prices, such that we write

$$\frac{a_1 - (b_1 - c)\,\hat{p}}{(a_0 + a_1) - (b_0 + b_1 - 2c)\,\hat{p}} = \hat{\sigma} \; . \tag{30}$$

The own-price elasticity of (undifferentiated) demand at price $\hat{p}$ satisfies

$$\hat{\varepsilon}^{UU} = -\left(b_1 - \frac{c^2}{b_0} \right) \frac{\hat{p}}{\hat{Q}} \tag{31}$$

and the own-price elasticity of conventional demand elasticity at $p^0 = p^1 = \hat{p}$ satisfies

$$\hat{\varepsilon}^{00} = -b_0 \frac{\hat{p}}{a_0 - (b_0 - c)\,\hat{p}} \; . \tag{32}$$

To solve equations (28)–(32) for the parameters of interest, we set $\hat{\sigma} = 0.5$, $\hat{k} = 1.05$, $\hat{\varepsilon}^{00} = -4.5$, and, as in Moschini, Lapan, and Sobolevsky, $\hat{\varepsilon}^{UU} = -0.4$.

Calibrated supply parameters are obtained using specifications (18)–(23) together with specific assumptions as in Moschini, Lapan, and Sobolevsky. Specifically, as in that study, the unit seed costs $\delta\omega$ are set at {45, 40, 40, 40},[17] values consistent with data reported by the U.S. Government Accounting Office (USGAO) and Schnepf, Dohlman, and Bolling. The RR seed markups are set to μ = {0.4, 0.2, 0.2. 0.2}.[18] Note that the assumption of a constant markup is made to keep the analysis to a tractable scope. A more complete model would endogenize the pricing decision of the innovator (Lapan and

Moschini, 2004). The U.S. value of 0.4 reflects the observed technology fee charged by major seed companies (about $6 per bag). Furthermore, the assumption that seed price markups are lower outside the United States, as noted by a reviewer, is quite consistent with the presumption that an innovator-monopolist would rationally try to segment markets. Such an attempt at third degree price discrimination would tailor the seed price markup to local conditions, and a number of reasons suggest that the improved seed demand may be more elastic in non-U.S. regions. In particular, the strength of IPRs is crucial in determining the improved seed demand elasticity. For example, in Argentina RR seed prices have declined substantially, after being set initially at levels comparable to those seen in the United States, a fact ultimately due to the weaker IPRs for this crop in that country (USGAO; Goldsmith, Ramos, and Steiger).[19] Because IPR protection is unlikely to be any better in Brazil or the ROW, for the remaining three regions the RR seed markup is assumed to be one-half of the U.S. value, and thus we set μ = 0.2.

To calibrate the parameter α (i.e., the additive efficiency gain of the GM variety), we note that $\Delta\pi \equiv \pi_1 - \pi_0 = \alpha - \delta\omega\mu$ (under the baseline assumption of no segregation and $\beta = 0$). Based on U.S. data in 2000, we estimate that the cost savings of using RR technology lies between $8.90 and $22.49 per hectare and therefore for this country we conservatively set $\Delta\pi = 15$. We also assume that, if Brazil and Argentina were to face the same RR seed markup ($\mu = 0.4$) and the same soybean seed price ($\delta w = 45$), for these countries we would also have $\Delta\pi = 15$. For the ROW, on the other hand, the assumption is that it would have $\Delta\pi = 10$ under the same seed price parameters as the United States (the lower unit profit increase justified by the lower yields; see table 1). The actual calibration of the α parameter in each region, of course, adjusts the above $\Delta\pi$ assumptions by the previously discussed differences in seed prices. To calibrate θ, it is useful to relate this parameter to the more standard notion of elasticity of land supply with respect to soybean prices. Specifically, $\theta = r\psi$, where ψ is elasticity of land supply with respect to soybean prices and $r \equiv \pi/(p_B y)$ is the farmer's share (rent) of unit revenue. The elasticity ψ is set to 0.8 in the United States and 0.6 in the ROW, based on the review of the literature discussed in

Moschini, Lapan, and Sobolevsky. The value of ψ =1.0 used in Moschini, Lapan, and Sobolevsky for South America here applies to Brazil, whereas we set ψ =0.6 for Argentina.[20]

The technical coefficients γ_M and γ_O are set to their world average values for the 1998–99 crop year; that is, γ_M =0.7985 and γ_O =0.1810. As for segregation costs, we rely on Lin, Chambers, and Harwood, who extend the segregation cost estimates available for specialty crops grown in the United States (Bender *et al.*) to non-GM soybeans. They project that for U.S. grain handlers, segregating non-GM soybeans may cost from \$6.60 to \$19.80/mt (depending on whether handling process patterns for high-oil corn or the ones for sulfonylurea-tolerant soybeans were used).[21] Because segregation costs are crucial to our investigation, the model is solved for both the minimum and maximum values of the range identified by Lin, Chambers, and Harwood, as well as the midpoint of that range and costless segregation. That is, for all regions, we alternatively set φ = 0, φ = 6.6, φ =13.2, and φ =19.8. Finally, we need to account for the fact that LDPs were effective in the benchmark year 1998–99. Thus, the U.S. producer price is set at \$193/mt in 1998–99, and in scenarios in which the U.S. price support program is assumed to remain in force we also will have $p_{LDP} = 193$. The summary of all parameters and their values used for model calibration purposes and for the baseline solution of the world soybean complex partial equilibrium defined by equations (12)–(25) is provided in table 2.

Results

The model is solved for several parameter values and policy scenarios. We study the implications of introducing the RR technology in the soybean complex, look at the effects of the U.S. domestic price support policy, and analyze the impacts of policy aimed at the new GM product in the ROW and/or in Brazil. One result common to all scenarios is that the direction of trade flows, when flows are nonzero, does not change in any equilibrium from what is observed in the pre-innovation market. Trade in all products and in all varieties flows from the United States, Argentina, and Brazil to the ROW except for special cases when particular regions find themselves in autarky in a particular product variety.

Consider first the case of no U.S. price support. Equilibrium adoption rates, prices, soybean supply, and exports for various scenarios are reported in table 3. Our basic benchmark is the "pre-innovation" scenario. Because the model was calibrated on 1998–99 data, when LDPs were in fact effective and when considerable adoption of RR soybeans had already occurred, the simulated equilibrium prices under the "pre-innovation" scenario are higher than observed in that year. Next, consider the "no segregation" scenario, which would attain if segregation costs were prohibitively high. In such a case, there is no effective demand for the conventional product and thus the world moves to complete adoption of the new (more efficient) production technology. U.S. soybean prices fall by 4%, oil by 7%, and meal by 1%, and prices in all other regions decline as well from the pre-innovation benchmark. U.S. soybean supply falls because the region's new technology cost savings are the smallest among the four regions, owing to enforcement of IPRs, and are not high enough to offset the price decline. Other regions' supplies grow. Consumption increases in all regions but the ROW, where GM-conscious consumers cut down on the consumption of inferior RR soybeans and soybean oil.

