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

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Abstract

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Keywords

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Disciplines

Agricultural and Resource Economics | Agricultural Economics | Biotechnology | Economics | Intellectual Property Law | Technology and Innovation

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Abstract

We develop a new partial equilibrium, four-region world trade model for the soybean complex comprising soybeans, soybean oil, and soybean meal. In the model, some consumers view genetically modified Roundup Ready (RR) soybeans and products as weakly inferior to conventional ones; the RR seed is patented and sold worldwide by a U.S. firm; and producers employ a costly segregation technology to separate conventional and biotech products in the supply chain. The calibrated model is solved for equilibrium prices, quantities, production patterns, trade flows, and welfare changes under different assumptions regarding regional government's production and trade policies, differentiated consumer tastes, and several other demand and supply parameters. Incomplete adoption of RR technology naturally arises in the free trade equilibrium, with the United States producing both genetically modified and conventional soybeans. The United States, Argentina, Brazil and the Rest of the World all gain from the introduction of RR soybeans, although some groups of agents (producers or consumers) may lose. Compared to free trade with no domestic bans, a ban on RR production in the Rest of the World improves that region's welfare at some levels of segregation costs but hurts the United States. Introduction of the same ban in Brazil benefits its farmers but makes the region worse off, and an import ban on RR products significantly reduces welfare of all agents. Price support programs for U.S. farmers, despite hurting the United States, have the potential to further improve the world's efficiency. The distribution of welfare between consumers and producers appears to be sensitive to several parameters of the model, but region-level outcomes are robust with respect to most of them and are sensitive only to parameters defining the share of consumers conscious of genetically modified organisms and the elasticity of demand for conventional product varieties.

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GENETICALLY MODIFIED CROP INNOVATIONS AND PRODUCT DIFFERENTIATION: TRADE AND WELFARE EFFECTS IN THE SOYBEAN COMPLEX

Introduction

Biotechnology innovations in agriculture represent a recent trend that is providing both dazzling opportunities as well as unexpected challenges. Genetically modified (GM) crops, first grown commercially in 1996, already account for a major share of U.S. cultivation of soybeans, maize, and cotton. Whereas a few countries have followed the United States's lead in this setting (notably Argentina, Canada, and China), most countries are proceeding very cautiously in response to considerable public opposition to this technology. The GM crops that have been most successful embody a single-gene transformation that makes the crop resistant to herbicide (e.g., Roundup Ready soybeans and Roundup Ready cotton) or resistant to a particular pest (e.g., Bt maize and Bt cotton). These improved crops reduce production costs, ceteris paribus, or increase (expected) yield. As such, they represent a typical process innovation, increasing the efficiency of production but not supplying any new attribute that consumers value per se (Moschini 2001). But 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] Indeed, a number of countries are implementing mandatory labeling regulations that aim at providing exactly that choice.

An implication of this opposition is that some consumers view the new GM crops as a peculiar kind of product innovation, one that is bringing to market a product that is considered inferior to its traditional counterpart. This induced (and ex ante unintended) product differentiation that has been brought about by GM crops has a number of economic implications that need to be addressed. In particular, it is becoming clear that in order to deliver the consumers' right to choose, 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 2002).

Some models recently have attempted to incorporate differentiated final product demands and the supply-side need to accommodate identity preservation. Whereas these models vary in their approaches and the issues they address (Lindner et al. 2001; Nielsen and Anderson 2000; Nielsen, Thierfelder, and Robinson 2001; Lence and Hayes 2001), 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. 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. Such market power in the input market should not be ignored in assessing the welfare effect of innovations (Moschini and Lapan 1997). Studies that overcome some of these limitations (Moschini, Lapan, and Sobolevsky 2000; Falck-Zepeda, Traxler, and Nelson 2000) still do not address the issue of induced product differentiation mentioned earlier.

Two recent papers have addressed the implication of product differentiation and identity preservation. Desquilbet and Bullock (2001) provide preliminary analysis of potential adoption of GM rapeseed with non-GM market segregation in the European Union. Their model, which splits the world into two regions, looks at individual consumers, crop handlers, and farmers who differentiate between GM and non-GM varieties to build up market supply and demand functions. This approach allows the researchers to circumvent the problem of insufficient data for aggregate demand and supply calibrations. The model is expected to be useful for answering welfare and policy questions. Lapan and Moschini (2001, 2002) build a two-country partial equilibrium model of an agricultural industry to analyze some implications of the introduction of GM products. In the model, one country, with consumers indifferent between GM and non-GM products, develops a new GM crop and adopts it. The second country, with consumers who view the GM crop as a product weakly inferior to the non-GM one, is the importing country (it does not produce the GM crop) and has the ability to impose regulations and/or protectionist policies to limit its exposure to genetically modified organisms (GMOs). Whereas these studies take the analysis in a desired direction, the treatment is mostly theoretical and the need for quantitative estimates concerning the impact of GM innovations is very much present.

In this study, we develop a four-region world trade model that can provide quantitative answers to many economic and policy questions connected with the production of GM crops in a market with differentiated demands and segregation costs. The model is specifically tailored to the world soybean industry. In this model, the four regions produce, consume, and trade a limited number of related products. Some of these products exist in two varieties: conventional and GM. Producer and consumer decisions are modeled explicitly in each region. In principle, demands in all regions can be differentiated, but for the purpose of the analysis, only one (the Rest of the World, hereafter ROW) will be modeled with differentiated demands. The model allows for costly identity preservation, an endogenous adoption rate of the new technology, and noncompetitively supplied GM seed by an innovator-monopolist residing in one of the regions (the United States). The model is calibrated to replicate observed data in a benchmark year, solved under both spatial and vertical equilibrium conditions, and simulated to analyze various policy scenarios of interest. The restrictions on the particular parameter values used at the calibration stage are also studied through an extensive sensitivity analysis.

The questions to be addressed 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 addressed is the effect of relevant government policies on both trade and welfare under different assumptions about market structure, differentiated consumer tastes, and other demand and supply conditions.

Background

Soybeans are one of the major oilseed crops, along with cottonseed, rapeseed (canola), and sunflower seed. Processed soybeans are the largest source of protein feed and vegetable oil in the world, and the United States is the world’s largest soybean producer and exporter (Table 1). Although the United States has maintained the leading

TABLE 1. Soybean production and utilization, 1998–99 (million mt)

	Area (mil ha)	Yield	Production	Net Exports	Δ in Stocks	Direct Use	Crush
World	71.16	2.25	161.67	NA	2.39	23.58	135.70
United States	28.51	2.62	74.60	21.82	4.05	5.47	43.26
South America	22.93	2.41	55.34	12.89	-0.27	2.43	40.29
Argentina	8.17	2.45	20.00	2.70	-0.16	0.66	16.80
Brazil	12.90	2.43	31.30	8.27	-0.09	1.52	21.60
Paraguay	1.20	2.50	3.00	2.30	0.00	0.05	0.65
Rest of the World	19.72	1.61	31.73	-34.71	-1.39	15.68	52.15
European Union	0.52	2.95	1.53	-16.07	-0.16	1.53	16.23
China	8.50	1.78	15.16	-3.66	-1.11	7.32	12.61
Japan	0.11	1.45	0.15	-4.81	-0.02	1.28	3.70
Mexico	0.09	1.59	0.14	-3.76	-0.08	0.03	3.95

Source: U.S. Department of Agriculture 2002a.

position in the world soybean markets, its share of global soybean and soybean product exports has steadily diminished in the past two decades. One of the reasons for this decline is the emergence of South America, particularly Brazil and Argentina, as a very strong soybean producing region (Schnepf, Dohlman, and Bolling 2001). In the 1998–99 crop year, Brazil produced 31 million metric tons (mt) of soybeans, Argentina produced 20 million mt, and the United States produced almost 75 million mt. Brazil and Argentina represent more than 90 percent of South America's soybean production, with Paraguay producing 75 percent of the remaining volume.

Only a small share of U.S., Brazilian, and Argentine soybean production is consumed directly (as seed, on-farm dairy feed, or direct food uses such as tofu). A larger share is exported to the ROW consisting of the European Union, China, Japan, Mexico, and other, smaller importing countries, with the European Union being the world's single largest soybean importer. Soybeans primarily are crushed to extract the soybean oil and meal (which also are actively traded internationally).

Soybean oil constitutes approximately 18 to 19 percent of the soybean's weight and has both food and industrial uses. It accounts for about two-thirds of all the vegetable oils and animal fats consumed in the United States and is used mainly in salad and cooking oil, bakery shortening, and margarine. The United States, Argentina, and Brazil also are the three leading producers of soybean oil (Table 2). Most of it is consumed at home, but some—around 20 percent of worldwide production—is imported by the ROW. Notably,

TABLE 2. Soybean oil production and utilization, 1998–99 (million mt)

	Production	Net Exports	Δ in Stocks	Consumption
World	24.56	NA	-0.02	24.58
United States	8.20	1.04	0.06	7.10
South America	7.55	3.78	-0.02	3.79
Argentina	3.16	3.08	-0.02	0.10
Brazil	4.04	1.22	0.00	2.82
Paraguay	0.12	0.09	-0.00	0.04
Rest of the World	8.81	-4.82	-0.06	13.69
European Union	2.92	1.06	0.03	1.83
China	2.05	-0.87	-0.16	3.08
Mid-East/N Africa	0.26	-1.64	0.03	1.87

Source: U.S. Department of Agriculture 2002a.

the European Union is self-sufficient in soybean oil production (thanks to sizeable crushing of imported soybeans), but many other countries, including China and the countries of the Middle East and North Africa, import oil.

Soybean meal is the most valuable product obtained from soybean processing. It is the world's dominant high-protein feed, accounting for nearly 65 percent of world supplies (USDA 2002b). About 98 percent of soybean meal is used for livestock feed, and the remainder is used in human foods such as bakery ingredients and meat substitutes. The European Union is the largest importer of soybean meal, and trade in that market flows from the United States, Brazil, and Argentina to the ROW (Table 3).

In summary, the world's soybean market consists of three closely related products: soybeans, soybean oil, and soybean meal. These three products form what is called the soybean complex, which will be the subject of further analysis in this paper. The main players in the soybean complex in terms of their production and trading status are the United States, South America, and the ROW.

The soybean crop has been one of the first to take advantage of agricultural biotechnology. Since their commercial introduction in 1996, herbicide-tolerant Roundup Ready (RR) soybeans gained rapid acceptance among U.S. and Argentine farmers (Table 4). In the 1998–99 marketing year, the adoption rate was 36 percent in the United States and more than double that in Argentina, and both rates continued to grow in subsequent years. The adoption of agricultural biotechnology thus constitutes another important dimension based on which one soybean region can be differentiated from another. In South

TABLE 3. Soybean meal production and utilization, 1998–99 (million mt)

	Production	Net Exports	Δ in Stocks	Consumption
World	108.36	NA	0.99	107.37
United States	34.29	6.37	0.11	27.81
South America	32.19	22.01	0.15	10.03
Argentina	13.69	13.22	0.02	0.45
Brazil	17.01	9.98	0.13	6.90
Paraguay	0.51	0.41	0.00	0.10
Rest of the World	41.88	-28.38	0.73	69.53
European Union	12.92	-14.91	0.17	27.66
China	10.03	-1.39	0.00	11.42
Mid-East/N Africa	1.23	-3.70	0.01	4.92

Source: U.S. Department of Agriculture 2002a.

TABLE 4. Acreage and adoption of Roundup Ready soybeans (million ha)

	1997	1998	1999	2000	Adoption Rate 1998–99[a]
World	5.1	14.5	21.6	25.8	
Unites States	3.6	10.2	15.0	16.5	0.36
South America	1.4	4.3	6.4	9.1	
Brazil	0.0	0.0	0.0	0.0	
Paraguay	0.0	0.0	0.0	0.0	0.00
Argentina	1.4	4.3	6.4	9.1	0.72
Other	0.0	0.0	0.0	0.0	
Rest of the World	0.1	0.0	0.2	0.2	0.00

Source: James 2000.

[a] Marketing year: September–August.

America, Brazil, and Argentina took different paths with respect to adopting RR soybeans because of different government policies. It is therefore important to account for these differences in current and possible future regional policies by separating South America into two regions. Thus, in addition to the United States and the ROW, the present model distinguishes the regions of Brazil and Argentina.[2]

The Model

In the model, product differentiation applies only to soybeans and soybean oil because, to date, biotech-based product differentiation in soybean meal (which is essentially used as feed) looks very unlikely. Differentiated demands for soybeans and soybean oil exist because of the underlying heterogeneity of consumers in the respective regions, resulting in the RR variety being weakly inferior to the conventional one. The specification of supply is based on Moschini, Lapan, and Sobolevsky 2000 and is extended to account for identity preservation costs. It is assumed that identity preservation is achieved by a constant-cost segregation technology. RR soybean seed is sold by an innovator-monopolist at a premium. In addition, the model takes into account government price support policy available to U.S. farmers in the form of marketing assistance loans and loan deficiency payments (LDPs). The model is calibrated so as to predict prices and quantities in the soybean complex for the crop year 1998–99, the most recent complete year when the analysis was undertaken, and is solved for several scenarios of interest.

Demand

Introducing a product innovation in our setting requires specifying two separate demands—for conventional and RR varieties—in the post-innovation period both for soybeans and soybean oil. Also, the model must allow for the pre-innovation demand for only the conventional variety and for the post-innovation demand for only the (de facto) RR variety in the world with no segregation technology. All these demands should arise from the same preference ordering if welfare calculations are to be meaningful. There are many possible approaches for modeling demand in this product-differentiation setting, including the use of product characteristics models (e.g., Hotelling 1929; Lancaster 1979; see also Helpman and Krugman 1989) and of love-of-variety models (e.g., Dixit and Stiglitz 1977; see also Helpman and Krugman 1989). However, as emphasized in Lapan and Moschini 2001, in our setting it is important that the demand specification embody the fact that the GM product is a “weakly inferior” substitute for the traditional one (not just an imperfect substitute). The presumption here is that consumers agree that the GM soybean product does not have any additional attribute from the consumers’ point of view. 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, some 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, Moschini and Lapan (2000) postulate a population of heterogeneous consumers where some consumers consider the two varieties to be perfect substitutes while others consider the new GM variety to be inferior to the existing variety. Under perfect information, these latter consumers will be willing to buy the GM variety only at a discount. Specifically, preferences for consumers of type θ are represented by the quasilinear utility function:

$$U = u\left(q_0 + \theta q_1\right) + y \tag{1}$$

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 parameter $\theta \in [0,1]$ reflects the fact that consumers value the GM variety of the good less (strictly so if $\theta < 1$) than the non-GM one. Given this structure, the demand by a consumer of type θ depends upon the relative prices of each variety. In particular, a consumer of type θ will buy the GM variety if and only if $p^1 \leq \theta p^0$.[3] Thus, from (1), the individual demand curves can be written as

$$q_0 = d\left(p^0\right) \text{ and } q_1 = 0 \quad \text{for } \theta < \hat{\theta} \tag{2}$$

$$q_0 = 0 \text{ and } q_1 = \frac{1}{\theta} d\left(p^1/\theta\right) \text{for } \theta \geq \hat{\theta} \tag{3}$$

where $\hat{\theta} \equiv Min\left[\left(p_1/p_0\right),1\right]$ and the demand function satisfies $d^{-1}(.) = u'(.)$. Aggregate market demand functions can then be defined as

$$Q^0\left(p^0, p^1\right) = \int_0^{\hat{\theta}} d\left(p^0\right) dF(\theta) \tag{4}$$

$$Q^1\left(p^0, p^1\right) = \int_{\hat{\theta}}^1 \frac{1}{\theta} d\left(p^1/\theta\right) dF(\theta) \tag{5}$$

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

Because aggregation in such a case is exact, 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 consumes both varieties (provided that $p^0 \geq p^1$). Assuming that these goods are measured in the same physical units, two possible types of indifference sets for the representative consumer are represented in Figures A.1 and A.2 in Appendix A. The first case represents preferences that are strictly convex, so that to obtain a positive demand for the new product one must have $p^1 < p^0$. The second case is more general, allowing (in the heterogeneous consumers' interpretation) a positive mass of consumers being perfectly indifferent between good 0 and good 1 as long as $p^1 = p^0$.