The "zero-segregation-cost" scenario, reported at the bottom of table 3, is the other polar case and it is useful because it isolates the RR technology impacts from those caused by segregation costs. Here the United States grows most of the conventional soybeans (Brazil adds a tiny amount). The fact that the ROW does not, despite its having the GM-conscious consumers, is because in our model U.S. producers experience a smaller cost reduction owing to the RR technology, as previously discussed. Thus, "comparative advantage" in this model is very much affected by uneven IPR protection across countries. Without any segregation costs, the world share of the conventional soybean market reaches 17%. The U.S. adoption rate is a low 62% and the region finds itself in an autarky equilibrium in the RR market, exporting only the conventional variety to the ROW. As a result, RR prices in the other regions fall compared to the low-segregation-cost scenario (see below) under the pressure of weakened RR import demand from the ROW. In regions that grow both varieties there is a "price premium" for conventional soybean producers, which is necessary to offset the higher production costs for this crop vis-à-vis RR soybeans. In the United States such a premium is \$5.7/mt (about 3.2% of the RR soybean price).

The fact that it actually costs to segregate affects the result in a predictable way. The high level of segregation costs that we considered, \$19.8/mt or 11% of the price received by U.S. farmers growing conventional soybeans, is almost enough to drive out conventional soybean production. A small amount of conventional soybeans is produced in this scenario (2% of world output), all in the United States, and the welfare gains relative to the no-segregation scenario are minimal. The United States is the only region producing both varieties (its adoption rate in equilibrium is 95%), while all other regions specialize in production of RR soybeans. As segregation costs decline to \$13.2/mt or to \$6.6/mt, the effects are shared between the conventional variety's consumers and producers because of the fact that demands are not completely inelastic and because conventional consumer prices fall and conventional producer prices increase. This benefits ROW consumers and U.S. producers, whose share of conventional soybean production increases to 30% when segregation costs are low. The United States remains the only producer of the conventional variety, with the worldwide share of the conventional soybean market growing to 13%. As more production shifts toward conventional soybeans, the world's RR supply decreases, causing RR prices to increase.

The next set of results, shown in table 4, repeats the analysis given the presence of the U.S. LDP price support program. The U.S. producer price floor of \$193/mt is effective both in the pre-innovation and post-innovation situations, with the latter entailing a support of about 10% over the market price. The presence of this price support program in the United States has a dramatic impact on the spatial allocation of soybean production, such that the United States does not produce the conventional variety at all. This is because LDPs equate farmer prices for conventional and RR soybeans and create a permanent incentive to specialize in the (more efficient) RR variety. Brazil emerges as the only producer and exporter of conventional products to the ROW in all scenarios but the zero-segregation-cost one, in which Argentina also dedicates 50% of its total production to conventional soybeans. The U.S. producer price support program depresses prices everywhere, such that in all regions except the United States such reduced prices tend to offset the supply expansion effect of the more efficient RR technology. The relative effect of various levels of segregation costs is similar to the case of no price support reported in table 3.

Welfare Effects

For each scenario we are particularly interested in computing the welfare change effects for each region and for distinct groups within regions. The benchmark for all welfare calculations is the pre-innovation scenario in which the RR soybean is not yet available ($\rho_i = 0$, i = U, A, Z, R), such that demands are described by equations (4) and (7), while supplies are described by (10) with $\varphi = \rho = 0$. If $\hat{p}^0_{j,i}$ is the equilibrium undifferentiated pre-innovation price for product *j* in region *i*, and $\tilde{p}^0_{j,i}$ and $\tilde{p}^1_{j,i}$ are equilibrium prices of conventional and RR varieties in the post-innovation differentiated market, then, setting the reservation price $\hat{p}^1_{j,i} \equiv \hat{p}^0_{j,i}$, the change in consumer surplus is defined as follows:

$$(33) \qquad \Delta CS_{j,i} = \int_{\tilde{p}^1_{j,i}}^{\hat{p}^1_{j,i}} Q^1_{j,i}(\hat{p}^0_{j,i}, p^1_{j,i})dp^1_{j,i} + \int_{\tilde{p}^0_{j,i}}^{\hat{p}^0_{j,i}} Q^0_{j,i}(p^0_{j,i}, \tilde{p}^1_{j,i})dp^0_{j,i} \quad .$$

Consumer surplus changes in undifferentiated markets are computed in the standard way:

$$(34) \qquad \Delta CS_{j,i} = \int_{\tilde{p}^1_{j,i}}^{\hat{p}^1_{j,i}} Q^U_{j,i}(p)dp \, .$$

A change in producer surplus between pre-innovation and differentiated market scenarios is

$$(35) \qquad \Delta PS_i = \int_{\hat{\bar{\pi}}_i}^{\tilde{\bar{\pi}}_i} L_i(v)dv \ ,$$

where L_i is the land allocation function, $\hat{\bar{\pi}}_i$ is the pre-innovation equilibrium average unit profit, and $\tilde{\bar{\pi}}_i$ is the differentiated market equilibrium average unit profit. The innovator-monopolist's profit is computed as

$$(36) \qquad \Pi^M = \sum_{i=U,S,R} \tilde{\rho}_i L_i(\tilde{\bar{\pi}}_i)\mu_i \delta w_i \ ,$$

where $\tilde{\rho}_i$ is the equilibrium rate of adoption in region *i*. Finally, the total change in welfare is defined as

$$
\begin{aligned}
&\Delta W_U = \sum_{j=B,O,M} \Delta CS_{j,U} + \Delta PS_U + \Pi^M + \Delta Gov \\
&\Delta W_i = \sum_{j=B,O,M} \Delta CS_{j,i} + \Delta PS_i \quad i = A, Z, R \quad ,
\end{aligned}
\tag{37}
$$

where ΔGov denotes the change in U.S. taxpayer surplus due to changes in LDP outlays.

Table 5 reports the estimated welfare effects for various scenarios, for both the case of no U.S. price support and for the case when LDPs are effective. Considering first the case of no U.S. price support, it is apparent that there is a sizeable welfare gain that would arise from a worldwide adoption of the more efficient RR technology, even when no segregation takes place. The estimated gain of \$1.564 billion is 25% lower than the worldwide gain estimated in Moschini, Lapan, and Sobolevsky, mostly because in their model they did not allow for preference differentiation. In this no-segregation scenario, consumers capture 39% of the welfare gain, while the innovator-monopolist captures another 53%. Note that consumers in the ROW gain, despite the fact that 50% of the market has preference for the conventional variety, which is unavailable in this scenario. U.S. farmers lose from the introduction of RR soybean in all scenarios except that of zero segregation costs. The fact that farmers elsewhere gain is due to their accessing the RR technology at a lower cost than U.S. farmers, because of lower IPR standards in these other regions. The further increase in welfare that takes place when segregation is possible at zero costs illustrates the benefits of allowing differentiated consumers (in the ROW) to exercise the choice to consume conventional products instead of RR products.

The existence of positive segregation costs, however, takes away most of the additional welfare gain arising because of unconstrained preferences. As noted earlier, the high segregation cost considered (\$19.8/mt) is nearly prohibitive, such that the model outcomes for this scenario are similar to the no-segregation scenario. But even the low-segregation cost scenario entails an overall welfare gain from RR innovation similar to the no-segregation scenario. Consumers in the ROW, however, benefit from feasible segregation in all scenarios. It is also interesting to note that the profit of the RR seed supplier is positively related to the level of segregation costs, because higher segregation costs lead to higher RR adoption rates in equilibrium.