Based on the foregoing discussion, we specify a linear demand system for conventional and RR differentiated products that allows for gross substitution, weak preference for the conventional good, and some degree of indifference between the two goods. The following parameterizations apply to any product in any region, but for notational simplicity, the subscripts denoting a product and a region are omitted in this section.

Adopting a linear specification for $Q^0(p^0, p^1)$ and $Q^1(p^0, p^1)$, the demand functions for conventional and RR soybean products are written as

$$\left.\begin{aligned} Q^0 &= a_0 - b_0 p^0 + c p^1 \\ Q^1 &= a_1 - b_1 p^1 + c p^0 \end{aligned}\right\} \qquad if \quad p^0 > p^1 \tag{6}$$

$$\left.\begin{aligned} &Q^0 \in \{a_0 - (b_0 - c)p,\ (a_0 + a_1) - (b_0 + b_1 - 2c)p\} \\ &Q^1 \in \{0,\ a_1 - (b_1 - c)p\} \end{aligned}\right\} \qquad if \quad p^0 = p^1 \equiv p \tag{7}$$

$$\left.\begin{aligned} Q^0 &= (a_0 + a_1) - (b_0 + b_1 - 2c)p^0 \\ Q^1 &= 0 \end{aligned}\right\} \qquad if \quad p^0 < p^1 \tag{8}$$

where all parameters are strictly positive. Note that 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. The total demand that is implied by this structure is

$$Q^T = (a_0 + a_1) - (b_0 - c)p^0 - (b_1 - c)p^1 . \tag{9}$$

Note that the curvature conditions associated with (6), $b_0 > c$ and $b_1 > c$, imply that the total demand is non-increasing in either price. Also note that, at $p^0 = p^1$, (6) gives $Q^1 = a_1 - (b_1 - c)p^0$ (subject to $p^0 \le a_1 / (b_1 - c)$). This is the maximum quantity that "indifferent" consumers buy of RR product at these prices, and if they buy less, the difference must be covered by purchases of the conventional variety. With $p^0 < p^1$, demand for Q^1 vanishes.

The underlying preferences are described by the quasilinear indirect utility function:

$$V(p^0, p^1, I) = I - \left(a_0 p^0 + a_1 p^1 - \frac{1}{2} b_0 (p^0)^2 - \frac{1}{2} b_1 (p^1)^2 + c p^0 p^1 \right) \tag{10}$$

where I is income and the price of the *numéraire* good is normalized to one. It is useful to note that our approach allows us to handle welfare measurement in a coherent way. A conceptual difficulty with analyzing the welfare implications of new products arises because of the need to compare pre- and post-innovation states of the world that have different dimensions in product space. Fisher and Shell (1968) showed that new products could be consistently modeled by being entered in the pre-innovation product space with their market prices set to reservation (also called "choke") values, that is, the hypothetical prices at which their derived demands equal zero.

Following this approach, the specification in equation (8) will be used to describe the differentiated market before the introduction of RR products, with the RR reservation price implicitly set above p^0 (i.e., we imagine that the new technology is possible but prohibitively expensive). When the new technology is adopted, no matter how incompletely, and the RR and conventional varieties are not separated in the supply chain, the effective demand for conventional product is assumed to be zero (we postulate that this case reflects the fact that the price that must be paid to ensure that the consumed product is GM-free is prohibitively high). To describe this scenario, for any given p^1, the "choke" price $\bar{p}^0 \equiv (a_0 + c p^1) / b_0$ drives the demand for the conventional product to zero. Therefore,

$$\left.\begin{aligned} &Q^0 = 0 \\ &Q^1 = a_1 + \frac{ca_0}{b_0} - \left(b_1 - \frac{c^2}{b_0}\right)p^1 \end{aligned}\right\} \; if \quad p^0 \geq \overline{p}^0 . \tag{11}$$

Note that the conditions $b_0 > c$ and $b_1 > c$ ensure that this demand is also downward sloping.

A complete specification of the demand system (6)–(8) for all prices in the nonnegative quadrant $\mathbb{R}_+^2$ is represented in Figures A.3 and A.4. Two distinct specifications arise depending on the relative values of demand parameters. By comparison, the general two-good linear demand system specification is represented in Figure A.5.

For later use, the price elasticities of differentiated demands for the case $p^0 \geq p^1$ are defined as

$$\varepsilon^{11} = -b_1 \frac{p^1}{Q^1}, \quad \varepsilon^{10} = c\frac{p^0}{Q^1}, \quad \varepsilon^{00} = -b_0 \frac{p^0}{Q^0}, \text{ and } \varepsilon^{01} = c\frac{p^1}{Q^0}. \tag{12}$$

It also may be useful to define an aggregate elasticity, call it a scale elasticity, that tells us how total demand (for conventional and RR varieties) reacts to scaling of all prices:

$$\varepsilon^T = \left.\frac{\partial Q^T\left(tp^0, tp^1\right)}{\partial t}\frac{t}{Q^T}\right|_{t=1} = \frac{-(b_0 - c)p^T - (b_1 - c)p^T}{Q^T\left(p^0, p^1\right)} \tag{13}$$

Finally, the undifferentiated demand is assumed to have a linear functional form:

$$Q^U(p) = a - bp \tag{14}$$

where p is either the own price of undifferentiated soybean meal or the price of the cheaper or the only available variety (which could be a conventional variety) in a region inhabited by consumers who do not have differentiated tastes. The own-price elasticity of the demand (14) is defined as

$$\varepsilon^{UU} = -b\, p/Q^U . \tag{15}$$

Supply

A parsimonious specification of the soybean supply function that 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 was developed in Moschini, Lapan, and Sobolevsky 2000. This specification is briefly restated, and its extensions necessary for the purposes of this paper are discussed next.

Moschini, Lapan, and Sobolevsky's (2000) model assumes homogeneous soybean farmers who have the choice of growing conventional or RR soybeans or both, who are not required to segregate the two varieties during the production process, and who 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, and y denotes yield (production per hectare).[4] Production per hectare depends on the use of seeds x and of all other inputs z. It is assumed that the per-hectare production function $f(z,x)$ requires a constant optimal density of seeds δ (amount of seed per unit of land), irrespective of the use of other inputs, for all likely levels of input and output prices. Hence, the variable profit function (per hectare), defined as

$$\pi(p_B, r, w) = \max_{z,x} \{ p_B f(z,x) - r \cdot z - wx \}, \tag{16}$$

is written in the additive form $\pi(p_B, r, w) = \tilde{\pi}(p_B, r) - \delta w$, where p_B is the price of soybeans, r is the price vector of all inputs (excluding land and seed), and w is the price of soybean seed. These assumptions imply that the (optimal) yield function does not depend on the price of seed:

$$\frac{\partial \pi(p_B, r, w)}{\partial p_B} = \frac{\partial \tilde{\pi}(p_B, r)}{\partial p_B} \equiv y(p_B, r)\,. \tag{17}$$

Land devoted to soybeans is the result of an optimal land allocation problem that depends on net returns (profit per hectare) of soybeans and of other competing crops, as well as the total availability of land. If all other unit profits (and total land) are treated as constant, they can be subsumed in the functional representation $L = L(\pi)$ such that total supply of soybeans is written as

$$Y_B = L(\tilde{\pi}(p_B, r) - \delta w) \cdot y(p_B, r) . \tag{18}$$

The new RR technology is embedded in the seed. By assumption, the amount of seed used per hectare is constant, but the new technology is assumed superior such that, at all relevant input price levels (and excluding seed price), the profit per hectare is increased. That is, if the superscripted 1 denotes the new technology and 0 the old one, then

$$\tilde{\pi}^1(p_B, r) > \tilde{\pi}^0(p_B, r) . \tag{19}$$

Specifically, the per-hectare profit functions for the conventional technology (π^0) and for the RR technology (π^1) are parameterized as follows:

$$\pi^0 = A + \frac{G}{1+\eta} p_B^{1+\eta} - \delta w \tag{20}$$

$$\pi^1 = A + \alpha + \frac{(1+\beta)G}{1+\eta} p_B^{1+\eta} - \delta w(1+\mu) \tag{21}$$

where η is the elasticity of yield with respect to soybean price; A and G are parameters subsuming all other input prices, presumed constant; β is the coefficient of yield change due to the RR technology; α is the coefficient of unit profit increase due to the RR technology; and μ is the markup (which reflects the technology fee) on RR seed price charged by the innovator-monopolist who developed the RR technology. Therefore, the unit profit advantage of the new technology can be written as

$$\Delta\pi = \alpha + \frac{\beta G}{1+\eta} p_B^{1+\eta} - w\delta\mu . \tag{22}$$

It is useful to note that this formulation allows the new technology to affect yield (through the parameter β), and profit per hectare is affected through this parameter and, separately, through the parameter α. The yield functions are $y^0 = Gp_B^{\eta}$ for the conventional technology and $y^1 = (1+\beta)Gp_B^{\eta}$ for the RR one.

Although the behavior of the innovator-monopolist will take into account the equilibrium conditions in the system (Lapan and Moschini 2002), in this study we will not attempt to endogenize the innovator's optimizing behavior. Instead, we will rely on the observed pricing practice and the RR seed markup, and study the new technology's diffusion process conditional on that. Thus, for a given adoption rate of RR technology $\rho \in [0,1]$, measured as a share of RR soybean acres in total land devoted to soybeans and the non-segregated soybean price p_B, the average profit per hectare is

$$\bar{\pi} = A + \rho\alpha + \frac{(1+\rho\beta)G}{1+\eta} p_B^{1+\eta} - \delta w(1+\rho\mu) \tag{23}$$

such that the corresponding average yield is $y = (1+\rho\beta)Gp_B^{\eta}$. Supply of land to the soybean industry is written in constant-elasticity form as a function of average land rents that depend on output price and adoption rates; that is,

$$L = \lambda\bar{\pi}^{\theta} \tag{24}$$

where θ is the elasticity of land supply with respect to soybean profit per hectare, and λ is scale parameter. For calibration purposes, it is useful to note that the parameter θ can be readily related to the more standard 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. Finally, the aggregate supply of soybeans in a non-segregated market is written as

$$Y_B = \lambda\left[A + \rho\alpha + \frac{(1+\rho\beta)G}{1+\eta} p_B^{1+\eta} - \delta w(1+\rho\mu)\right]^{\theta}(1+\rho\beta)Gp_B^{\eta}. \tag{25}$$

As was mentioned before, this model is based on the assumption that farmers are homogeneous. To some extent, this assumption is a simplification. The RR technology seems to benefit farmers by reducing costs and, to a lesser extent, by increasing yields, albeit these gains are partially offset by the higher seed prices. The profitability of the new technology is likely to be subject to variation at the farm level. To be sure, a supply model that explicitly accounts for heterogeneity of farm characteristics, and which can naturally explain incomplete adoption of the new technology, could be specified as in

Lapan and Moschini 2002. The approach taken here abstracts from farm-level heterogeneities and thus simplifies the calibration and simulation process. But the model still allows for incomplete adoption, which here arises because the two types of goods are imperfect substitutes.

Differentiated Products and Segregation Costs

The requirement that two distinct varieties of soybeans be maintained in order to serve differentiated soybean product markets (GM and non-GM) gives rise to additional production and marketing costs associated mainly with the nonbiotech variety, costs that would not exist otherwise. Consumers who do not have differentiated tastes (or, equivalently, who regard the GM and non-GM products as perfect substitutes) will be indifferent between consuming GM and non-GM varieties. Consequently, the production and marketing chain of nonbiotech soybeans ultimately will bear the additional cost of segregating the non-GM product because GMO-conscious consumers will demand certification that the product they consume is free from GM material (Golan and Kuchler 2000). From this standpoint, the voluntary efforts of nonbiotech producers and marketers are all that is needed to have both product varieties available in the marketplace. However, as analyzed in Lapan and Moschini 2002, mandatory labeling that imposes an additional wasteful cost on the biotech market segment is also possible, as evidenced by policies being implemented in the European Union. In what follows, however, we do not model explicitly the impact of such additional regulatory costs. In any case, prohibitively high regulatory costs imposed by importing regions would make biotech exports simply cease, which is equivalent to the import ban scenario that we analyze.

Separation of non-GM soybeans and soybean products requires extensive segregation activities known as “identity preservation” (Lin, Chambers, and Harwood 2000; Bullock and Desquilbet 2002). That includes separation of non-GM beans at all levels of production and in the supply chain, from planting through harvest, storage, and transportation, at the expense of additional cleaning of equipment, cleaning or maintaining separate storage facilities, and testing for GM content at various points in the marketing system. Some of these additional costs may stay constant but others are likely to diminish per unit of output as the scale of nonbiotech production increases. As nonbiotech demand becomes more sizeable, there would be more elevators in the vicinity of any given soybean farm operation willing to accept non-GM soybeans, which may be expected to reduce farmers' transportation costs. For as many as 95 percent of U.S. elevators, separating non-GM soybeans is likely to require new investments (Lin, Chambers, and Harwood 2000), and in other regions of the world, the situation should be similar, implying processing economies of scale. Even with existing facilities, elevators should enjoy economies of scale as costs of maintaining separate loading, unloading, and storage facilities or routine cleaning of common facilities before accepting non-GM crop—as well as costs of "storing air"—will fall per ton of non-GM soybeans if the quantity were to increase. Economies of scale in shipping, especially containerized shipping, may be less evident unless shipments of non-GM soybeans are so small that such commonly used means of transportation as unit trains of about 100 cars or river barges cannot be fully utilized.

In this model we simplify the specification of unit segregation costs, denoted by φ, by assuming that they are a positive constant if the region in question produces both varieties, and that they are zero if the region only grows the traditional variety. Thus,

$$\varphi = \begin{cases} \text{constant} & \text{if} \quad \rho > 0 \\ 0 & \text{if} \quad \rho = 0 \end{cases}. \tag{26}$$

In our model, segregation costs arise 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). Thus, φ represents a wedge between the producer and the home consumer price or, if the product is not consumed at home, the importing region's consumer price minus transportation costs.

Assuming that segregation or identity preservation costs are borne entirely by the users of conventional technology, the profit functions per hectare in each region consistent with the parametric specifications in (20) and (21) are defined as follows:

$$\pi^0 = A + \frac{G}{1+\eta}\left(p_B^0 - \varphi\right)^{1+\eta} - \delta w \tag{27}$$

$$\pi^1 = A + \alpha + \frac{(1+\beta)G}{1+\eta}(p_B^1)^{1+\eta} - \delta w(1+\mu) \tag{28}$$

where p_B^0 is the market price (at the demand level) of conventional soybeans and p_B^1 is the market price of RR soybeans, so that the farmer (producer) price in the conventional soybean market is $p_B^0 - \varphi$.

The relationship between π^0 and π^1 determines which technology is adopted by farmers. Because no heterogeneity among farmers is allowed in the model, the equilibrium in which both soybean varieties are produced requires that farmers are indifferent between the two technologies, i.e., $\pi^0 = \pi^1$. Thus, equilibrium in the soybean market where both varieties are produced rules out a non-binding incentive compatibility constraint.

As discussed, in our model we take the choice of the monopolist as given; that is, the parameter μ that measures the markup on RR seed prices is taken from the data. Definitions (27) and (28) imply that yield functions are $y^0 = G(p_B^0 - \varphi)^\eta$ for the conventional technology and $y^1 = (1+\beta)G(p_B^1)^\eta$ for the RR technology. Total supply of land to the soybean industry in each region is written in constant-elasticity form (24) as a function of average land rents, where

$$\bar{\pi} = \begin{cases} \pi^0 & \rho = 0 \\ (1-\rho)\pi^0 + \rho\pi^1 = \pi^0 = \pi^1 & \rho \in (0,1). \\ \pi^1 & \rho = 1 \end{cases} \tag{29}$$

The region's adoption rate ρ 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

$$Y_B^0 = \lambda\left[A + \frac{G}{1+\eta}(p_B^0 - \varphi)^{1+\eta} - \delta w\right]^\theta (1-\rho)G(p_B^0 - \varphi)^\eta \tag{30}$$

$$Y_B^1 = \lambda\left[A + \alpha + \frac{G(1+\beta)}{1+\eta}(p_B^1)^{1+\eta} - \delta w(1+\mu)\right]^\theta \rho(1+\beta)G(p_B^1)^\eta . \tag{31}$$

U.S. Price Support Policies

The supply equations (30) and (31) were obtained under the assumption of no government intervention in the soybean sector. In reality, many countries in the world pursue high price support policies to encourage agricultural production. For the soybean sector, in particular, a major support program in recent years has been provided to U.S. producers based on the Federal Agriculture Improvement and Reform Act of 1996, which established that nonrecourse marketing assistance loans and LDPs be administered for the 1996 through 2002 crop years (USDA 1998). Farmers may choose one of the two support options: a loan or an LDP. A loan pays a fixed dollar amount per bushel of soybeans, uses the harvested crop as collateral, and has a maturity period of nine months. A national average loan rate is fixed at the beginning of the crop year. For soybeans, it is established at the level of 85 percent of the simple average price received by producers during the marketing years for the immediately preceding five crops, excluding the highest and lowest prices, but no less than $4.92 per bushel ($180.76 per mt) and no more than $5.26 per bushel ($193.25 per mt). The U.S. Department of Agriculture (USDA) tracks current market prices using so-called posted county prices (PCPs). The loan plus accrued interest may be repaid in full any time before maturity when the PCP is higher than that combined amount. If the PCP is lower than the loan rate plus interest, the loan is repaid by paying just the PCP, with producers realizing a “marketing loan gain.” Finally, the farmer may simply wait until maturity and forfeit the collateral crop to the Commodity Credit Corporation (CCC), the issuer of the loan.

When a farmer decides to receive an LDP, he gets the difference between his county’s loan rate and the PCP if the latter is lower. This price support program gives farmers a number of options, but essentially, it establishes 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 start to recover and they exceeded the loan rate in July for the first time in four years. But during that four-year period, LDPs played a significant role in the U.S. soybean industry and they will continue to do so if prices decline again.

In the context of our model, we wish to account for the effects of this particular price support program. In particular, we want to assess the impact that this market distortion has on the size and distribution of the estimated benefits from RR soybean innovation. A number of studies, summarized in Alston and Martin 1995, explain how price-distorting policies may affect the size and distribution of returns to research. Murphy, Furtan, and Schmitz (1993) even demonstrate the possibility of immiserizing technical change, a possibility actually envisioned earlier in Johnson 1967 and Bhagwati 1968 (who demonstrate that growth may be welfare-reducing because of various trade policy distortions and terms-of-trade effects caused by market power in trade). When domestic producers in the large exporting country enjoy a fixed price support, the research-induced supply shift has a range of implications. The welfare-reducing implications are the leftward shift in the ROW's excess demand due to the spillover of new technology overseas and the increase in the export subsidy bill at home caused by higher exports and a lower world price. The welfare-enhancing implications are the increase in producer and consumer surplus at home and overseas.[5] Murphy, Furtan, and Schmitz (1993) show that taking most of these effects into account—they assume domestic consumers are locked into high support prices and omit any rents arising from patenting the new technology—makes it theoretically possible for a technical change to have a negative *ex post* (i.e., without accounting for R&D expenditures) welfare impact not only for the exporting country undergoing technological growth but for the world at large. Alston and Martin (1995) confirm with their more general model that technical change can lead to a loss or gain in welfare depending on whether it worsens an existing distortion to the extent that the increase in social costs of the distortion is greater than the maximum potential benefit of the technical change.

The implications of the price support programs for unit profit and supply functions of U.S. farmers are straightforward. Denoting by p_{LDP} the average price offered by price support programs and assuming that these programs treat conventional and RR soybean growers uniformly (i.e., pay the same price for conventional and RR soybeans), supply equations (30) and (31) for the United States may be rewritten as

$$Y_B^0 = \lambda \left[A + \frac{G}{1+\eta} (\overline{p}_B^0)^{1+\eta} - \delta w \right]^{\theta} (1-\rho) G (\overline{p}_B^0)^{\eta} \tag{32}$$

$$Y_B^1 = \lambda \left[A + \alpha + \frac{G(1+\beta)}{1+\eta} (\overline{p}_B^1)^{1+\eta} - \delta w (1+\mu) \right]^{\theta} \rho (1+\beta) G (\overline{p}_B^1)^{\eta}, \tag{33}$$

where $\overline{p}_B^0 = \max\{p_{LDP}, p_B^0 - \varphi\}$ and $\overline{p}_B^1 = \max\{p_{LDP}, p_B^1\}$.

Trade and Market Equilibrium

In our model, the world is divided into four regions: the United States (subscripted U), Brazil (subscripted Z; includes Brazil and Paraguay), Argentina (subscripted A; includes all other countries of South America), and the ROW (subscripted 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 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.

In the model, trade takes place at all levels of the soybeans complex: in soybeans (subscripted B), soybean oil (subscripted O), and soybean meal (subscripted 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.

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:

$$\sum_{i=U,A,Z,R} Q^0_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} \sum_{i=U,A,Z,R} Q^0_{O,i}(p^0_{O,i}, p^0_{O,i}) = \sum_{i=U,A,Z,R} Y^0_{B,i}(p^0_{B,i}, \rho_i) \tag{34}$$

$$Q^0_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} Q^0_{O,i}(p^0_{O,i}, p^1_{O,i}) = Y^0_{B,i}(p^0_{B,i}, \rho_i),\ i \in I^0 \subset \{U, A, Z, R\} \tag{35}$$

$$\sum_{i=U,A,Z,R} Q^1_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} \sum_{i=U,A,Z,R} Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) = \sum_{i=U,A,Z,R} Y^1_{B,i}(p^1_{B,i}, \rho_i) \tag{36}$$

$$Q^1_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) = Y^1_{B,i}(p^1_{B,i}, \rho_i),\ i \in I^1 \subset \{U, A, Z, R\} \tag{37}$$

$$\frac{1}{\gamma_M} \sum_{i=U,A,Z,R} Q_{M,i}(p_{M,i}) = \frac{1}{\gamma_O} \left(\sum_{i=U,A,Z,R} Q^0_{O,i}(p^0_{O,i}, p^1_{O,i}) + \sum_{i=U,A,Z,R} Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) \right) \tag{38}$$

$$p^0_{B,i} + m_i = \gamma_M p_{M,i} + \gamma_O p^0_{O,i}\ ,\ i \in I^0 \cup I^2,\ I^2 \subset \{U, A, Z, R\} \setminus I^0 \tag{39}$$

$$p^1_{B,i} + m_i = \gamma_M p_{M,i} + \gamma_O p^1_{O,i}\ ,\ i \in I^1 \cup I^3,\ I^3 \subset \{U, A, Z, R\} \setminus I^1 \tag{40}$$

$$\begin{array}{lll} \pi^0_i(p^0_{B,i}) = \pi^1_i(p^1_{B,i}) & \text{if} \quad \rho_i \in (0,1) & \\ \pi^0_i(p^0_{B,i}) \ge \pi^1_i(p^1_{B,i}) & \text{if} \quad \rho_i = 0 & i = U, A, Z, R \\ \pi^0_i(p^0_{B,i}) \le \pi^1_i(p^1_{B,i}) & \text{if} \quad \rho_i = 1 & \end{array} \tag{41}$$

$$\left| p^0_{B,i} - p^0_{B,j} \right| \le t^0_{B,ij}\ ,\ i,j = U, A, Z, R,\ i \ne j \tag{42}$$

$$\left| p^1_{B,i} - p^1_{B,j} \right| \le t^1_{B,ij}\ ,\ i,j = U, A, Z, R,\ i \ne j \tag{43}$$

$$\left| p^0_{O,i} - p^0_{O,j} \right| \le t^0_{O,ij}\ ,\ i,j = U, A, Z, R,\ i \ne j \tag{44}$$

$$\left| p^1_{O,i} - p^1_{O,j} \right| \le t^1_{O,ij}\ ,\ i,j = U, A, Z, R,\ i \ne j \tag{45}$$

$$\left| p_{M,i} - p_{M,j} \right| \le t_{M,ij}\ ,\ i,j = U, A, Z, R,\ i \ne j \tag{46}$$

Equations (34) and (36) are market clearing equations requiring that the total world soybean demand for direct use and processing equals world supply in each variety. Equations (35) and (37) specify market clearing conditions in conventional and RR markets of regions that do not trade in conventional or RR soybeans and oil in equilibrium, if such regions exist. These non-trading regions' indices are stored in I^0 and I^1, the subsets of the index set *{U, A, Z, R}*. Of course, it is possible that I^0 is an empty set. Also, given (34), the number of elements in I^0 should not exceed three. The same applies to I^1. Equation (38) ensures that the soybean equivalents of oil and meal demands are the same on aggregate.

Equations (39) and (40) ensure that soybean processors of either variety receive a constant crushing margin m_i, *i=U, A, Z, R,* to cover their costs (m_i is the exogenous parameter determined at the calibration stage). 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 any non-trading regions if such exist. For equation (39) this means that it must be imposed in every region whose index is stored in I^0 and I^2, where I^2 is the set containing a single index of any of the regions trading in the conventional variety. Similarly, equation (40) applies in regions with indices from I^1 and I^3, where I^3 is the set containing a single index of any of the regions trading in the RR variety.

Equation (41) describes the incentive compatibility constraints that must be satisfied in each region in equilibrium. Production of both conventional and RR soybeans takes place only when the respective unit profits are the same, i.e., when farmers are indifferent about which variety to produce. Otherwise, they produce only the more profitable variety.

Equations (42) through (46) define the spatial configuration of prices. Because differentiated markets for GM and non-GM soybean products are not well developed at present, various assumptions can be made with respect to possible configuration of trade flows, which warrants the most general specification. However, the four-region spatial model is restricted to 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 trade flows that are most likely to prevail in any conceivable equilibrium. Currently, the trade takes place between the United States and the ROW, between Brazil and the ROW, and between Argentina and the ROW, but whether this is the case in differentiated markets will be determined by equilibrium. Let $t^k_{m,ij}$ denote price differentials (transportation costs) that are assumed symmetric for each pair of regions.[6] Whenever trade between two regions in a particular product variety exists, the corresponding inequality becomes an equality; otherwise, the inequality must be strict. An assumption about the direction of trade is necessary to replace absolute values with an appropriate sign.

The existence and uniqueness of equilibrium is guaranteed by the normal shape of demand and supply curves as defined earlier (Samuelson 1952). 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.

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), we can then define the demands that appeared in (34)–(46) more explicitly:

$$
\begin{gathered}
Q^0_{B,i}(p^0_{B,i}, p^1_{B,i}) \equiv 0, \; i = U, A, Z \\
Q^0_{O,i}(p^0_{O,i}, p^1_{O,i}) \equiv 0, \; i = U, A, Z \\
Q^1_{B,i}(p^0_{B,i}, p^1_{B,i}) \equiv Q^U_{B,i}(p^1_{B,i}), \; i = U, A, Z \\
Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) \equiv Q^U_{O,i}(p^1_{B,i}), \; i = U, A, Z \\
Q_{M,i}(p_{M,i}) \equiv Q^U_{M,i}(p_{M,i}), \; i = U, A, Z, R\,.
\end{gathered}
\tag{47}
$$

Were we to assume that all four regions have differentiated demands in soybeans and soybean oil, only the last of the five identities in (47) would apply.

A limitation of the equilibrium system (34)–(46) is that it does not allow recovery of individual trade flows for all goods, i.e., to provide separate values for exports/imports of soybeans, soybean oil, and soybean meal. The reason for this ambiguity is that, once a region has an excess supply of soybeans available for meeting an excess demand for oil and/or meal, these soybeans can be either crushed in the exporting region and exported in the form of oil and meal or they can be equivalently exported in the form of soybeans and crushed by the region-importer. This feature is ultimately due to the assumption of the constant-returns-to-scale crushing technology in all regions of the world, which makes the interregional distribution of crush undetermined in equilibrium.

Consequently, the only meaningful trade flow result that can be reported in 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:

$$ES_{B,i}^{j} = Y_{B,i}^{j} - Q_{B,i}^{j} - \frac{1}{\gamma_O} Q_{O,i}^{j} \quad i = U, A, Z, R; \; j = 0,1 . \tag{48}$$

We can call $ES_{B,i}^{j}$ the soybean-equivalent net exports. However, this definition is not very precise because this "equivalence" measure does not capture all volume of trade between regions. The missing element is the residual excess supply of soybean meal arising because the soybeans that are crushed to meet domestic oil demand need not yield the amount of meal exactly equal to domestic meal demand:

$$ES_{M,i} = \frac{1}{\gamma_O}\left(Q_{O,i}^{0} + Q_{O,i}^{1}\right)\gamma_M - Q_{M,i} \quad i = U, A, Z, R . \tag{49}$$

The "meal exports" heading in the results tables in the appendix reports $ES_{M,i}$.

Solution Algorithm

Given this setting, we are faced with the task of solving a spatial four-region, three-good equilibrium model. The literature on spatial equilibrium models can be traced back to Samuelson (1952), who shows that in the partial-equilibrium (one commodity) context the problem of finding a competitive equilibrium among spatially separated markets could be converted mathematically into a maximum problem. Defining the net social payoff function as the sum of the areas under all regions' excess demand curves minus total transportation cost, Samuelson proves that maximization of this net welfare function, providing that all domestic supply curves cut demand curves from below as price rises, would result in a unique solution with prices and quantities that satisfied all properties of the spatial price equilibrium. He also suggests that this maximization problem could be solved by trial and error or by a systematic procedure of varying export shipments consistently in the direction of increasing social welfare.

Samuelson's result not only makes it easy to produce rigorous qualitative comparative statics predictions but also shows how to actually solve some spatial equilibrium models in an era of limited computing resources. Takayama and Judge (1964, 1970) extend Samuelson's work to a multiple-commodity competitive equilibrium case and demonstrate that the problem, under the additional assumption of linear aggregate regional demand and supply functions, can be converted to a quadratic programming problem and solved using available simplex methods. Takayama and Judge (1970, 1971) also show that their approach would work not only for linear demand specifications that satisfy symmetry conditions but also for spatial models with asymmetric demand coefficients, and that the model can still be solved using a quadratic programming technique when competition is replaced by monopolistic behavior.

Although the quadratic programming approach in the framework of linear market specification proved to be very efficient and hence very popular in economic research on agriculture, energy, and minerals, the attempts to introduce nonlinear demand and supply specifications in the spatial equilibrium models were not as successful. Takayama and Labys (1986) pointed out that optimization-based solution algorithms with nonlinear demands and supplies were becoming extremely complicated and time consuming, imposing a computational burden that, in their view, was just too high to justify choosing nonlinear specifications.