Table 5 illustrates that the presence of LDPs in the United States entails large welfare redistribution effects and a small efficiency loss (relative to no LDPs). Worldwide welfare gains are similar to those in the no-LDP scenario, which means that the possibility of immiserizing growth, discussed earlier, does not occur. The U.S. price support program, not surprisingly, has a large positive impact on the welfare of U.S. farmers, ensuring that they benefit substantially from the introduction of the new technology. This price distortion, however, depresses RR prices worldwide to the degree that farmers in Brazil and Argentina lose whenever segregation costs are positive and are able to gain only in the zero-segregation-cost case when 50% of their production is in the higher-priced conventional market. The overall effect of the U.S. price support program is to reduce welfare in all regions except the ROW, a net importing region that therefore benefits from the price decline. Interestingly, the U.S. price support actually improves world welfare at the low ($6.6/mt) level of segregation costs. This is a classic second-best result. The existence of market power for the innovator-monopolist means that the adoption rate of the innovation, *ex post*, is lower than socially optimal. Because the U.S. price support increases adoption of RR seeds, it counters that effect, but this useful impact disappears as the segregation cost rises (because conventional production is driven out of the market anyway).

Effects of Policies for GM Products

In table 6 we report the impact of various policies that countries can consider (and are considering) to deal with the introduction of GM products. Here we restrict ourselves to the case of only the medium-level segregation costs ($13.2/mt), and to the case where there is no price support program in the United States. The first set of results in table 6 looks at what is currently the case for the EU and several Asian countries that are part of the ROW region—a ban on local production of RR soybeans and products. As the last column in table 6 shows, the ban benefits the ROW (as well as Argentina and Brazil), but it hurts the United States as well as world welfare. This case is characterized by complete regional specialization in production. The ROW meets its domestic demand for conventional soybean products, while the United States, Brazil, and Argentina produce and export only the RR variety. *De facto* segregation costs are zero in equilibrium because no actual segregation needs to take place. In comparison to the unregulated production scenario, the ban improves the ROW welfare by $35 million because of the positive change in consumer surplus that arises from lower conventional product prices (driven down by the effectively zero segregation costs) under the ban, which more than offsets the corresponding negative change in producer surplus.[22] The ban reduces U.S. welfare by $81 million, primarily because of forgone innovator-monopolist profit.

As noted earlier, Brazil has for many years declined to approve the growing of RR soybeans but, in response to the massive clandestine growing of GM soybeans, in September 2003 it enacted a temporary and limited exemption for the 2003-04 crop year. Brazil's attempt at implementing a local production ban for GM products has been rationalized by Brazil's alleged interest in avoiding segregation costs in order to gain a competitive advantage selling conventional soybeans and soybean products to Europe and the ROW. The second set of results in table 6 shows that the ban on RR production in Brazil actually does not benefit the region overall, although it benefits that country's farmers. Again, the ban results in the complete regional specialization in production, with the United States, Argentina, and the ROW producing and trading only the RR variety. Because Brazil specializes in producing conventional beans, it does not incur segregation costs and therefore prices received by Brazilian farmers increase relative to the pre-innovation benchmark. These higher prices benefit the region's farmers but hurt its consumers, who consume the domestically grown and crushed conventional products despite having no differentiated tastes. Comparing welfare changes between the ban and no-ban scenarios, we see that whereas Brazilian farmers gain from the ban by switching to higher-priced conventional soybeans, the same switch in consumption due to the non-competitive pricing from potential RR imports hurts the region more and results in a net $109 million loss of welfare.

If the ROW and Brazil ban RR production simultaneously, our third set of results in table 6 suggests that welfare will fall for the two regions and for the world in general. Brazil exports the conventional variety to the ROW, and the United States and Argentina produce only RR products for domestic consumption and export. With two regions growing conventional soybeans, the size of the conventional soybean sector proves to be quite large in equilibrium. As a result, equilibrium is characterized by equal conventional and RR soybean and oil prices in the ROW, with 17% of the indifferent demand actually satisfied by conventional soybeans and soybean oil. In general, all prices in this equilibrium are lower than their pre-innovation benchmark counterparts, implying that consumers gain from the RR technology in all regions, and producers in Brazil and the ROW lose. A welfare comparison between the ban and no-ban scenarios shows that forced abundance of the conventional variety and a relative scarcity of the RR product imply that equilibrium conventional prices in the ban scenario are lower than their counterparts in the unregulated scenario, whereas RR prices are higher. As a result, producers in Brazil and the ROW and all but ROW consumers lose, and Argentina is the only region that benefits from this RR production ban in Brazil and the ROW.

Depending on the severity of GM aversion in the EU and other countries manifested in their official government regulations, the ROW may choose to ban any presence of crops and food products with biotech content on its territory. In other words, the ROW may ban both RR production and imports, which would have dramatic consequences for production patterns in exporting regions as some of them would have to scale back on their adoption of RR technology. First, considering the case when Brazil does not ban RR production, we see from table 6 that having no export destination for the RR soybeans and products, the United States, Argentina, and Brazil each produce both varieties—RR for domestic consumption and conventional for export to the ROW. The adoption rate for RR technology in the United States is 65%, in Brazil, 51%, and in Argentina, 30%. ROW consumers experience very large losses in excess of $1 billion because of the unavailability of the cheaper RR variety. This fact drives the overall welfare loss for the ROW as a result of the introduction of RR technology. Other regions gain despite the welfare losses by producers, and the world's welfare improves, albeit slightly. Adding an RR production ban in Brazil changes the characteristics of the equilibrium only to the extent that Brazil experiences a loss of consumer surplus because of consumption of more expensive conventional products and an increase in the producer surplus due to specialization (see the last set of results in table 6). However, unlike the ROW, Brazil's overall welfare improves as compared to the pre-innovation benchmark. Welfare comparisons between the unregulated and ban scenarios show that all regions lose overall as a result of the combined production and import ban in the ROW no matter whether Brazil introduces the RR production ban or not. The only benefiting parties are consumers in unregulated regions and ROW producers. But note that, given an RR production and import ban in ROW, the introduction of a production ban in Brazil actually improves world welfare, again an instance of a second-best result.

Sensitivity Analysis

All parameters of the model were subjected to extensive sensitivity analysis, some of which is reported here. The model's sensitivity to the segregation cost parameter φ was discussed in the previous section, where we considered three alternative values for this parameter. We analyzed the sensitivity to the share of "indifferent" demand $\hat{\sigma}$; the coefficient of total demand increase due to conventional and RR price equalization $\hat{k}$; the own-price elasticity of conventional demand $\hat{\varepsilon}^{00}$; the own-price elasticities of demand for non-segregated soybeans, soybean oil, and soybean meal $\hat{\varepsilon}^{UU}$; the elasticity of land supply with respect to soybean price ψ; and the coefficient of yield increase due to the RR technology β. Parameter values used in the analysis are provided in table 7.

Sensitivity results for the aforementioned parameters are illustrated in table 8. The first set of results shows the effects of halving and doubling the base values of elasticities of (total) demand for non-segregated soybeans, soybean oil, and soybean meal. Compared to the base-values scenario, the only noticeable change is in the distribution of welfare gains between consumers and producers: a lower elasticity increases consumer benefits and reduces producer gains, while a higher one has the opposite effect. The innovator-monopolist's profit remains essentially insensitive to variations in

$\hat{\varepsilon}^{UU}$. In fact, these results hold equally for free trade and ban scenarios, and the overall region-level results appear robust. The second set of results in table 8 summarizes the adoption and welfare results when the elasticity of land supply with respect to soybean prices ψ is halved or doubled. Doubling ψ works just the opposite of doubling $\hat{\varepsilon}^{UU}$, and the same can be said about halving ψ versus halving $\hat{\varepsilon}^{UU}$. The innovator-monopolist's profit is robust, deviating within 1% of the base value. Again, none of the qualitative results of the model changes.