In the present model, the size of the spatial equilibrium system is not very large, and computer time at modern processing speeds is not a limiting factor. Nevertheless, because of nonlinearities in the model's supply specification, the existing quadratic programming algorithms cannot be applied, and no other ready algorithm is available. Therefore, the choice was made to solve directly the system of nonlinear equations defining the spatial equilibrium conditions by using available numerical techniques.

The model (34)–(46) is solved using GAUSS, the software equipped with the eqSolve procedure that solves $N \times N$ systems of nonlinear equations by inverting the system's Jacobian while iterating until convergence. Obviously, all equations must be binding. In our case, however, the number of binding equations in (34)–(46) 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. For example, when differentiated markets exist only in the ROW, the size of the binding portion of the system (34)–(46) can be anywhere from N=5 to N=21.

GAUSS provides no capability for changing the dimensions of the system of equations as it is being solved. Thus, the solution algorithm looks for the equilibrium by repeatedly solving the fluctuating-in-size binding portion of the system (34)–(46) 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). When each of the above scenarios is solved, the solution—if it exists—is checked against the remaining non-binding equations of the system (34)–(46). When a differentiated market equilibrium satisfying the system (34)–(46) is found, the model solves the benchmark pre-innovation, undifferentiated equilibrium and computes consumer and producer surpluses, innovator-monopolist's profit, and the subsidy to U.S. farmers.

Calibration

The parameters of the model are calibrated such as to predict 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 Tables 1 through 3. The history of world adoption rates for RR soybeans is provided in Table 4, with the adoption rates used in calibration shown in the last column of the table. Price data are in Table 5. U.S. prices for soybeans, oil, and meal were taken to be equal to \$176, \$441, and \$145 per mt, respectively. In the United States, the producer (farmer) price for soybeans was different from \$176/mt because of LDPs. Because world trade patterns in 1998–99 have not changed compared to the preceding crop year, with the United States, Argentina, and Brazil being net exporters and the ROW being a net importer of soybeans and all soybean products, the spatial price differentials were taken at the levels used in Moschini,

TABLE 5. Prices in the soybean complex ($/mt)

	93–94[a]	94–95[a]	95–96[a]	96–97[a]	97–98[a]	98–99[a]	94–99 (Average)
Soybeans							
U.S. farm price[b]	233	205	263	274	230	176	230
U.S. Gulf, f.o.b.[b]	248	226	288	293	247	193	249
Argentina, f.o.b.[b]	231	214	277	288	231	179	238
Brazil, f.o.b.[b]	235	217	284	285	240	184	242
Rotterdam, c.i.f.[b]	259	248	304	307	259	225	269
Soybean meal							
U.S. (Decatur), 44%[b,d]	199	167	248	286	193	145	208
Brazil, 44–45% f.o.b.[b,d]	182	172	256	289	201	150	214
Argentina, (pell.) f.o.b.[b]	174	151	233	257	174	130	189
Rotterdam, c.i.f. (Argentina 44%–45%)[c,d]	202	184	256	278	197	150	213
Rotterdam, c.i.f. (Brazil 48%)[c,d]	211	194	266	293	212	161	225
Soybean oil							
U.S. (Decatur)[c]	596	605	550	504	571	441	534
U.S. (Decatur)[b]	595	606	545	496	569	438	531
U.S. Gulf, f.o.b.[c]		643	569	527	622	471	566
Brazil, f.o.b.[c]	546	629	540	518	618	456	552
Brazil, f.o.b.[b]	539	608	537	514	608	452	544
Argentina, f.o.b.[c]	545	625	540	517	617	456	551
Argentina, f.o.b.[b]	543	623	533	515	614	453	548
Rotterdam, f.o.b.[c]	580	642	575	536	633	483	574

[a] Fiscal years: October–September.
[b] *Source*: U.S. Department of Agriculture 2000a.
[c] *Source*: Oil World 2000.
[d] Percentage refers to protein content

Lapan, and Sobolevsky (2000, p. 46), who analyzed the issue for 1997–98. Argentine and Brazilian differentials are set equal to those of South America in Moschini, Lapan, and Sobolevsky (2000) because both regions' free-on-board (f.o.b.) prices for soybeans and soybean products are very close to each other (Table 5).

Separately, the recent USDA report on agriculture in Brazil and Argentina (Schneph, Dohlman, and Bolling 2001) supported 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. See Table 6 for individual transportation cost values.

Demand

The assumption is that, in a region with heterogeneous preferences with respect to GM and non-GM crops, soybean demand will be differentiated. In soybean oil, detection of GMOs depends on the degree of the oil's refinement. Still, some concerned food manufacturers, such as baby food and E.U. producers, have recently expressed their intention to voluntarily procure GM-free ingredients in order to avoid their customers' concerns, retain their market shares, and avoid biotech labeling requirements (Lin, Chambers, and Harwood 2000). In view of that evidence, soybean oil is also modeled as a differentiated product in the ROW. The current situation with soybean meal is one where countries have no legislation concerning GM animal feed, and biotech soybean meal is widely used by animal stock producers all over the world, including Japan, which represents the largest niche market for non-GM soybeans at present. However, feed labeling legislation is being drafted in the European Union and elsewhere and can be imposed in the near future. For now, demand for meal is not differentiated and is calibrated accordingly.

In order to solve for the five parameters of the differentiated demand system (either for soybeans or oil), we need to specify five relationships involving these parameters. As

TABLE 6. Transportation costs ($/mt)

k=0,1	m = B	m = O	m = M
$t^k_{m,RU}$	30	60	30
$t^k_{m,RA}$	40	70	40
$t^k_{m,RZ}$	40	70	40
$t^k_{m,UA}$	30	60	30
$t^k_{m,UZ}$	30	60	30
$t^k_{m,AZ}$	27	47	27

Notes: $t^k_{m,ij}$ denotes transportation cost between regions i and j for variety k of product m. B, O, and M stand for beans, oil, and meal; R, U, A, and Z stand for ROW, U.S., Argentina, and Brazil.

no mass segregation of RR and conventional soybeans has taken place in the 1998–99reference year, we can assume, as discussed earlier, that in that 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

$$\hat{Q} = a_1 + \frac{ca_0}{b_0} - \left(b_1 - \frac{c^2}{b_0} \right) \hat{p} . \tag{50}$$

Now, consider the case when p^0 falls from the choke level $\overline{p}^0$ so that $p^0 = p^1 = \hat{p}$. First, we can assume that the fraction of the total demand that is "indifferent" at these prices is $\hat{\sigma} \in (0,1)$, to obtain

$$\frac{a_1 - (b_1 - c)\hat{p}}{(a_0 + a_1) - (b_0 + b_1 - 2c)\hat{p}} = \hat{\sigma} . \tag{51}$$

Secondly, the total demand can be assumed to have increased because of this price reduction by a factor of $\hat{k}$ with respect to the total demand at prices $\overline{p}^0, \hat{p}$ in the reference year:

$$a_0 + a_1 - \left(b_0 + b_1 - 2c\right)\hat{p} = \hat{k}\hat{Q},\ \hat{k} \geq 1 . \tag{52}$$

Finally, we bring elasticity assumptions to bear. In the reference year, the observed own-price demand elasticity at price $\hat{p}$ is

$$\hat{\varepsilon}^{UU} = -\left(b_1 - \frac{c^2}{b_0} \right) \frac{\hat{p}}{\hat{Q}} . \tag{53}$$

Also, assume that the own-price conventional demand elasticity at $p^0 = p^1 = \hat{p}$ is $\hat{\varepsilon}^{00}$:

$$\hat{\varepsilon}^{00} = -b_0 \frac{\hat{p}}{a_0 - (b_0 - c)\hat{p}} . \tag{54}$$

The solution of the system (50)–(54) and the resulting restrictions on the parameters of the demand system are discussed further in Appendix B.

The parameters of undifferentiated demands are calibrated as follows:

$$a = \hat{Q}(1 - \hat{\varepsilon}^{UU}),\ b = -\hat{\varepsilon}^{UU} \frac{\hat{Q}}{\hat{p}}. \tag{55}$$

The following values of parameters were chosen for both beans and oil: $\hat{\sigma} = 0.5$, $\hat{k} = 1.05$, and $\hat{\varepsilon}^{00} = -4.5$ (see Appendix B for more explanations). In all regions and for all products, $\hat{\varepsilon}^{UU} = -0.4$ (Moschini, Lapan, and Sobolevsky 2000).

Supply

All supply function parameters, unless explicitly discussed in this section, are assigned their values according to the findings and assumptions of Moschini, Lapan, and Sobolevsky (2000), with Brazil and Argentina assigned the South American values. Calibrated parameters are obtained using specifications (20)–(25). In line with Moschini, Lapan, and Sobolevsky 2000, the unit seed cost $\delta\omega$ is set at {45, 40, 40, 40}.[7] The \$45/ha U.S. cost comes from Table 7. In Argentina, conventional soybean seeds sold for \$8–\$10/bag in 1998 (Table 8). In per-hectare terms, it is at most \$30 before taxes or \$36 after the 21 percent tax charged to farmers. On the other hand, Schneph, Dohlman, and Bolling (2001) provide a \$44/ha estimate for Argentina and a \$41/ha estimate for the Southern part of Brazil. Therefore, we set $\delta\omega$ = 40 in Argentina and Brazil and assume the same for the ROW. RR seed monopolist's markup is set to μ = {0.4, 0.2, 0.2. 0.2}. The 0.4 U.S. estimate is the result of the \$6 per bag technology fee charged by Monsanto (Table 7). In Argentina, Monsanto does not charge an explicit technology fee and is limited to collecting the value of the RR technology via agreements with Argentine seed companies (U.S. Government Accounting Office 2000). The situation is aggravated by the fact that a large share of seed is not purchased via commercial channels. From Table 9, one would conservatively assume that at least 50 percent of soybean seed planted in Argentina is not commercially purchased, implying that the average markup in Argentina is at best μ = 0.2. Intellectual property rights protection is unlikely to be better in Brazil or the ROW, and therefore we set μ = 0.2 in these two regions as well.

The cost savings due to RR technology parameter $\Delta\pi$ has been estimated at \$15/ha for the United States. As Table 7 illustrates, following the introduction of competitively priced RR weed control systems, the prices for competing herbicides, especially those used for conventional soybeans, have declined over the last two years in the United

TABLE 7. Estimated costs of soybean production in Iowa, 2000 ($/acre, conventional tillage, soybeans following corn, assuming 45 bu/acre yield)

		Conventional	RR[a]	RR[b]
Pre-harvest machinery		22.06	22.06	22.06
Seed[c]		18.00	18.00	18.00
Technology fee[d]		-	7.20	7.20
Herbicide		25.97	15.38	10.21
Fertilizer and other intermed. inputs		35.75	35.75	35.75
Interest		5.43	5.22	4.89
Harvest machinery		20.30	20.30	20.30
Labor		18.99	18.99	18.99
Land		120.00	120.00	120.00
Total		266.50	262.90	257.40
RR cost reduction	$/acre		3.60	9.10
	$/hectare		8.90	22.49

Source: Author's adaptation of Iowa State University Extension budgets (ISU Weed Science 2001 for herbicide costs; Duffy and Smith 2000 for the rest).

[a] Based on herbicide treatment consisting of 48 oz/acre of Roundup Ultra and 5 lbs/acre of ammonium sulphate.

[b] Based on herbicide treatment consisting of 32 oz/acre of Roundup Ultra and 3 lbs/acre of ammonium sulphate, with no adjustment for labor and preharvest machinery costs to reflect the savings of reduced treatment.

[c] $15.00 per 50-lb bag. Conventional tillage requires 1.2 bags/acre.

[d] $6.00 per 50-lb bag (average, due to various promotions/discounts).

TABLE 8. Soybean seed prices per 50-lb bag, before taxes, 1998

	Conventional Seeds	**RR Seeds**
United States	$13-17	$20-23[a]
Argentina	$8-10	$12-15

Source: U.S. Government Accounting Office 2000.

Notes: No taxes on seed purchases are levied in Illinois and Iowa; Argentine farmers' net tax burden is about 12%.

[a] Includes technology fee.

TABLE 9. Sources of soybean seeds, 1998

	Estimated Percentage of Total Soybean Acreage Planted	
Source of Seeds	**United States**	**Argentina**
Commercial sales	80-85	28-50
Farmer-saved	15-20	25-35
Black market sales	0-2	25-50

Source: U.S. Government Accounting Office 2000.

States. For 2000, it is estimated that the cost savings of using RR technology lies between \$8.90 and \$22.49 per hectare and therefore we conservatively set it at \$15. Because planting conditions and technologies in Brazil and Argentina are very close to those in the United States, as manifested by very similar soybean production yields, $\Delta\pi$ is expected to be the same in these regions if RR pricing conditions were the same. Given that the RR seed markup coefficient in Brazil and Argentina is one-half that in the United States, these two regions gain an additional \$8/ha ($\delta\omega$=40 times the markup differential 0.2) for the total $\Delta\pi$=23, based on $\Delta\pi = \alpha - \delta\omega\mu$ (assuming $\beta = 0$; see equation (22)). Because the ROW yield is only two-thirds of the yield in the other three regions, it is expected to gain proportionally at \$10/ha under U.S. pricing conditions. And, because the RR seed markup coefficient in the ROW is one-half that in the United States, the additional advantage of \$8/ha results in the $\Delta\pi$=18. To summarize, $\Delta\pi$ = {15, 23, 23, 18}, and the steps of its estimation are illustrated in Table 10.

The elasticity of land supply with respect to soybean prices ψ remains 0.8 in the United States and 0.6 in the ROW (Moschini, Lapan, and Sobolevsky 2000). The value of ψ=1.0 previously estimated for South America still applies to Brazil, but not to Argentina. Brazil has vast areas of undeveloped arable land in its Center-West and North regions that can serve and have served as engines of soybean production growth (Schneph, Dohlman, and Bolling 2001). In Argentina, much like in the United States, growth in soybean areas can be achieved only by substitution. Therefore, parameter ψ is set equally in the United States and Argentina and, overall, ψ = {0.8, 1.0, 0.8, 0.6}.

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.

TABLE 10. Estimation of parameter $\Delta\pi = \alpha - \delta\omega\mu$

	United States	**Brazil**	**Argentina**	**ROW**
$\Delta\pi$ subject to μ = {0.4, 0.4, 0.4, 0.4}	15	15	15	10
$\Delta\mu$ differential with the United States	0.0	-0.2	-0.2	-0.2
$\delta\omega$ seed cost	45	40	40	40
$\Delta\pi$ final estimate	15	23	23	18

Note: 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.

Segregation Costs

Lin, Chambers, and Harwood (2000) extend the segregation cost estimates available for specialty crops grown in the United States (Bender et al. 1999) 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 STS [sulfonylurea-tolerant soybeans] were used).[8] Bullock and Desquilbet (2002) provide an observable segregation cost estimate of \$11.00/mt based on the Japanese GMO-free soybean importer premiums and premiums to farmers shipping non-GM soybeans to elevators near the Illinois River. These estimates refer only to grain handlers' costs, covering country elevators, subterminals, and export elevators. Possible farm-level and additional handling and transportation costs beyond export elevators are not taken into account in these estimates, which is consistent with our definition of φ. To study the effects of segregation costs in the given range, the model is solved with the following alternative segregation costs set equally in all regions (in addition to $\varphi = \{0, 0, 0, 0\}$): $\varphi = \{6.6, 6.6, 6.6, 6.6\}$, $\{13.2, 13.2, 13.2, 13.2\}$, and $\{19.8, 19.8, 19.8, 19.8\}$. These cost levels will be often referred to as low, medium, and high.

Loan Deficiency Payments in the United States

In 1998–99, consumer and producer soybean prices were not the same in the United States. The actual price support activity in the U.S. soybean sector is presented in Table 11. While in the 1997–98 crop year only 10 percent of soybean production enjoyed price support, in 1998–99, support covered 90 percent of the crop, of which 78 percentage points received LDPs, and 0.5 percentage points were delivered to the CCC on the loan's

TABLE 11. Loan deficiency payments and price support loan activity, 1997–99

	LDP[b]			Loan Activity[b]			
Year[a]	Loan Rate\$/mt	Total Quantity	Total Payment	Quantity Under Loan	Repayment Quantity	Mkt Gain Quantity	Mkt Gain Amount
1997	193.25	0.00	0.0	7.20	7.02	1.44	15.8
1998	193.25	58.04	883.5	9.19	8.81	8.63	338.2
1999	193.25	63.09	2,106.6	7.78	4.29	4.26	110.7

Source: U.S. Department of Agriculture 2000b.

[a] Crop year: September–August.

[b] Quantities in million mt; payments/amounts in million dollars.

maturity, leaving 11.5 percentage points in marketing loan gains. This means that approximately 90 percent of the 1998 U.S. soybean crop was sold by farmers at the loan rate of \$193/mt and not at the average 1998–99 U.S. farm price of \$176/mt. A similar situation emerged in 1999, when U.S. soybean production reached 71.9 million mt and about 98 percent of it relied on government price support.

Therefore, assuming that all farmers make rational economic decisions, the average 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 it is assumed that $p_{LDP} = 193$ given that the average national loan rate in 2000 and 2001 remained at \$193.25.

Calibration Summary

The summary of all parameters and their values used for model calibration purposes and for solving the world soybean complex partial equilibrium defined by equations (34)–(47) is provided in Table 12. Some parameter values are borrowed from Moschini, Lapan, and Sobolevsky (2000), who estimate them for a simpler soybean complex model with no differentiated markets and no segregated supply lines. These parameter values are believed to apply in the current model because there was either no additional data found to challenge them or the additional data confirmed their validity. Other parameter values were amended as discussed earlier, and several new parameters were added.

Results

The model described by equations (34)–(47) was solved for several parameter values and policy scenarios. As stipulated by equation (47), only the ROW is assumed to have consumers with differentiated tastes for soybeans and soybean oil. Consumers in the United States, Argentina, and Brazil do not differentiate between conventional and RR soybean products and consume the variety that is cheaper in equilibrium.

Several scenarios are of interest in this setting. First, we study the implications of introducing the RR technology in the soybean complex that is free of any government intervention (Scenerio 1). Regional adoption rates, prices, production and consumption patterns, trade flows, and welfare associated with this equilibrium are discussed. Scenario 2 looks at how regions are affected if the United States were to pursue a domestic price support policy to help its farmers in the form of LDPs and market loans. This scenario is

TABLE 12. Model's parameters and their values

Parameter	Description	Values			
		U.S.	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	15.0	23.0	23.0	18.0
r	Producer rent share in average profit	0.4	0.4	0.4	0.4
μ	Innovator-monopolist 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	193.0			
φ	Segregation cost per mt	0.0 6.6 13.2 19.8	0.0 6.6 13.2 19.8	0.0 6.6 13.2 19.8	0.0 6.6 13.2 19.8

[a] See text for details.

important because the United States has a history of providing sizable price support to its soybean producers. Scenario 3 is the first in the series of government ban scenarios considered next. It simulates the situation in which the ROW introduces a ban on RR soybean production at home. The ROW region includes the European Union, Japan, and several other countries that have already adopted regulations prohibiting production of unapproved biotech crops that led to a de facto ban on all biotech production in the region. Scenario 4 looks at the same production ban but in Brazil. To date, Brazil has not adopted RR soybeans—despite their wide popularity in neighboring Argentina—and is seen as trying to differentiate itself from other soybean exporting nations by establishing itself as a GMO-free soybean region. The next two scenarios are variations on the same theme. Scenario 5 investigates the effects of simultaneous RR production bans in Brazil and the ROW, and Scenario 6 adds an import ban on sales of RR products in the ROW in addition to production bans. Finally, we discuss the separate question of the economic benefits of RR technology under alternative market structures. Changes in market structure are realized by changing the behavior of the innovator-monopolist that sells RR seed.

All aforementioned scenarios except for the last one are solved for four distinct levels of segregation costs in order to provide initial sensitivity assessment of results with respect to this variable. In addition, we obtain a solution for the full adoption scenario ($\rho_i = 1$, i = U, A, Z, R) that arises when no segregation technology is available yet, so that no soybeans can be guaranteed to be GMO-free and the differentiated demand for conventional product varieties is driven to zero by prohibitively high (“choke”) prices. The regional demand functions for this scenario are defined in (11) and (14), and supply functions satisfy (24). 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 (8) and (14), while supplies are described by (24). In each of these two special scenarios with only one soybean variety produced and consumed in equilibrium, the equilibrium trade and market conditions are still described by (34)–(47), with some of the equations collapsed into trivial identities.

Consumer and producer surplus and the innovator-monopolist profit are computed and reported in all regions. Specifically, 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 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 (Just, Hueth, and Schmitz 1982):

$$\Delta CS_{j,i} = -\int_{\hat{p}^1_{j,i}}^{\tilde{p}^1_{j,i}} Q^1_{j,i}(\hat{p}^0_{j,i}, p^1_{j,i})dp^1_{j,i} - \int_{\hat{p}^0_{j,i}}^{\tilde{p}^0_{j,i}} Q^0_{j,i}(p^0_{j,i}, \tilde{p}^1_{j,i})dp^0_{j,i}\,. \tag{56}$$

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

$$\Delta CS_{j,i} = \int_{\tilde{p}^1_{j,i}}^{\hat{p}^1_{j,i}} Q^U_{j,i}(p)dp\,. \tag{57}$$

Now, let $\hat{\bar{\pi}}_i$ be the pre-innovation equilibrium average unit profit that satisfies (23), and $\tilde{\bar{\pi}}_i$ be the differentiated market equilibrium average unit profit that satisfies (29). Then the change in producer surplus between pre-innovation and differentiated market scenarios is

$$\Delta PS_i = \int_{\hat{\bar{\pi}}_i}^{\tilde{\bar{\pi}}_i} L_i(v)dv \tag{58}$$

where L_i is the land allocation function (24). The innovator-monopolist's profit is computed simply as

$$\Pi^M = \sum_{i=U,S,R} \tilde{\rho}_i L_i(\tilde{\bar{\pi}}_i)\mu_i \delta w_i \tag{59}$$

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

$$\begin{aligned} \Delta W_U &= \sum_{j=B,O,M} \Delta CS_{j,U} + \Delta PS_U + \Pi^M \\ \Delta W_i &= \sum_{j=B,O,M} \Delta CS_{j,i} + \Delta PS_i \quad i = A, Z, R. \end{aligned} \tag{60}$$

One important result common to all scenarios will be discussed in the subsequent parts of this section. That is, 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 some instances when particular regions find themselves in autarky in a particular product variety. These exceptions will be noted explicitly. All results are shown in the tables in Appendix C.

Scenario 1: No Loan Deficiency Payments[9] in the United States

Absent any government intervention, the soybean complex is subject only to the market distortion that comes from the U.S.-based monopolist selling RR seed to all regions. We find a unique equilibrium solution for this scenario for each of the four selected levels of segregation costs. Equilibrium adoption rates, consumer, producer, monopolist, and total welfare changes, as well as production and trade flow results, are provided in Table C.1 of Appendix C. Equilibrium price and consumption data for soybeans and soybean oil of both varieties, as well as for soybean meal, are provided in Table C.2.

As the world moves to the full adoption of the cost-saving RR technology, U.S. soybean prices fall by 4 percent, oil by 7 percent, and meal by 1 percent, and prices in all other regions decline as well, as shown in the “no segregation technology” set of results in Table C.1. U.S. soybean supply falls because the region’s new technology cost savings are the smallest among the four regions, due to the 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 GMO-conscious consumers cut down on the consumption of inferior RR soybeans and soybean oil. Each region and the world in general benefit by moving to the complete adoption, with the worldwide efficiency gain estimated at $1.56 billion. This is 25 percent lower than the worldwide gain estimated using the Moschini, Lapan, and Sobolevsky (2000) soybean model with this paper’s parametric assumptions. The lower welfare gain is explained by the negative value RR soybeans generate consumers in the ROW who prefer the conventional variety. Consumers capture 39 percent of the welfare gain, while the innovator-monopolist captures another 53 percent. Farmers in the United States lose for the same reason the region’s supply decreases, while farmers in other regions gain. Note that consumers in the ROW gain despite the baseline assumption that 50 percent of them would prefer the conventional soybean and soy oil variety if it were sold at prices equal to prices of non-segregated (blend) products in the reference year. Clearly, this is a net effect of GMO-conscious consumers losing from prohibitively high prices for conventional products and GMO-indifferent consumers benefiting from lower prices.

Depriving the ROW consumers of exercising the choice to consume conventional products is clearly not the welfare-maximizing solution, as evidenced from the scenario with segregation costs set to $19.8/mt worldwide, or 11 percent of the price received by U.S. farmers growing conventional soybeans. However, the increase in welfare gain relative to the no-segregation scenario is only 1 percent. In other words, the costs of segregation “burn” most of the additional gain because of conventional product availability.

The high-segregation-cost equilibrium, likely the first to emerge at the early stages of introduction of the new segregation technology, is very similar to the no-segregation-technology one because the share of conventional soybeans is a mere 2 percent in worldwide production and 23 percent in total soybean demand in the ROW. The United States is the only region producing both varieties, while all other regions specialize in production of RR soybeans. The fact that the United States produces conventional soybeans rather than the ROW with its GMO-conscious consumers is explained by the relatively smaller cost savings in the United States associated with the RR technology that make U.S. farmers more easily attracted to growing non-GM soybeans. In equilibrium, the U.S. adoption rate for RR soybeans is 95 percent. Compared to the pre-innovation benchmark, RR prices fall; conventional producer prices fall, too, but conventional consumer prices increase because of segregation costs.

Now, we trace the changes in equilibrium prices, quantities, and welfare as segregation costs start to fall. The decline in these costs is shared between the conventional variety’s consumers and producers thanks to the fact that demands are not completely inelastic. As illustrated by medium- and low-segregation-cost scenarios in Table C.2, conventional consumer prices fall and conventional producer prices increase as segregation costs decline. This benefits ROW consumers and U.S. producers whose share of conventional soybean production increases to 30 percent 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 percent. As more production shifts toward conventional soybeans, the world’s RR supply decreases, causing RR prices to increase. Therefore, producer surplus improves in all four regions and consumer surplus in the United States, Brazil, and Argentina, where only RR products are consumed, falls.

In the zero-segregation-cost equilibrium, which is useful to analyze because it isolates the RR technology impacts from those caused by segregation costs, the share of the conventional soybean market reaches 17 percent. Brazil finds it profitable to grow conventional soybeans but allocates only 1 percent of total soybean land to them. The U.S. adoption rate is a low 62 percent 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 under the pressure of weakened RR import demand from the ROW. The high autarkic RR prices in the United States finally help U.S. farmers to benefit from the RR technology—the only simulated scenario when this happens. Conversely, the seed monopolist benefits the least in this scenario because of a large worldwide share of conventional soybean production and captures 38 percent of the total welfare gain. Notably, the monopolist's profit in general is positively correlated with the level of segregation costs, as higher costs lead to higher RR adoption rates in equilibrium. This sets the monopolist at odds with the interests of both conventional and RR soybean producers who benefit from higher prices in the lower-segregation-cost equilibria.

Scenario 2: Loan Deficiency Payments in the United States

Assume now that U.S. farmers receive LDPs of $193/mt both in the counterfactual market equilibria and the pre-innovation benchmark (supply equations (32) and (33) apply in this case). Results are shown in Tables C.3 and C.4 of Appendix C. The United States does not produce the conventional variety because LDPs equate farmer prices for conventional and RR soybeans and create a permanent incentive to specialize in the RR variety. Brazil emerges as the only producer and exporter of conventional products to the ROW in all three positive segregation cost cases, with the United States, Brazil, and Argentina exporting RR products. In the zero-segregation-cost scenario, Brazil allocates a high 49 percent of its soybean land to the conventional variety and does not export RR beans and oil. Argentina, too, dedicates 50 percent of its total production to conventional soybeans when segregation costs are zero. As in Scenario 1, the world in general and each region in particular benefit from the complete adoption of the RR technology. Similarly, the differentiated market equilibrium scenarios yield even higher overall gains, which means that the theoretically possible immiserizing growth, discussed earlier, does not take place.

Relative to the pre-innovation benchmark, U.S. farmers, unlike in Scenario 1, are guaranteed to benefit from the RR technology because the LDP price is binding and the gain stems from the cost-reducing nature of RR innovation. This price distortion, however, depresses the 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 percent of their production is in the higher-priced conventional market.

Beyond that, the LDP scenario offers the same welfare and price movement patterns as the no-LDP scenario when segregation costs start to decline. This decline causes conventional consumer prices to decline. Conventional producer prices increase, the RR market share declines, and this drives the RR prices up. The net effect on the ROW consumer surplus is positive, but consumers in other regions where only the cheaper RR products are purchased see their welfare gains lessened. Producer surplus in Argentina, Brazil, and the ROW improves with lower segregation costs but is unaffected in the United States where farmers receive a fixed LDP price.

The objective of the price subsidy in the United States is to help U.S. farmers. However, its overall effect on U.S. and world welfare can be negative. The results in Tables C.1 and C.3 can be subtracted from each other to show changes in welfare when LDPs are introduced in the soybean complex with differentiated tastes and potentially segregated markets. These welfare changes are presented in Table C.5.

The U.S. price support puts a downward pressure on prices worldwide and benefits consumers across the world. Obviously, it benefits U.S. farmers. Also, it benefits the innovator-monopolist by improving the worldwide adoption of the RR technology. However, it hurts Brazilian, Argentine, and ROW producers who see their competitive positions worsened. It also puts pressure on the U.S. government budget: the amount of the subsidy exceeds 30 percent of the world's gross welfare gain from introducing the RR technology in the marketplace. As a result, the LDP scenario is welfare reducing in the United States, despite the fact that the region's consumers and producers both benefit. Brazil and Argentina lose in this LDP scenario relative to the no-LDP one, but the ROW emerges as the only region that benefits from the introduction of LDPs at all levels of segregation costs. If not for the market power of the innovator-monopolist, LDPs would hurt the world's welfare for all levels of segregation costs. But in fact, LDPs are found globally welfare improving at the low ($6.6/mt) level of segregation costs. This is because monopoly pricing in the seed market results in a less-than-optimal adoption of efficient technology, whereas the output subsidy in the form of LDPs corrects this underadoption and puts the industry in the second-best equilibrium.

Scenario 3: Production Ban on Roundup Ready Products in the Rest of the World

In this and the next two sections, we provide estimates of how regional welfare and trade are affected by protectionist government policies that are already observed in the soybean world or that are being contemplated and may be implemented in the future. Scenario 3 looks at the measure that the European Union and several Asian countries that are part of the ROW region currently have in place—the ban on production of RR soybeans and products. Results in Table C.6 are provided both for the LDP and for no-LDP scenarios in the United States. They show that under the medium and high segregation costs, the ROW benefits from the ban.

The ban on RR production in the ROW results in the situation of complete regional specialization at positive levels of segregation costs. Because the ROW is restricted to produce only the conventional variety, which allows it to meet its domestic demand for conventional soybean products, the United States, Brazil, and Argentina specialize in the RR variety and export it to the ROW. No segregation technology is needed in this case; de facto segregation costs are zero in equilibrium and the level of segregation costs postulated by the technology does not affect the equilibrium solution.