The model's results appear to be more sensitive to the change in the RR technology induced yield increase parameter β. A positive yield gain is equivalent to an outward supply shift relative to the base-values scenario. Therefore, in the free-trade equilibrium with $\beta = 0.02$, all prices are lower, which leads to the reallocation of welfare gains between consumers and producers: while both producers and consumers benefit at the world level from the new technology in the base-values scenario, producers at the world level lose and consumers gain when $\beta = 0.02$. At the region level, Brazilian and U.S. farmers lose by adopting the RR technology, although overall region-level results are robust to the increase in the yield parameter.

Parameter $\hat{\sigma}$ measures the relative size of demand that is indifferent between conventional and RR varieties at specific prices. Naturally, lower $\hat{\sigma}$ increases the relative share of the worldwide conventional demand and reduces the share of demand for the RR variety, causing higher conventional and lower RR equilibrium prices relative to the base-values scenario. Higher $\hat{\sigma}$ works in the opposite direction. The same can be said about parameter $\hat{\varepsilon}^{00}$: given that the total soybean and soybean oil demands are inelastic, making conventional demands less own-price elastic translates into lower cross-price elasticity, which means less flexibility in the demand system to shift from consuming the conventional to the RR variety.[23] This relationship makes the model and our conclusions in ban scenarios somewhat sensitive to the values of $\hat{\sigma}$ and $\hat{\varepsilon}^{00}$ (suggesting that more work to shed empirical light on these parameters may be useful). Table 8 shows that when $\hat{\sigma} = 2/3$, the ROW does not benefit from its RR production ban relative to the no-ban scenario. In addition (not shown in the table), the ROW benefits from the simultaneous RR production bans at home and in Brazil when $\hat{\varepsilon}^{00} = -3.0$ or $\hat{\sigma} = 1/3$, and Brazilian farmers lose under the production ban at home relative to the no-ban scenario when either parameter takes on a high (absolute) value.

Lastly, the changes in the value of parameter $\hat{k}$ have some minor quantitative and no qualitative effects on the results of the model. A lower $\hat{k}$ acts as an inward demand shift that lowers all prices (except for meal) in all equilibria, while a higher $\hat{k}$ acts as an outward demand shift that leads to an increase in soybean and soybean oil prices.

Conclusion

The distinctive feature of our new partial-equilibrium, four-region world trade model for the soybean complex is that consumers in the importing region view genetically modified RR soybeans, and products derived from them, as weakly inferior substitutes for their conventional counterparts. Thus, this article shows that differentiated preferences can be introduced into a conventional spatial equilibrium model in a simple yet consistent fashion that permits standard welfare calculations. Our model provides a close representation of the world soybean market by also accounting for the fact that the RR seed is protected by IPRs and sold worldwide by a U.S. firm at a premium, and that producers have to employ a costly segregation technology to separate conventional and biotech products in the supply chain. The model is disaggregated just enough to capture individual behavior of the industry's main players, and allows us to analyze the impact of their (possibly different) policies toward GM products.

Our analysis shows that in the world with no feasible segregation technology, the long-run equilibrium state of the world after the cost-saving RR technology is introduced is that of complete worldwide adoption. This equilibrium is characterized by lower prices for soybeans and soybean products, a continued U.S. lead in world soybean exports, and welfare gains to all regions and all economic agents (producers, consumers, and the innovator-monopolist selling RR seed), except U.S. farmers. When segregation technology is available at a positive cost, absent any government production and trade regulations, the United States emerges as the only region producing both RR and conventional soybeans; all other regions specialize in RR production. The introduction of the RR technology leads to reduced prices for RR products, lower prices for producers of the conventional variety, and higher consumption prices of conventional products. Lower segregation costs reduce the prices of conventional products, increase the prices received by farmers who grow the conventional variety, and are associated with more land allocated to growing conventional soybeans, which hurts the profits received by the innovator-monopolist. This result implies a conflict of interest between the RR input supplier and farmers who benefit from lower segregation costs. The world in general benefits from using the segregation technology at any feasible cost level, as GM-conscious consumers realize their right to choose.

The analysis shows that an output subsidy received by U.S. farmers, although clearly beneficial for them and the region's consumers, is nevertheless welfare reducing to the United States as a whole because of the high cost of the subsidy. The only region that gains in this situation is the ROW, but the world in general can potentially benefit from this policy as the subsidy works to correct a less-than-optimal adoption of the RR technology caused by the distorted RR seed prices established by the monopoly.

When the ROW and Brazil impose production bans on RR products, the ROW has a clear potential to benefit from such a ban relative to the no-ban scenario if segregation costs are not too low, while in Brazil only farmers would benefit from such regulation. These results are, however, somewhat sensitive to the underlying assumptions. In particular, this gain is more likely to hold the higher the size of the conventional market and/or the lower the elasticity of conventional demands (which indirectly affects the market share of interest). Also, it is possible that the ROW can gain relative to the no-ban scenario when RR production bans are implemented in the two regions simultaneously, although this result is not observed at base parameter values. But our analysis also shows that, whenever beneficial to the ROW, production bans reduce U.S. welfare, which justifies the region's concerned position with regard to anti-GM regulation. Also, Brazil as a whole never benefits from a unilateral production ban. The last important result of this paper is the robust welfare losses to all regions when an import ban on RR products is introduced in the ROW. Overall, all conclusions of the model, except for those mentioned above, prove to be robust to some variation in critical parameter values.

An emerging literature is attempting to characterize the economic impact of GM products in agriculture. We believe that this article provides an important addition by validating some of the theoretical results hitherto derived in very stylized models, by showing how the critical inferior-substitute property of GM products can be empirically implemented in a simple yet coherent fashion, by explicitly modeling the intellectual property rights dimensions of the problem, by investigating the interaction of new technology adoption with existing price supports programs, and by evaluating some critical GM-related policies being considered by some importing and exporting countries. In particular, this article is the first to provide quantitative estimates of the welfare effects of the large scale adoption of an existing GM crop in a differentiated-product, open-economy context. As such, the results of this article provide a range of important insights into the channels through which the benefits (and unintended costs) of the current generation of GM products arise, and explain the possible implications of existing and pending policies pursued by the countries across the world in response to the challenges posed by the dawn of biotechnology in agriculture.

Footnotes

[1] A survey of a representative sample of 16,000 citizens of the European Union confirms the existence of a potentially sizeable customer base with differentiated preferences (Eurobarometer).

[2] The complaint alleges not only that the EU policy is closing that market for potential U.S. exports but also that it affects the policies of other countries towards GM crop adoption because of the countries' concerns over future market access.

[3] Soybeans have been the most successful GM crop to date. In 2002 GM soybeans accounted for 62% of the world area cultivated to GM crops, and GM soybeans accounted for more than half of world soybean production (James).

[4] Because meal is used as feed, and animals so fed need not carry any GM label, there appears to be no reason why demand for meal should be differentiated.

[5] Whereas Argentina was an early adopter and has the world's highest adoption rates of RR soybeans, the use of GM soybeans in Brazil has not yet been permanently authorized. But following widespread growing of GM soybeans smuggled in from Argentina, Brazil has enacted a temporary and limited authorization for GM soybeans. With the decree enacted in September 2003, farmers who have GM soybean seeds are allowed to plant them for the 2003-04 crop year, and market the harvest through the 2004 year. But seed companies are yet not allowed to legally sell RR soybean seeds in Brazil.