In the zero-segregation-cost case, lower conventional prices generate more demand for conventional products than ROW farmers can handle, and the United States emerges as the second region producing conventional soybeans by allocating 4 percent of its land to it. At all levels of segregation costs, all agents benefit relative to the pre-innovation benchmark. However, if LDPs are introduced, ROW producers stand to lose relative to the pre-innovation benchmark because the region's conventional prices fall, whereas technology remains the same. The decrease in the conventional prices is observed for soybeans and soybean meal, and conventional soybean oil prices increase in comparison to the pre-innovation benchmark. This decrease in the conventional soybean price because of the introduction of RR technology was not observed in other scenarios. It is due to the particular nature of the ban, in which the region that consumes the conventional variety is allowed to specialize in its production at no additional segregation cost, while other regions provide cheap exports of the RR variety to some ROW consumers willing to buy it.

Comparison to unregulated production scenarios from Tables C.1 and C.3 is provided in Table C.7. It shows that RR production ban in the ROW appears to improve the ROW's welfare in the \$35–\$55 million range if segregation costs are medium to high. The welfare gain is driven by the positive change in consumer surplus thanks to the lower conventional product prices (driven down by zero segregation costs) under the ban. It more than offsets the corresponding negative change in producer surplus and happens only at sufficiently high levels of segregation costs that depress consumer surpluses in the unregulated equilibrium. The positive effect of the ban on the ROW holds in both the no-LDP and LDP scenarios. Whenever the ban benefits the ROW, it also benefits Brazil and Argentina but hurts the Unites States, reducing its welfare by \$80–\$90 million, primarily because of forgone innovator-monopolist profit.

Scenario 4: Production Ban on Roundup Ready Products in Brazil

To date, Brazil has not adopted RR soybeans because of the government's position on the GMO issue, which is essentially tantamount to a production ban. This can be explained by Brazil's interest in avoiding segregation costs in order to gain a competitive advantage selling conventional soybeans and soybean products to the ROW. Results for this ban scenario are summarized in Tables C.8 and C.9, where both the no-LDP and LDP scenarios are considered. It appears that the ban on RR production in Brazil does not benefit the region overall, although it benefits the country's farmers.

The ban on production of RR soybeans in Brazil results in the complete regional specialization in production at medium and high segregation costs, with the United States and Argentina producing only the RR variety and exporting it to the ROW, which also produces only RR beans. Under the low and zero segregation costs, the United States begins to produce both varieties, with conventional production being exclusively exported to the ROW.

As in the no-ban Scenario 1, introduction of RR technology results in higher conventional prices for consumers and lower RR prices. Because Brazil specializes in producing conventional beans, it does not incur segregation costs and therefore prices received by Brazilian farmers also increase relative to the pre-innovation benchmark. These higher prices benefit the region’s farmers but hurt its consumers, who in equilibrium consume the domestically grown and crushed conventional products despite having no differentiated tastes.

The same happens in the LDP scenario at positive segregation costs. When segregation costs are zero, Argentina joins Brazil in producing conventional soybeans, with the RR adoption rate at 52 percent. In this case, not only consumers but also producers show welfare losses relative to the pre-innovation benchmark as Brazil posts lower soybean and meal prices and higher oil prices.

Welfare changes between the ban and no-ban scenarios are provided in Table C.9. It is clear that whereas at all positive levels of segregation costs, 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 loss of welfare in the neighborhood of $100 million. This conclusion applies both to the no-LDP and LDP scenarios and to the zero-segregation-cost case in which both consumer and producer welfare decline because of the ban. These findings suggest that Brazil does not have economic reasons to continue not adopting RR technology, and if it does continue to bar RR soybeans, then the reasons are either political or related to a farmer lobby that benefits from the status quo.

Scenario 5: Production Bans on Roundup Ready Products in Brazil and the Rest of the World

What would happen if the ROW and Brazil banned RR production simultaneously? This logical extension of Scenarios 3 and 4 is summarized in Tables C.10 and C.11. Our results suggest that such simultaneous production bans are welfare reducing for both regions implementing them and for the world in general.

Both the no-LDP and LDP scenarios result in equilibria with full specialization in production and therefore segregation cost levels are irrelevant in determining equilibrium. Brazil and the ROW are forced to produce only conventional soybeans, with Brazil exporting to the ROW, and the United States and Argentina produce only RR soybeans and soybean products for domestic consumption and export to the ROW.

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 percent of the indifferent demand attributed to conventional soybeans and soybean oil at these prices in the no-LDP scenario. 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 is provided in Table C.11. The 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, only producers in Brazil and the ROW lose. All but the ROW consumers lose in all positive segregation cost scenarios, and Argentina emerges as the only region that benefits from the simultaneous RR production bans in Brazil and the ROW. Brazil loses approximately $260 million, while the ROW may lose between $80 and $170 million depending on the level of segregation costs.

Scenario 6: Production and Import Bans on Roundup Ready Products in the Rest of the World

Depending on the severity of GMO aversion in the European Union 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. For the soybean complex this would mean that the ROW will ban any RR imports in addition to RR production, which will have dramatic consequences for production patterns in exporting regions as some of them will have to scale back on their adoption of RR technology. The impact of the RR import ban in addition to the RR production ban in the ROW is estimated in Table C.12. Results for the scenario when, in addition to ROW bans, Brazil bans RR production are provided in Table C.13. The welfare changes between the ban and no-ban scenarios in both cases are shown in Table C.14. In all tables, the effects of the import ban are illustrated using the no-LDP scenario only.

First, we consider the case when Brazil does not ban RR production. Having no export destination for the RR soybeans and products, the Unites States, Argentina, and

Brazil each produce both varieties—RR for domestic consumption and conventional for export to the ROW. Depending on the level of segregation costs, the adoption rate for RR technology in the United States is 62–67 percent, in Brazil, 49–52 percent, and in Argentina, 28–30 percent. The common feature of lower RR and higher conventional prices relative to the pre-innovation benchmark explains consumer surplus increases in the Unites States, Brazil, and Argentina as RR technology is introduced. ROW consumers experience very large losses of up to $1.5 billion when segregation costs are high 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 in all but the high-segregation-cost scenarios.

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 due to consumption of more expensive conventional products and an increase in the producer surplus due to specialization. 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 at medium and high levels of segregation cost.

Economic Benefits of Roundup Ready Technology Under Alternative Market Structures

The fact that one of the players in the soybean complex is the innovator-monopolist producing RR seed raises a series of important questions about the role that the existing market power plays in determining equilibrium outcomes in differentiated markets. The new RR technology has been developed and patented in the United States by Monsanto, and the size of its spillover to world regions measured by their adoption rates ρ depends, both in the present model and in real life, on the level of monopoly rents extracted from farmers. Of course, the competitive provision of the new technology is the most beneficial. On the other hand, the present model relies on observed monopolistic behavior instead of solving for the optimal behavior endogenously, leaving open the question of whether observed behavior is optimal and whether optimal behavior is attainable.

To address these questions, we provide solutions to the soybean trade model described by equations (34)–(47) for the three levels of the monopolist's RR seed markup: $\mu=\{0, 0, 0, 0\}$, $\mu=\{0.4, 0.4, 0.4, 0.4\}$, and μ that maximizes the innovator-monopolist's profit . Note that the baseline solutions to the model are obtained assuming $\mu=\{0.4, 0.2, 0.2, 0.2\}$. Results of these simulations are provided in Table C.15 for the specific level of segregation cost ($13.2/mt) and two no-LDP scenarios: unregulated and the RR production ban in Brazil and the ROW simultaneously.

The $\mu=\{0, 0, 0, 0\}$ case represents the competitive provision of RR technology worldwide. As shown in Table C.15, the United States is the only region producing both soybean varieties, while other regions specialize in the RR variety, in line with the baseline equilibrium when $\mu=\{0.4, 0.2, 0.2, 0.2\}$ (Table C.1). However, the U.S. rate of adoption increases from 90 percent to 95 percent because RR soybeans become more attractive, and the U.S. welfare gain is $400 million smaller as it is being reallocated to other regions. Overall, the world welfare gain increases by only 1 percent. Adoption rates in the simultaneous Brazil/ROW RR production ban do not change, as the United States and Argentina already have 100 percent adoption rates.

If the innovator-monopolist were able to enforce IPRs equally in all parts of the world, the new technology could be sold at a markup $\mu=\{0.4, 0.4, 0.4, 0.4\}$ based on what Monsanto currently charges in the United States. In that case, the monopolist's profit would be $1.13 billion, which is $350 million higher than the baseline case. The welfare gains in other regions would be smaller, but the overall worldwide welfare loss relative to the baseline equilibrium would be only $2 million.

What is the optimal markup? Table C.15 shows it for the scenario when both Brazil and the ROW impose a production ban on RR soybeans, which is the closest representation of the current situation in the soybean complex. Here we assume that the markup remains at 20 percent in Argentina where the enforcement of IPRs by Monsanto had little success. When the segregation cost is $13.2/mt, the estimated optimal markup is $\mu=\{1.5, 0.0, 0.2, 0.0\}$, which proves to be especially taxing for consumers because of higher production costs that result in higher equilibrium prices worldwide. The high 150 percent markup arises in the United States because of the low conventional prices (they equal RR prices in this equilibrium with forced overproduction of the conventional variety and sizable consumption by indifferent consumers) that also have to be reduced by the amount of segregation cost when evaluating relative profitability of the two varieties at the farm level. If segregation costs were zero, the optimal markup would be $\mu=\{0.73, 0.0, 0.2, 0.0\}$, 33 percentage points higher than currently observed in the United States.

To summarize, the present model does not appear to be sensitive to small variations in the innovator-monopolist's seed price markup around the baseline assumption. At the same time, the baseline assumption of $\mu=\{0.4, 0.2, 0.2, 0.2\}$, which is based on the monopolist's currently observed behavior, is far from the optimal. Still, the optimal markup rates that are three to four times higher than the existing ones may be practically unattainable.

Sensitivity Analysis

The results discussed in the previous section are based on several parametric assumptions and a number of parameter estimates. Specifically, assumptions were made with respect to the three parameters that describe differentiated demands for soybeans and soybean oil in the ROW: the share of "indifferent" demand $\hat{\sigma}$, the coefficient of the total demand increase due to conventional and RR price equalization $\hat{k}$, and the own-price elasticity of conventional demand $\hat{\varepsilon}^{00}$. Among the estimated parameters, the ones with perhaps the least consensus in the research literature regarding their values are 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. Needless to say, all parameters, including the ones just mentioned, were researched in every detail, and their proposed values are believed to provide as close a representation of the world soybean market as exists today and as it most likely will look in the near future.

Nevertheless, the sensitivity analysis of key parameters is necessary to evaluate the robustness of conclusions that emerged from the model's results and to understand whether these conclusions are subject to change should the model's parameter values change. Two parameters were already indirectly subjected to the sensitivity analysis when the model was solved for four levels of segregation costs and when the effect of alternative market structures was studied by varying the innovator-monopolist's seed price markup. Therefore, no additional sensitivity analysis for parameters φ and μ will be offered here.

The six parameters and their base and suggested alternative values that form this section's analysis are summarized in Table 13. To keep the scope of the analysis manageable, we restrict the sensitivity discussion to the no-LDP scenario with the $13.2/mt segregation cost in each region. The tables in Appendix D provide equilibrium adoption and welfare results for the model's simulations under the new parameter values. Each table contains results for the "free trade" scenario (scenario in which regions do not implement any production or trade bans) and for all ban scenarios discussed earlier. Increases and decreases in each parameter value are implemented ceteris paribus (that is, holding all other parameters at their base values). In the tables, the model's results for the base values of parameters also are shown for ease of comparison. One ancillary outcome of the sensitivity analysis that we carried out was to demonstrate that the soybean complex can have multiple trade and market equilibria because of the nonconvexity introduced by the discontinuous constant segregation cost function. Finally, we discuss how different assumptions regarding the transportation costs between Argentina and Brazil may affect the equilibrium solution for Brazil's RR production ban scenario. Recall that in this equilibrium, Brazilian consumers purchase conventional soybean and soybean oil variety despite the fact that that they do

TABLE 13. 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	–
$\hat{\sigma}$	-4.5	Base value × ⅔	Base values × 1⅓
$\hat{k}$	1.05	Base value - 0.025	Base value + 0.025
$\hat{\varepsilon}^{00}$	0.5	Base value × ⅔	Base values × 1⅓

not have differentiated tastes. We show that it is possible that they choose to import RR products in equilibrium, although this probably would not be allowed as it violates the purpose of a production ban.

Model's Sensitivity to Non-Segregated Demand and Supply Parameters

The effects of halving and doubling the base values of elasticities of (total) demand for non-segregated soybeans, soybean oil, and soybean meal are presented in Appendix D, Table D.1. Setting $\hat{\varepsilon}^{UU}$=-0.2 for all soybean products in all regions does not change production or trade patterns in the free trade equilibrium, nor does it change the fact that all regions and the world in general benefit from the RR technology. However, compared to the base-values scenario, it changes the distribution of welfare gains between consumers and producers by increasing consumer benefits and reducing producer gains. While in the base-values scenario consumers worldwide received 38 percent of the total welfare gain, the halved elasticity would imply that they reaped 49 percent. Doubling $\hat{\varepsilon}^{UU}$ for all products in all regions has the opposite effect: consumers in that case benefit less than in the base-values scenario (33 percent of the total welfare gain) while producers benefit more. The innovator-monopolist's profit remains essentially insensitive to variations in $\hat{\varepsilon}^{UU}$.

Subjecting the ban scenarios (Scenarios 3 through 6) to the same changes in non-segregated demand elasticities does not change any conclusions regarding the direction of their impact on the four regions. As in the base-values scenario, the ROW still benefits from the production ban on RR products, enjoying no segregation costs and hence lower conventional prices. Brazilian farmers still benefit from the RR production ban at home, but overall, Brazil loses while the ROW gains again thanks to lower conventional prices relative to the free trade equilibrium. Simultaneous RR production bans in Brazil and the ROW, as well as additional import bans on RR products in the latter region, continue to hurt the welfare in regions that initiate them. The distribution of welfare between consumers and producers in these ban scenarios changes in the same manner as in the free trade case as demand elasticities are halved and doubled, but the overall region-level results appear robust.

Table D.2 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 $\hat{\varepsilon}^{UU}$. When ψ is doubled, consumers gain more relative to the pre-innovation benchmark than in the base-values scenario and producers gain less, and vice versa when ψ is halved. Innovator-monopolist's profit shows more sensitivity as supply elasticity changes but is still very robust, as its deviation is within 1 percent of the base value. Again, none of the qualitative results of the ban scenarios changes.

The model's results seem quite sensitive to the change in the yield increase parameter because of the RR technology β. As discussed in Moschini, Lapan, and Sobolevsky 2000, experimental evidence suggests that the RR soybean yields are somewhat lower than the yields of their conventional counterparts. However, these results could be impacted by farmers' economic decisions, or they could be temporarily caused by the fact that the RR technology is gradually working its way into better commercial varieties, and thus could be misleading. Also, the additive nature of the RR technology gives us reason to believe that RR soybeans should potentially outperform conventional varieties thanks to better weed management. Indeed, Monsanto has argued that the RR technology gives a 5 percent yield edge. In what follows, we assume a more moderate yield gain of β =0.02 (2 percent) and provide results in Table D.3.

A positive yield gain associated with the RR technology is equivalent to the outward supply shift relative to the base-values scenario. Therefore, it is not surprising that in the free trade equilibrium with β =0.02, all prices are lower, which leads to the reallocation of welfare gains between consumers and producers. In this equilibrium, the United States has an 88 percent adoption rate versus 90 percent in the base-values scenario, and all regions benefit from the RR technology. However, while both producers and consumers benefited at the world level from the new technology in the base-values scenario, producers at the world level lose and consumers gain when β =0.02. At the region level, Brazilian and U.S. farmers lose by adopting the RR technology.

This result also applies to all production and import ban scenarios, although overall, region-level results of the bans are robust to the increase in the yield parameter. For example, while the ROW still benefits from the home production ban on RR products thanks to large consumer benefits, ROW farmers find themselves not only worse off than before the ban but also worse off than before the RR technology was adopted.

To summarize, the sensitivity analysis with respect to the three non-segregated demand and supply parameters shows that the qualitative results and the general model's conclusions for the free trade and all ban scenarios discussed in the previous section are robust. What is subject to change is the distribution of welfare between producers and consumers. Also, the baseline argument—that in all regions but the United States producers gain when the RR technology is introduced—is sensitive to the value of yield parameter, and the higher value of this parameter may force other regions' producers to lose in equilibrium. What is most robust is the profit of the innovator-monopolist, which remains essentially unaffected by these parametric changes.

Model's Sensitivity to Differentiated Demand Parameters

Parameter $\hat{\sigma}$ measures the share of demand that is indifferent between the conventional and the RR varieties when the conventional variety's price is the same as the price for the RR (non-segregated) product in the reference year. This indifferent demand can be met by consuming either variety. The parameter is used in both the soybean and the soybean oil differentiated demand functions and is set to 0.5 (50 percent) for both products in the base-values scenario. In other words, at a particular price level, with prices of both varieties the same, 50 percent of consumers demand conventional variety and 50 percent are indifferent as to which one to consume.

This assumption appears to be quite reasonable when applied to the ROW and in particular to the European Union. A recent survey of 16,000 E.U. citizens (Eurobarometer 2001) found that 56.5 percent of those questioned believe that GMO-based food is dangerous, while the rest either do not believe so or do not have an opinion. For the purpose of the sensitivity analysis, we select alternative values of $\hat{\sigma}=0.333$ and $\hat{\sigma}=0.667$ (the same for soybeans and soybean oil) and report the results in Table D.4.

As can be seen from the formulas of differentiated demand coefficients provided in Appendix B, parameter $\hat{\sigma}$ affects slopes and intercepts of both the conventional and RR demands. This leads to changes in equilibrium prices and quantities in all scenarios including the pre-innovation benchmark simulation, which makes comparisons of RR-technology-induced welfare changes between the base-values and alternative-values scenarios significant. What is clear in this case, however, is that 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 by shrinking the size of the market for conventional products and depressing equilibrium conventional prices while increasing the RR prices.

Judging by the free trade results in Table D.4, the Unites States remains the only producer of both varieties under different values of $\hat{\sigma}$, with an adoption rate of 87 percent at low values and 93 percent at high values. Variation in $\hat{\sigma}$ mainly affects the welfare of the ROW consumers, causing only a small quantitative and no qualitative change in the benefits derived by other agents from the introduction of the RR technology. When $\hat{\sigma}$ is small, ROW consumers gain 85 percent less than in the base-values scenario, and when $\hat{\sigma}$ is high, they gain 120 percent more.

Whereas simulating the RR production ban in the ROW under low $\hat{\sigma}$ does not produce new outcomes, the results for the high $\hat{\sigma}=0.667$ suggest that the ROW does not benefit from the ban. The low share of GMO-conscious consumers in the region makes the ROW production capacity too large for the size of the conventional market. This depresses conventional prices to the point where they equal RR prices, and 81 percent of indifferent soybean and soybean oil demand at these prices is met by conventional varieties. Although this definitely benefits ROW consumers, it at the same time hurts domestic producers to the point where the ban is actually welfare reducing when compared to the free trade scenario.

The RR production ban in Brazil benefits the ROW consumers, too. In addition, as the results in previous section show, it benefited Brazilian producers who switched to producing the higher-priced conventional variety and benefited from it more than from producing less costly but lower-priced RR soybeans in the free trade equilibrium. However, when $\hat{\sigma}=0.667$, this trade-off stops working in their favor and Brazilian farmers lose under the production ban at home relative to the no-ban scenario.

Another situation where the size of the market for conventional products affects the baseline result of the model is the simultaneous RR production ban in Brazil and the

ROW. Under the base and the high values of $\hat{\sigma}$, the world produces more than GMO-conscious consumers demand in the ROW and therefore a portion of conventional products is used to meet undifferentiated demand in Brazil and indifferent demand in the ROW (where conventional and RR prices are equal in equilibrium). This does not happen when $\hat{\sigma}$=0.333 and the size of the market for conventional products is much larger. In this case, the ROW benefits from the ban when compared with the free trade scenario because of the combination of favorable conditions under the ban and unfavorable conditions under the free trade equilibrium with its high segregation costs. Brazil and the Unites States still lose and Argentina gains as in the base-values scenario.

Parameter $\hat{k}$ is set to 1.05 for both soybean and soybean oil demands in the base-values scenario, implying that the total demand for each product grows 5 percent as the price for the conventional variety falls from the prohibitively high reference year level to the RR price level in the same year. The sensitivity analysis reported in Table D.5 looks at two reasonable alternative levels of this parameter: $\hat{k}$ =1.025 and $\hat{k}$ =1.075. A lower $\hat{k}$ acts as the inward demand shift that lowers all prices (except for meal) in all equilibria, while a higher $\hat{k}$ acts as the outward demand shift that leads to the increase in soybean and soybean oil prices. The changes in the value of parameter $\hat{k}$ have some minor quantitative and no qualitative effects on the results of the model.

The own-price elasticity of conventional demand $\hat{\varepsilon}^{00}$, evaluated at the reference year RR price and the conventional price set to the same value, is assumed to equal -4.5 for both soybean and soybean oil demands in the baseline simulations of the model, to reflect the notion of close substitutability between the two varieties in the differentiated demand system. The two alternative values for this parameter are set to $\hat{\varepsilon}^{00}$=-3.0 and $\hat{\varepsilon}^{00}$=-6.0 (for both soybean and soybean oil demands simultaneously). The model's sensitivity results with respect to these values are provided in Table D.6.

Given that the total soybean and soybean oil demands are inelastic, making conventional demands less own-price elastic translates into lower cross-price elasticity. This means less flexibility in the demand system to shift from consuming the conventional variety to the RR variety. The opposite is true when the own-price elasticity is increased (in absolute value). As a result, the low-elasticity equilibrium is characterized by the relatively high share of the market for conventional products (13 percent in the free trade case), whereas in the high-elasticity equilibrium this share is lower than in the base-values scenario (2 percent versus 4 percent in the free trade case). Not surprisingly, the welfare results of these simulations are very close to those of the low and high values of the share parameter $\hat{\sigma}$.

In the free trade equilibrium, the adoption rate in the United States, the only region producing both soybean varieties, is 71 percent when $\hat{\varepsilon}^{00}$=-3.0 compared to the 90 percent rate in the base-values scenario and the 95 percent rate when $\hat{\varepsilon}^{00}$=-6.0. Similar to what we have already seen in the sensitivity analysis for $\hat{\sigma}$, the gains to the ROW consumers vary greatly depending on the value of $\hat{\varepsilon}^{00}$ but remain positive. Also, when the ROW bans RR production, it suffers a welfare loss when $\hat{\varepsilon}^{00}$=-6.0 for the same reasons as in the $\hat{\sigma}$=0.667 case, albeit prices for the conventional variety now are not as low as their RR counterparts but are low enough. Finally, the ROW benefits from the simultaneous RR production bans at home and in Brazil when $\hat{\varepsilon}^{00}$=-3.0 much alike, as in the $\hat{\sigma}$=0.333 discussion. The innovator-monopolist profit remains robust in all ban scenarios but is affected by the low adoption rate in the free trade scenario with low elasticity.

In summary, differentiated demand parameters $\hat{\sigma}$ and $\hat{\varepsilon}^{00}$ appear to be much more crucial in determining the direction of results of several ban scenarios introduced in the results section. While the sensitivity analysis confirms that all regions and the world in general benefit from the introduction of the RR technology at medium segregation costs, the size of the benefit, especially for the ROW consumers, and the level of adoption of the RR technology in the free trade scenario are the increasing functions of the (absolute) value of either parameter. The conclusion that the ROW benefits from a home production ban on RR products is positively related to the equilibrium share of the market for conventional soybean products, which in turn is negatively related to the size of $\hat{\sigma}$ and $\hat{\varepsilon}^{00}$, and the same can be said about the benefit of Brazil's RR production ban for its farmers. Also, the ROW may gain from a simultaneous RR production ban at home and in Brazil when at least one of the parameters is low. Which of the results is more likely to hold clearly can be the subject of speculation in the present environment because differentiated markets for soybean products are in their infancy, but some thoughts on this question will be offered in the conclusions.

Possible Multiple Equilibria and the Effect of Low Brazil-Argentina Transportation Costs

Two additional results that have surfaced in the results discussions are subject to change under alternative parametric assumptions. The first one is the uniqueness of the market and trade equilibrium described by equations (34)–(46). The segregation cost function described by equation (26) creates a nonconvexity in the production space because of the discontinuity at the point where the region switches between producing no RR soybeans and producing some. Specifically, the segregation cost is assumed to be zero when only conventional soybeans are produced and a positive constant when at least some RR soybean production takes place. Therefore, the uniqueness of equilibrium cannot be guaranteed. Although neither the baseline nor the sensitivity simulations of the model's scenarios result in more than one equilibrium, taking some parameters to extreme values leads to a multi-equilibrium example. This example appears in Table D.7.

The two equilibria exist when a no-LDP scenario with the $13.2/mt segregation cost is run with unusually low own-price conventional demand elasticity $\hat{\varepsilon}^{00}$=-1.0. The free trade Equilibrium #1 scenario in Table D.7 is characterized by the 61 percent rate of adoption of RR technology in the United States and 73 percent in Brazil, with Argentina and the ROW specializing in RR production. This equilibrium holds no matter whether the discontinuity in the constant $13.2/mt segregation cost is allowed or it is assumed that the $13.2/mt cost applies when a region specializes in conventional soybean production. Equilibrium #2 is possible only in the former case (the case of this paper). In it, the ROW takes advantage of the zero segregation cost in the no-adoption case, enjoys a welfare gain over the pre-innovation benchmark, and contributes to a higher worldwide welfare gain relative to Equilibrium #1. Equilibrium #2 represents a voluntary welfare-enhancing ban on RR production in the ROW. It suggests, at least theoretically, that it is possible that a region's government that pursues protectionist policy can improve its own and the world's welfare by sending the markets on the welfare-enhancing equilibrium path. It must be reiterated, however, that it does not happen in this model within the reasonable range of parameter values.

The second result concerns Scenario 4—the RR production ban in Brazil. The unique equilibrium solution for this scenario (see Table C.8) suggests that Brazilian consumers demand conventional soybeans and soybean oil despite the fact that they do not have differentiated tastes. This is the result of quite high transportation costs between Brazil and Argentina that are assumed to be two-thirds of the transportation cost from either region to the ROW (Table 6). Because at present large-scale shipments of soybeans and soybean products do not take place between Brazil and Argentina, it is difficult to say whether these cost estimates are high or low. If they were assumed to be one-fourth of the transportation costs between South America and the ROW, the equilibrium results would be as shown in Table D.8.

Table D.8 provides price, production, consumption, and welfare results in this equilibrium. In the case of low Brazil-Argentina transportation costs and Brazil's ban on RR production, Brazil would consume conventional soybeans but would import the RR variety from Argentina to meet its soybean oil and meal demands, which will not benefit Brazil relative to the high-transportation cost case but will benefit the ROW. The problem with this equilibrium lies in the assumption that Brazil runs a zero segregation cost even though RR products enter the region, which is unreasonable. In order for the government of Brazil to maintain competitive advantage in the conventional soy markets by means of the RR production ban and zero segregation cost, it probably should run a concurrent consumption (or import) ban on RR products. In the present model, such a consumption ban is implicitly imposed by means of (prohibitively) high transportation costs.

Conclusion

In this paper, we have developed a new partial equilibrium, four-region world trade model for the soybean complex comprising soybeans, soybean oil, and soybean meal in order to study some of the economic questions arising from the large-scale adoption of GM soybeans. The distinctive feature of the model is that consumers in one of the four regions—the ROW—view genetically modified RR soybeans, and products derived from them, as weakly inferior to their conventional counterparts. The model provides a close representation of the world soybean market as it exists today and as it will most likely evolve in the near future. Specifically, the model explicitly accounts for the fact that the

RR seed is patented and sold worldwide by a U.S. firm at a premium, and that producers have to employ a costly segregation technology in order to separate conventional and biotech products in the supply chain. Differentiated preferences were introduced into the model in a consistent fashion that permits standard welfare calculations. Finally, the model is disaggregated just enough to capture individual behavior of the industry's main players and analyze the impact of their policies toward GMOs. The calibrated model was solved for equilibrium prices, quantities, production patterns, trade flows, and welfare changes under different assumptions regarding market structure, differentiated consumer tastes, regional governments' production and trade policies, and several other supply and demand characteristics. Finally, the restrictions on the particular parameter values used at the calibration stage were evaluated through an extensive sensitivity analysis.

Our analysis offers a comprehensive view of the evolution of agricultural biotechnology in the soybean complex and begins with the pre-innovation benchmark—the state of the world in which the RR technology is not yet available. We show 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.

Moving on to the case where segregation technology is available at a positive cost, our analysis shows that, 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 latter's price and increase the price received by farmers who grow the conventional variety. However, lower segregation costs are associated with more land allocated to growing conventional soybeans, which hurts the profits received by the innovator-monopolist. This result is an unwelcome feature for the soybean industry because it 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 GMO-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.

The main lesson that is learned from considering what happens when the ROW and Brazil impose production bans on RR products is that the ROW has a clear potential to benefit from such a ban relative to the no-ban scenario, while in Brazil only farmers can take advantage of such regulation. In fact, our results suggest that the ROW should benefit from the ban if segregation costs were medium to high, while Brazilian farmers should see welfare gains at all positive levels of segregation costs. These results, however, prove to be sensitive to the underlying assumptions about the relative share of the conventional soybean market in the ROW, which is affected directly by the share parameter in the reference year and indirectly by the own-price conventional demand elasticity parameter for soybeans and soybean oil. The higher the size of the conventional market and/or the lower the elasticity of conventional demands, the more likely the observed gains will hold. 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. 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-GMO regulation. Which situation is more likely to emerge in reality may be subject to speculation, although the reversal of this paper's results requires parameter changes in an unlikely direction of a lower share of GMO-conscious consumers and/or a higher demand elasticity.

The last important result of this paper is the robust welfare losses to all regions as the result of the introduction of an import ban on RR products in the ROW. Overall, all conclusions of the model, except for those mentioned above, prove to be robust to variations in critical parameter values. As such, they provide a range of important insights into the channels through which benefits of the current RR technology for the soybean industry are derived and explain the possible implications of existing and pending policies pursued by the main players in the world soybean complex.

Endnotes

1. A recent survey of a representative sample of 16,000 citizens of the European Union overwhelmingly confirms the existence of a potentially sizeable customer base with differentiated preferences (Eurobarometer 2001). Fifty-five percent of those polled disagree that GM food is not dangerous and 59 percent believe that it can negatively impact the environment. Also, 95 percent of the respondents want to have the right to choose between biotech and nonbiotech products, which is exactly what the differentiated markets will offer.

2. For the purpose of this paper, the Brazil region includes the countries of Brazil and Paraguay, while the Argentina region includes all other countries of South America. This ensures that the Brazil and Argentina regions cover all of South America.

3. 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.

4. Analysis in this section applies to any region. The subscript denoting a region is omitted here and elsewhere in this section for notational simplicity.

5. Producers overseas will be hurt by lower world prices but will gain from the technology spillover, so that the net effect on them is ambiguous.