[6] To represent South America in our two regions, in our model the Brazil region includes both Brazil and Paraguay,

whereas the Argentina region includes the residual South American production.

[7] The consumer is actually indifferent between the two varieties if an equality holds, but in such a case we may as well assume that the new variety is purchased.

[8] For example, Fulton and Giannakas assume that consumers are restricted to buy either one unit or zero unit of the goods in question, that the utility function is linear, and that consumer types are uniformly distributed.

[9] This condition, which implies that own price effects dominates cross price effects, is a bit more restrictive than requiring the Slutsky matrix to be negative semidefinite. See Lapan and Moschini (2004) for more details.

[10] This is consistent with the current European Union proposal to set tolerance limits for non-GM products at the very low 0.9% level.

[11] Perhaps a more natural assumption would be that farmers are heterogeneous with respect to the profitability of the new technology, as in Lapan and Moschini (2004), which can explain incomplete adoption. But the approach taken here also allows for incomplete adoption, which here arises because the two types of goods are imperfect substitutes in demand, and it is easier to calibrate for the purpose of empirical analysis.

[12] The region subscript is omitted here and elsewhere in this section for notational simplicity.

[13] See the section on calibration and table 2 for more details.

[14] This software package is equipped with the eqSolve procedure that solves $N \times N$ systems of nonlinear equations by inverting the systems' Jacobian while iterating until convergence.

[15] For example, when differentiated markets exist only in the ROW, the size of the binding portion of the system (12)–(24) can be anywhere from N=5 to N=21.

[16] Data presented by Schnepf, Dohlman, and Bolling support the $30/mt soybean transportation cost estimate between the United States and the ROW and at least a $10/mt U.S. transportation cost advantage over Argentina and Brazil due to distance and higher insurance costs.

[17] Here and elsewhere in the text, the elements of the four-dimensional vectors refer to the United States, Brazil, Argentina, and the ROW, respectively.

[18] By setting a constant markup we are modeling a somewhat passive seed supplier. This is done to keep the analysis to a tractable scope. As pointed out by a reviewer, a more complete model would endogenize this parameter and account for the possibility that the GM seed supplier may attempt to segment markets

by third-degree price discrimination. See Lapan and Moschini (2004) for some theoretical results with an optimizing innovator-monopolist.

[19] For related issues on international IPR enforcement in agricultural biotechnology, see Gaisford *et al.*, and Giannakas.

[20] Brazil has vast areas of undeveloped arable land in its Center-West (the "cerrado") region that can serve, and have served, as engines of soybean production growth (Schnepf, Dohlman, and Bolling). In Argentina, as in the United States, growth in soybean areas can be achieved only by substitution for other crops.

[21] Estimates presented in Bullock and Desquilbet are within this range.

[22] But this ROW welfare gain disappears at lower levels of segregation costs.

[23] Because the impacts of changes in $\hat{\sigma}$ or $\hat{\varepsilon}^{00}$ are very similar, in table 8 we omit the explicit sensitivity results for $\hat{\varepsilon}^{00}$.

References

Alston, J.M., and W.J. Martin, "Reversal of Fortune: Immiserizing Technical Change in Agriculture." *American Journal of Agricultural Economics* 77(1995): 251-59.

Bender, K., L. Hill, B. Wenzel, and R. Hornbaker, "Alternative Market Channels for Specialty Corn and Soybeans." AE-4726, Dept. of Agricultural Economics, University of Illinois, February 1999.

Bhagwati, J., "Distortions and Immiserizing Growth: A Generalization." *Review of Economic Studies* 35(1968):481-85.

Bullock, D., and M. Desquilbet, "The Economics of Non-GMO Segregation and Identity Preservation." *Food Policy* 27(1)(2002): 81-99.

Desquilbet, M., and D. Bullock, "Who Pays the Costs of Non-GMO Segregation and Identity Preservation?" Paper presented at the 2001 *IATRC meeting*, Tucson, AZ, December 2001.

Eurobarometer. "Europeans, Science and Technology." Eurobarometer Standard *Report* 55.2. December 2001. http://europe.eu.int/comm/research/press/2001/pr0612en-report.pdf (accessed November 2002).

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson, "Surplus Distribution from the Introduction of a Biotechnology Innovation." *American Journal of Agricultural Economics* 82(2000): 360-69.

Fulton, M. and K. Giannakas, "Inserting GM Products into the Food Chain: The Market and Welfare Effects of Different Labeling and Regulatory Regimes." *American Journal of Agricultural Economics* 86(2004): 360-69.

Furtan, W.H., R.S. Gray, and J.J. Holzman, "The Optimal Time to License a Biotech 'Lemon'." *Contemporary Economic Policy* 21(2003):433-444.

Gaisford, J.D., R., Tarvydas, J.E. Hobbs, and W.A. Kerr, "Biotechnology Piracy: Rethinking the International Protection of Intellectual Property." *Canadian Journal of Agricultural Economics* 50(2002): 15–34.

Giannakas, K., "Infringement of Intellectual Property Rights: Causes and Consequences." *American Journal of Agricultural Economics* 84(2002):482–494.

Goldsmith, P., G. Ramos and C. Steiger, "A Tale of two Businesses: Property Rights and the Marketing of Agricultural Biotechnology." *Choices*, 2003 (third quarter): 25-30.

James, C., *Global Review of Commercialized Transgenic Crops: 2002 (Preview)*. ISAAA Brief No. 27, Ithaca, NY, 2002.

Lapan, H., and G. Moschini, "GMO Labeling and Trade: Consumer Protection or (Just) Protectionism?" Paper presented at the 2001 *IATRC meeting*, Tucson, AZ, December 2001.

———. "Innovation and Trade with Endogenous Market Failure: The Case of Genetically Modified Products." *American Journal of Agricultural Economics* 86(2004):634-648.

Lence, S., and D. Hayes, "Response to an Asymmetric Demand for Attributes: An Application to the Market for Genetically Modified Crops." *Working Paper* 01-MWP 5, Center for Agricultural and Rural Development, Iowa State University, November 2001.

Lin, W., W. Chambers, and J. Harwood, "Biotechnology: U.S. Grain Handlers Look Ahead." *Agricultural Outlook*, U.S. Department of Agriculture, Washington, D.C. April 2000.

Meilke, K.D. and Michael Swidinsky, "An Evaluation of Oilseed Trade Liberalization." Agriculture and Agri-Food Canada, *Report*, Trade Research Series, Ottawa, July 1998.

Moschini, G., "Biotech—Who Wins? Economic Benefits and Costs of Biotechnology Innovations in Agriculture." *Estey Centre Journal of International Law and Trade Policy* 2(2001): 93-117.

Moschini, G., and H. Lapan, "Intellectual Property Rights and the Welfare Effects of Agricultural R&D." *American Journal of Agricultural Economics* 79(1997):1229-42.

Moschini, G., H. Lapan, and A. Sobolevsky, "Roundup Ready Soybeans and Welfare Effects in the Soybean Complex." *Agribusiness* 16(2000): 33-55.

Mussa, M. and S. Rosen, "Monopoly and Product Quality." *Journal of Economics Theory* 18(1978):301-317.

Nelson, G. C. , ed. *Genetically Modified Organisms in Agriculture: Economics and Politics*. London, Academic Press, 2001.

Nielsen, C., and K. Anderson, “GMOs, Trade Policy, and Welfare in Rich and Poor Countries.” In K. Maskus and J. Wilson, eds., *Quantifying the Impact of Technical Barriers to Trade: Can It Be Done?* Ann Arbor: University of Michigan Press, 2001.

Nielsen, C., K. Thierfelder, and S. Robinson, “Consumer Attitudes Towards Genetically Modified Foods: The Modelling of Preference Changes.” SJFI *Working Paper*, January 2001.

Pardey, P.G., ed., *The Future of Food – Biotechnology Markets and Policies in an International Setting*. IFPRI, Washington, D.C., 2001.

Samuelson, P.A., “Spatial Price Equilibrium and Linear Programming.” *American Economic Review* 42(1952): 283-303.

Schnepf, R., E. Dohlman, and C. Bolling, “Agriculture in Brazil and Argentina: Developments and Prospects for Major Field Crops.” Agriculture and Trade *Report* WRS-01-3. U.S. Department of Agriculture, Washington, D.C. November 2001.

Sheldon, I., “Regulation of Biotechnology: Will We Ever ‘Freely’ Trade GMOs?” *European Review of Agricultural Economics* 29(2002):155-176.

Sobolevsky, A., G. Moschini and H. Lapan, “Genetically Modified Crop Innovations and Product Differentiation: Trade and Welfare Effects in the Soybean Complex.” *Working Paper* 02-WP 319, Center for Agricultural and Rural Development, Iowa State University, November 2002.

Takayama, T., and G.G. Judge, *Spatial and Temporal Price and Allocation Models*. Amsterdam: North-Holland, 1971.

Takayama, T., and W.C. Labys, “Spatial Equilibrium Analysis.” In *Handbook of Regional and Urban Economics*, vol. 1. I. E.S. Mills and P. Nijkamp, eds. Amsterdam: Elsevier Science Publishers, 1986.

Tirole, J., *The Theory of Industrial Organization*. The MIT Press, Cambridge, MA, 1988.

U.S. Department of Agriculture (USDA), “Nonrecourse Marketing Assistance Loans and Loan Deficiency Payments.” Farm Service Agency, Washington, D.C. March 1998.

———. "Production, Supply and Distribution (PS&D) Database: By Country, Commodity Supply, and Use Time Series." Economic Research Service, Washington, D.C. July 2002.

U.S. Government Accounting Office. "Information on Prices of Genetically Modified Seeds in the United States and Argentina." *Report* GAO/RCED/NSIAD-00-55. Washington, D.C. January 2000.

Table 1. **Soybean Complex Production and Utilization, 1998-1999** (mil. mt)

	Soybeans					Oil		Meal	
	Area (mil. Ha)	**Product**	**Net Exports**	**Direct Use**	**Crush**	**Product**	**Net Exports**	**Product**	**Net Exports**
World	71.16	161.67	n.a.	23.58	135.70	24.56	n.a.	108.36	n.a.
United States	28.51	74.60	21.82	5.47	43.26	8.20	1.04	34.29	6.37
South America	22.93	55.34	12.89	2.43	40.29	7.55	3.78	32.19	22.01
Argentina	8.17	20.00	2.70	0.66	16.80	3.16	3.08	13.69	13.22
Brazil	12.90	31.30	8.27	1.52	21.60	4.04	1.22	17.01	9.98
Paraguay	1.20	3.00	2.30	0.05	0.65	0.12	0.09	0.51	0.41
Rest of the World	19.72	31.73	-34.71	15.68	52.15	8.81	-4.82	41.88	-28.38
European Union	0.52	1.53	-16.07	1.53	16.23	2.92	1.06	12.92	-14.91
China	8.50	15.16	-3.66	7.32	12.61	2.05	-0.87	10.03	-1.39
Japan	0.11	0.15	-4.81	1.28	3.70	. . . .	. . . .	. . . .	. . . .
Mexico	0.09	0.14	-3.76	0.03	3.95	. . . .	. . . .	. . . .	. . . .
Mid East/N Africa	. . . .	. . . .	. . . .	. . . .	. . . .	0.26	-1.64	1.23	-3.70

Source: U.S. Department of Agriculture (2002).

TABLE 2. Model's Parameters and Their Baseline Values

Parameter	Description	Values			
		U.S.A.	Brazil	Argentina	ROW
$\hat{\varepsilon}_B^{UU}$	Own-price non-segregated bean demand elasticity	-0.4	-0.4	-0.4	-0.4
$\hat{\varepsilon}_O^{UU}$	Own-price non-segregated oil demand elasticity	-0.4	-0.4	-0.4	-0.4
$\hat{\varepsilon}_M^{UU}$	Own-price non-segregated meal demand elasticity	-0.4	-0.4	-0.4	-0.4
$\hat{\varepsilon}_B^{00}$	Own-price conventional bean demand elasticity				-4.5
$\hat{\varepsilon}_O^{00}$	Own-price conventional oil demand elasticity[a]				-4.5
$\hat{k}_B$	Total bean demand increase due to price decrease[a]				1.05
$\hat{k}_O$	Total oil demand increase due to price decrease[a]				1.05
$\hat{\sigma}_B$	Share of "indifferent" bean demand in total[a]				0.5
$\hat{\sigma}_O$	Share of "indifferent" oil demand in total[a]				0.5
ψ	Elasticity of land supply w.r.t. soybean price	0.8	1.0	0.8	0.6
η	Elasticity of yield w.r.t. soybean price	0.05	0.05	0.05	0.05
$\delta\omega$	Unit seed cost ($)	45.0	40.0	40.0	40.0
$\Delta\pi$	Producer unit profit change due to RR technology (*ceteris paribus*)	15.0	15.0	15.0	10.0
r	Producer rent share in average profit	0.4	0.4	0.4	0.4
μ	Markup on RR seed price	0.4	0.2	0.2	0.2
β	Coefficient of yield increase due to RR technology	0.0	0.0	0.0	0.0
p_{LDP}	Soybean farmer LDP/loan price ($/mt)	193.0			
φ	Segregation cost ($/mt)	0.0	0.0	0.0	0.0
		6.6	6.6	6.6	6.6
		13.2	13.2	13.2	13.2
		19.8	19.8	19.8	19.8
$t_{m,ij}^k$	Transportation costs ($/mt) [b]				
	U.S.A.	--	(30, 60, 30)	(30, 60, 30)	(30, 60, 30)
	Brazil	(30, 60, 30)	--	(27, 47, 27)	(40, 70, 40)
	Argentina	(30, 60, 30)	(27, 47, 27)	--	(40, 70, 40)
	ROW	(30, 60, 30)	(40, 70, 40)	(40, 70, 40)	--

[a] See text for details.

[b] Each triplet represents the transportation cost between the two source/destination regions for beans, oil and meal, respectively ($/mt).

TABLE 3. Equilibrium Solution with No U.S. Price Support, Various Scenarios

Region	ρ	Bean Price		Oil Price		Meal Price	Soybean Supply		Export BE[a]		Export Meal[b]
		Conv.	RR	Conv.	RR		Conv.	RR	Conv.	RR	
Pre-innovation											
USA	0.00	181.9		480.2		143.6	70.1		26.9		2.3
BR	0.00	171.9		470.2		133.6	35.6		18.8		5.1
AR	0.00	171.9		470.2		133.6	21.1		15.3		0.9
ROW	0.00	211.9		540.2		173.6	32.3		-60.9		-8.3
No segregation											
USA	1.00		174.5		444.8	142.3		69.3		24.8	3.2
BR	1.00		164.5		434.8	132.3		35.9		18.6	5.5
AR	1.00		164.5		434.8	132.3		21.2		15.2	1.0
ROW	1.00		204.5		504.8	172.3		32.6		-58.6	-9.7
High segregation cost											
σ = \$19.8/mt											
USA	0.95	200.4	174.8	586.7	445.5	142.5	3.7	65.8	3.7	21.3	3.2
BR	1.00		164.8		435.5	132.5	0.0	35.9	0.0	18.6	5.5
AR	1.00		164.8		435.5	132.5	0.0	21.3	0.0	15.3	1.0
ROW	1.00	230.4	204.8	616.4	505.5	172.5	0.0	32.6	-3.7	-55.2	-9.7
Medium segregation cost											
σ = \$13.2/mt											
USA	0.90	194.0	175.0	551.7	447.0	142.4	7.0	62.5	7.0	18.1	3.1
BR	1.00		165.0		437.0	132.4	0.0	36.0	0.0	18.7	5.5
AR	1.00		165.0		437.0	132.4	0.0	21.3	0.0	15.3	1.0
ROW	1.00	224.0	205.0	611.7	507.0	172.4	0.0	32.6	-7.0	-52.0	-9.7
Low segregation cost											
σ = \$6.6/mt											
USA	0.70	187.9	175.5	522.8	454.5	141.4	20.9	48.8	20.9	4.6	2.9
BR	1.00		165.5		444.5	131.4	0.0	36.1	0.0	18.9	5.4
AR	1.00		165.5		444.5	131.4	0.0	21.3	0.0	15.4	1.0
ROW	1.00	217.9	205.5	582.8	514.5	171.4	0.0	32.7	-20.9	-38.9	-9.2
Zero segregation cost											
$\sigma = 0$											
USA	0.62	183.6	177.9	502.9	471.1	140.5	27.0	43.6	27.0	0.0	2.3
BR	0.99	173.6	164.2	492.9	440.7	130.5	0.3	35.5	0.3	18.3	5.4
AR	1.00		164.2		440.7	130.5	0.0	21.2	0.0	15.2	1.0
ROW	1.00	213.6	204.2	562.9	510.7	170.5	0.0	32.5	-27.3	-33.5	-8.7

Notes

Prices are in U.S. \$/mt, quantities are in mil mt.

[a] BE=Bean Equivalent (see eq. (26)).

[b] Meal exports, additional to those imbedded in previous two columns (see eq. (27)).

TABLE 4. Equilibrium Solution with U.S. LDP Price Support Program, Various Scenarios

Region	ρ	Bean Price		Oil Price		Meal Price	Soybean Supply		Export BE[a]		Export Meal[b]
		Conv.	RR	Conv.	RR		Conv.	RR	Conv.	RR	
Pre-innovation											
USA	0.00	176.6		468.7		139.5	74.0		30.3		2.3
BR	0.00	166.6		458.7		129.5	34.4		17.5		5.2
AR	0.00	166.6		458.7		129.5	20.5		14.6		0.9
ROW	0.00	206.6		528.7		169.5	31.8		-62.3		-8.4
No segregation											
USA	1.00		165.6		425.4	135.5		75.7		30.3	3.2
BR	1.00		155.6		415.4	125.5		34.0		16.4	5.6
AR	1.00		155.6		415.4	125.5		20.3		14.2	1.0
ROW	1.00		195.6		485.4	165.5		31.7		-60.9	-9.9
High segregation cost											
σ = $19.8/mt											
USA	1.00		166.0		426.3	135.8	0.0	75.7	0.0	30.4	3.2
BR	0.91	185.3	156.0	578.0	416.3	125.8	3.1	31.0	3.1	13.3	5.6
AR	1.00		156.0		416.3	125.8	0.0	20.3	0.0	14.2	1.0
ROW	1.00	225.3	196.0	599.0	486.3	165.8	0.0	31.8	-3.1	-57.9	-9.9
Medium segregation cost											
σ = $13.2/mt											
USA	1.00		166.2		426.6	135.9	0.0	75.7	0.0	30.4	3.2
BR	0.87	178.8	156.2	541.9	416.6	125.9	4.3	29.8	4.3	12.2	5.6
AR	1.00		156.2		416.6	125.9	0.0	20.3	0.0	14.2	1.0
ROW	1.00	218.8	196.2	599.3	486.6	165.9	0.0	31.8	-4.3	-56.8	-9.9
Low segregation cost											
σ = $6.6/mt											
USA	1.00		166.7		432.0	135.4	0.0	75.7	0.0	30.6	3.0
BR	0.60	172.8	156.7	510.8	422.0	125.4	13.9	20.4	13.9	2.9	5.5
AR	1.00		156.7		422.0	125.4	0.0	20.4	0.0	14.3	1.0
ROW	1.00	212.8	196.7	580.8	492.0	165.4	0.0	31.8	-13.9	-47.8	-9.6
Zero segregation cost											
$\sigma = 0$											
USA	1.00		167.4		439.5	134.5	0.0	75.7	0.0	30.9	2.8
BR	0.51	167.0	157.6	482.9	430.6	124.5	17.1	17.4	17.1	0.0	5.4
AR	0.50	167.0	157.4	482.9	429.5	124.5	10.3	10.2	10.3	4.2	1.0
ROW	1.00	207.0	197.4	552.9	499.5	164.5	0.0	31.9	-27.4	-35.0	-9.1

Notes

Prices are in U.S. $/mt, quantities are in mil mt.

[a] BE=Bean Equivalent (see eq. (26)).

[b] Meal exports, additional to those imbedded in previous two columns (see eq. (27)).

TABLE 5. Estimated Welfare Effects of RR Soybean Innovation, Various Scenarios (U.S. $ mil)

	----- No U.S. Price Support -----				------- With U.S. LDP Price Support Program -------					
Region	**Δ CS**	**Δ PS**	**$\Delta\Pi^M$**	**Δ W Total**	**Δ CS**	**Δ PS**	**$\Delta\Pi^M$**	**Δ *Gov***	**Δ W Total**	**Δ W from no LDP**
No segregation										
US	323	-117	831	1,037	478	429	859	-860	907	-123
BR	120	72		192	169	-51			117	-75
AR	43	47		89	62	-27			35	-54
ROW	125	121		247	472	7			479	233
World	611	123	831	1,564	1,181	358	859	-860	1,538	-26
High segregation cost $\sigma = \$19.8/\text{mt}$										
US	310	-95	807	1,021	461	429	850	-830	910	-111
BR	116	83		199	163	-38			125	-74
AR	41	53		94	60	-19			41	-53
ROW	131	132		263	460	20			480	217
World	597	173	807	1,577	1,144	392	850	-830	1,556	-21
Medium segregation cost $\sigma = \$13.2/\text{mt}$										
US	301	-83	784	1,003	455	429	846	-819	911	-92
BR	112	90		202	161	-33			129	-73
AR	40	57		97	59	-16			43	-54
ROW	145	138		283	470	25			494	211
World	598	201	784	1,584	1,144	405	846	-819	1,577	-7
Low segregation cost $\sigma = \$6.6/\text{mt}$										
US	275	-46	690	919	428	429	816	-777	896	-24
BR	97	109		206	149	-14			134	-71
AR	36	69		104	55	-4			51	-53
ROW	198	155		353	474	42			516	163
World	606	286	690	1,582	1,106	452	816	-777	1,597	15
Zero segregation cost $\sigma = 0$										
US	169	120	651	940	396	429	772	-727	870	-70
BR	116	61		177	129	15			144	-32
AR	43	40		83	50	9			59	-24
ROW	399	111		511	552	63			615	104
World	727	332	651	1,710	1,127	517	772	-727	1,688	-22

TABLE 6. Economic Impacts of Government Policies (No-LDP Case with $13.2/mt Segregation Cost): Changes from Pre-Innovation Equilibrium and from No-Ban Scenario

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Bean Supply		Export BE[a]		Export Meal[b]	Δ W from no ban
						Conv.	RR	Conv.	RR		
RR Production Ban in ROW											
US	1.00	239	9	675	922	0.0	70.0	0.0	26.0	2.6	-81
BR	1.00	81	137		218	0.0	36.2	0.0	19.2	5.3	16
AR	1.00	30	85		116	0.0	21.4	0.0	15.5	1.0	19
ROW	0.00	277	41		318	32.4	0.0	0.0	-60.7	-8.9	35
World		626	272	675	1,573						-11
RR Production Ban in Brazil											
US	1.00	326	-124	712	914	0.0	69.3	0.0	24.8	3.1	-89
BR	0.00	-94	188		93	36.6	0.0	20.4	0.0	4.7	-109[c]
AR	1.00	43	45		87	0.0	21.2	0.0	15.2	1.0	-10
ROW	1.00	291	118		409	0.0	32.6	-20.4	-40.0	-8.8	127
World		565	226	712	1,504						-81
RR Production Ban in ROW and Brazil											
US	1.00	113	215	564	891	0.0	71.1	0.0	27.6	2.3	-112
BR	0.00	35	-96		-61	35.0	0.0	18.1	0.0	5.2	-262
AR	1.00	14	148		162	0.0	21.7	0.0	15.9	0.9	65
ROW	0.00	271	-87		183	32.0	0.0	-18.1	-43.5	-8.4	-99
World		432	180	564	1,176						-409
RR Production and Import Bans in ROW											
US	0.65	353	-149	391	594	24.1	45.1	24.1	0.0	3.8	-408
BR	0.51	208	-76		132	17.2	17.8	17.2	0.0	6.0	-70
AR	0.30	72	-45		27	14.6	6.2	14.6	0.0	1.2	-70
ROW	0.00	-1021	363		-658	33.3	0.0	-56.0	0.0	-11.0	-941
World		-389	93	391	95						-1,489
RR Production Bans in ROW and Brazil and Import Ban in ROW											
US	0.67	498	-371	337	464	22.3	45.7	22.3	0.0	4.2	-539
BR	0.00	-124	284		160	37.1	0.0	21.0	0.0	4.7	-42
AR	0.31	92	-112		-20	14.2	6.2	14.2	0.0	1.3	-117
ROW	0.00	-727	256		-471	33.0	0.0	-57.4	0.0	-10.2	-754
World		-261	57	337	133						-1,451

Notes:

Monetary variables are measured in mil U.S.$; quantities are in mil mt.

[a] See footnote a, Table 3.

[b] See footnote b, Table 3.

[c] Comprised of CS change of –206 and PS change of 98.

TABLE 7. Base and Alternative Values of Parameters Used in Sensitivity Analysis

Parameter	Base Value	Alternative Value 1	Alternative Value 2
$\hat{\varepsilon}^{UU}$	{-0.4,-0.4,-0.4,-0.4}	Base value × ½	Base value × 2
ψ	{0.8, 1.0, 0.8, 0.6}	Base value × ½	Base value × 2
β	{0, 0, 0, 0}	Base value + 0.02	–
$\hat{\sigma}$	0.5	Base value × ⅔	Base values × 1⅓
$\hat{k}$	1.05	Base value - 0.025	Base value + 0.025
$\hat{\varepsilon}^{00}$	-4.5	Base value × ⅔	Base values × 1⅓

TABLE 8. Model's Sensitivity to Key Parameters: Welfare Changes from the Pre-Innovation Equilibrium in No-LDP, No-Ban Scenarios (Unless Noted Otherwise), with $13.2/mt Segregation Cost

Region	Alternative Value 1					Base Value					Alternative Value 2				
	ρ	**Δ CS Total**	**Δ PS Total**	$\Delta\Pi^M$	**Δ W Total**	ρ	**Δ CS Total**	**Δ PS Total**	$\Delta\Pi^M$	**Δ W Total**	ρ	**Δ CS Total**	**Δ PS Total**	$\Delta\Pi^M$	**Δ W Total**
Parameter $\hat{\varepsilon}^{UU}$															
USA	0.90	359	-160	786	985	0.90	301	-83	784	1,003	0.90	280	-52	785	1013
BR	1.00	148	50		198	1.00	112	90		202	1.00	106	106		211
AR	1.00	49	34		83	1.00	40	57		97	1.00	37	67		104
ROW	1.00	231	102		333	1.00	145	138		283	1.00	91	152		243
World		787	26	786	1,599		598	201	784	1,584		514	273	785	1,571
Parameter ψ															
USA	0.90	281	-49	792	1024	0.90	301	-83	784	1,003	0.89	320	-109	772	983
BR	1.00	106	105		211	1.00	112	90		202	1.00	118	77		195
AR	1.00	37	67		105	1.00	40	57		97	1.00	42	48		90
ROW	1.00	94	152		246	1.00	145	138		283	1.00	191	126		317
World		519	275	792	1,586		598	201	784	1,584		670	143	772	1,585
Parameter β															
USA	0.88	411	-288	770	893	0.90	301	-83	784	1,003					
BR	1.00	146	-6		140	1.00	112	90		202					
AR	1.00	53	3		56	1.00	40	57		97					
ROW	1.00	409	51		459	1.00	145	138		283					
World		1019	-240	770	1,548		598	201	784	1,584					
Parameter $\hat{k}$															
USA	0.90	298	-76	784	1,006	0.90	301	-83	784	1,003	0.90	335	-133	785	987
BR	1.00	112	93		205	1.00	112	90		202	1.00	131	64		195
AR	1.00	39	59		99	1.00	40	57		97	1.00	45	42		87
ROW	1.00	132	140		272	1.00	145	138		283	1.00	207	114		321
World		581	216	784	1,581		598	201	784	1,584		717	87	785	1,590
Parameter $\hat{\sigma}$															
USA	0.87	335	-132	768	971	0.90	301	-83	784	1,003	0.93	300	-81	801	1020
BR	1.00	132	65		197	1.00	112	90		202	1.00	111	91		202
AR	1.00	45	43		88	1.00	40	57		97	1.00	40	58		97
ROW	1.00	21	115		136	1.00	145	138		283	1.00	317	138		456
World		533	90	768	1,391		598	201	784	1,584		768	206	801	1,775
Parameter $\hat{\sigma}$: RR production ban in the ROW															
USA	1.00	301	-85	673	889	1.00	239	9	675	922	1.00	184	94	679	957
BR	1.00	114	89		203	1.00	81	137		218	1.00	57	181		238
AR	1.00	40	57		97	1.00	30	85		116	1.00	23	111		134
ROW	0.00	145	121		267	0.00	277	41		318	0.00	442	-142		300
World		600	182	673	1,455		626	272	675	1,573		706	244	679	1,629

Notes:
Monetary variables are measured in mil U.S.$; quantities are in mil mt.

FIGURE 1. Parametric Domains for the Differentiated Demand System