6. See the section on calibration and Table 6 for more information on price differentials.

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

8. This does not contradict some earlier estimates produced by European studies, where elevator premiums necessary to cover IP costs for value-added GM soybeans are estimated for the United States at $1.80–$3.70/mt, crusher premiums are expected in the same range, and refiner-level premiums are at $4.40–$8.80/mt.

9. Here and elsewhere in the text, the term “LDPs” is used to refer to both loan deficiency payments and market loans received by U.S. farmers.

Appendix A: Demand

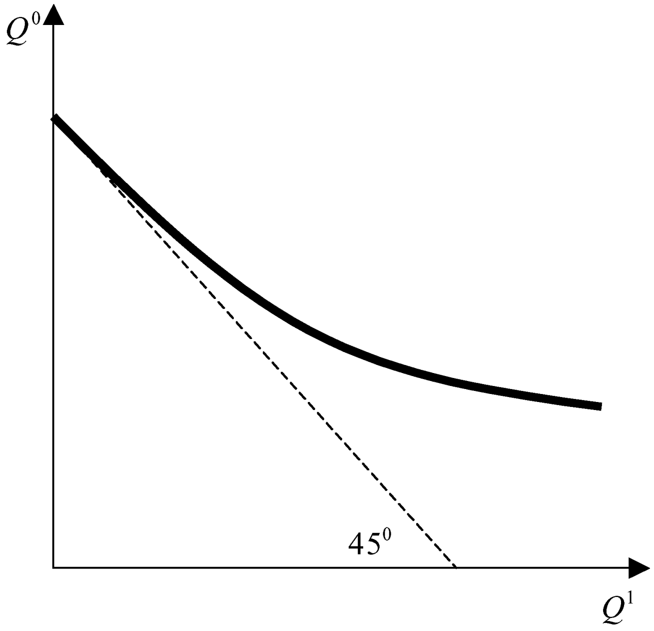

FIGURE A.1. Good Q^1 is weakly inferior and $Q^1 = 0$ at $p^1 = p^0$

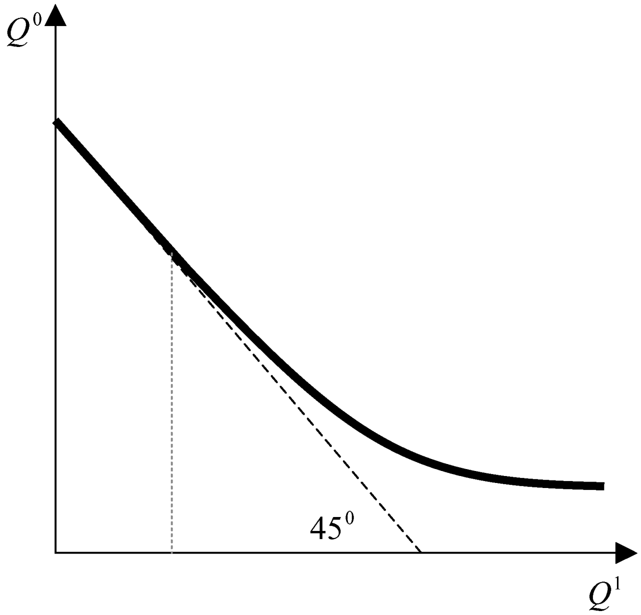

FIGURE A.2. Good Q^1 is weakly inferior and $Q^1 > 0$ at $p^1 = p^0$

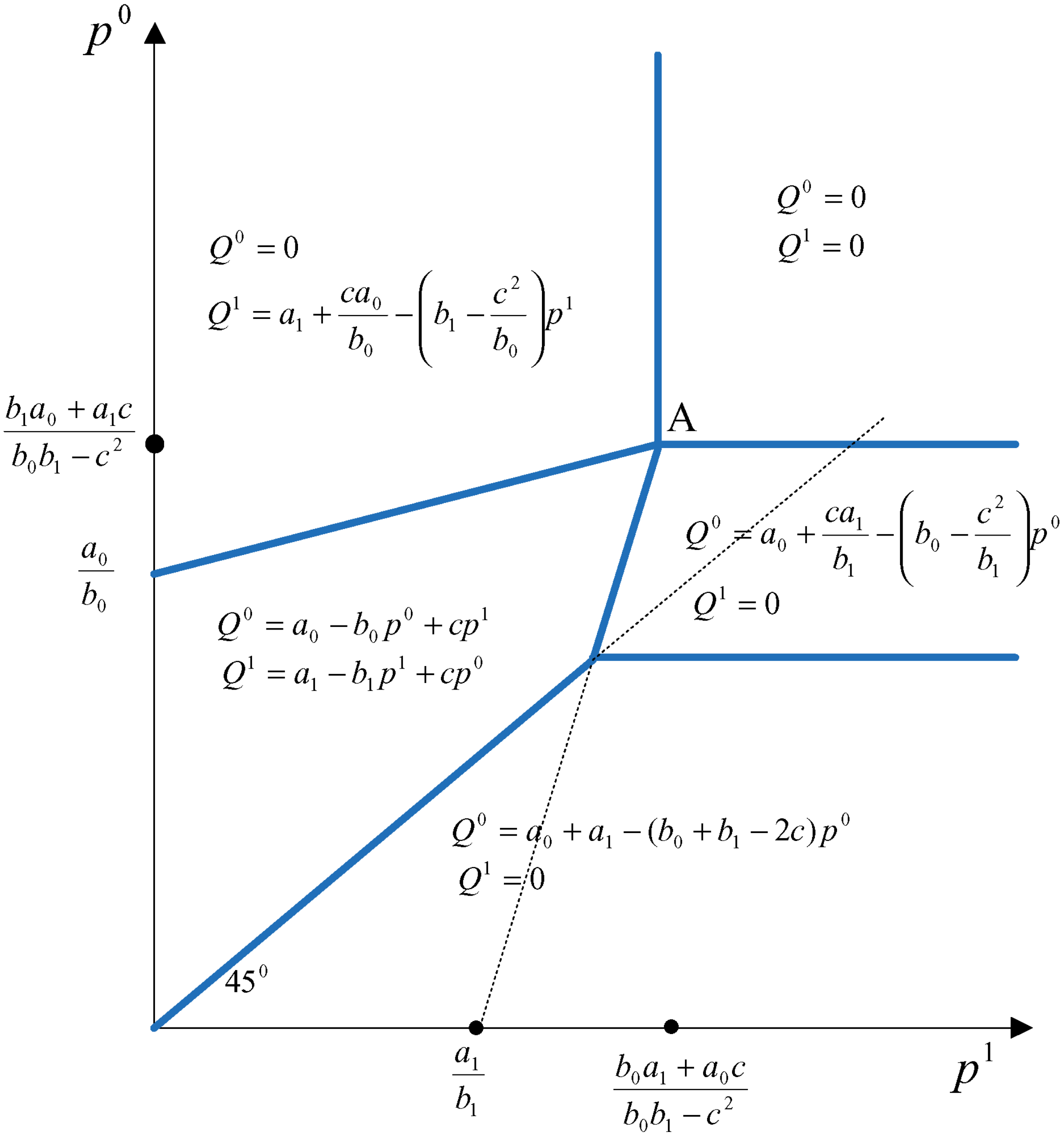

FIGURE A.3. Differentiated demand system where point A satisfies $\frac{b_1 - c}{a_1} > \frac{b_0 - c}{a_0}$

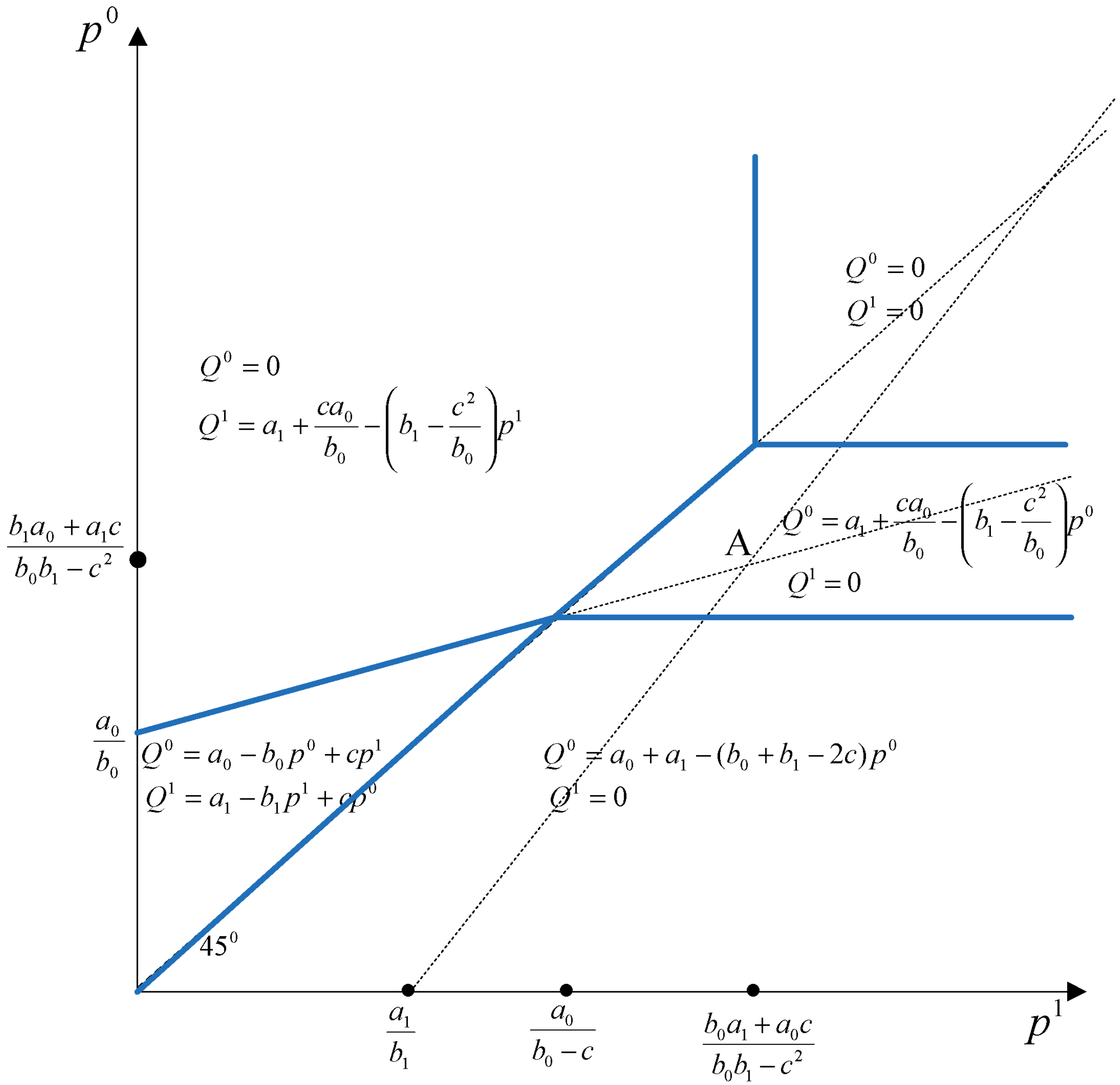

FIGURE A.4. Differentiated demand system where point A satisfies $\frac{b_1 - c}{a_1} < \frac{b_0 - c}{a_0}$

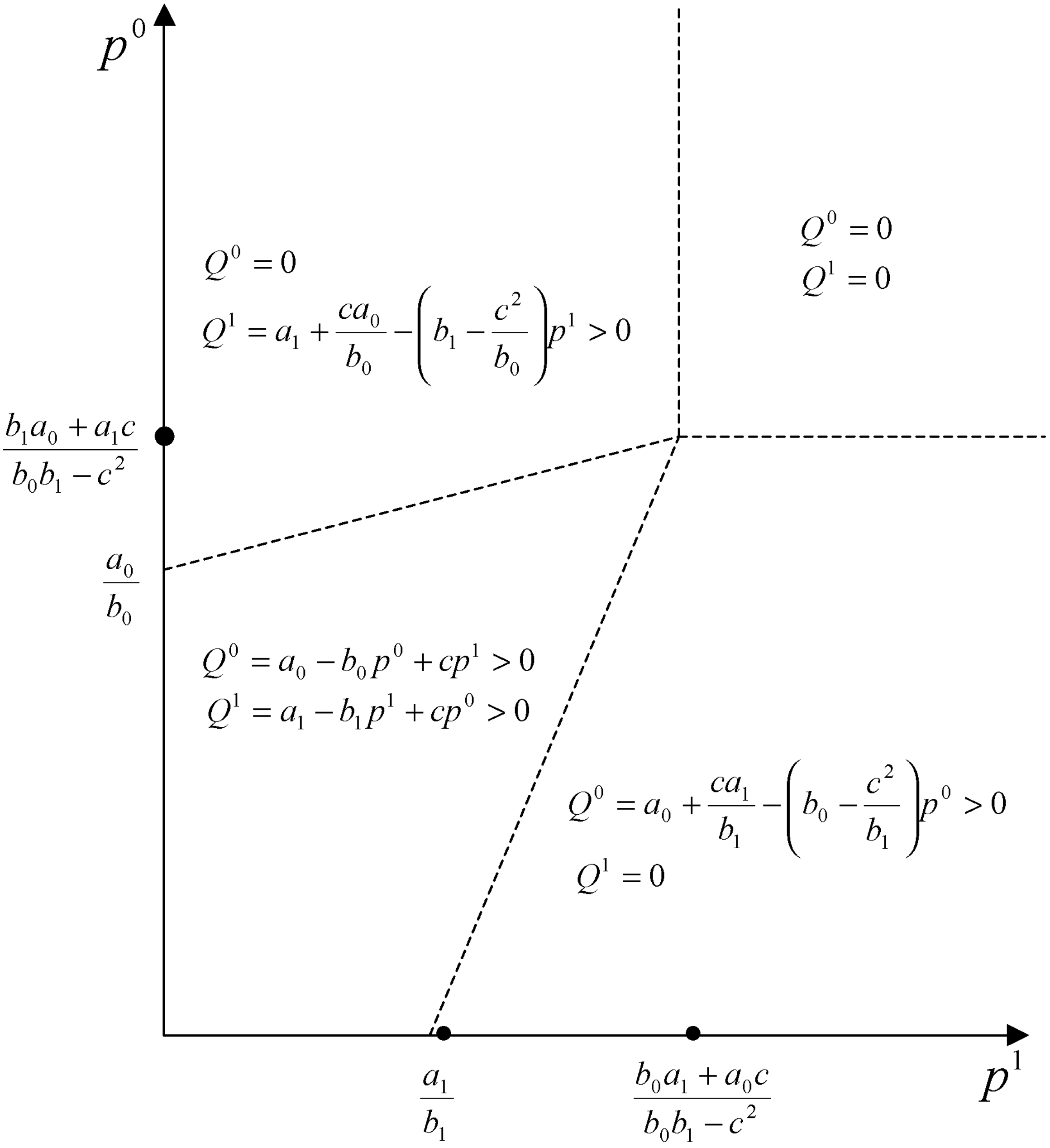

FIGURE A.5. A general two-good linear demand system

Appendix B: Demand Calibration

Solving the system of equations (50)–(54) yields the following calibrated demand parameters:

$$a_0 = \hat{Q}\left[\hat{k}(1-\hat{\sigma}) + \hat{\varepsilon}^{00}(1-\hat{k})\right] \tag{B.1}$$

$$a_1 = \hat{Q}\left[\hat{k}\hat{\sigma} - \hat{\varepsilon}^{UU} - \frac{(1-\hat{k}\hat{\sigma})(1-\hat{k})}{(1-\hat{\sigma})\hat{k}}\hat{\varepsilon}^{00}\right] \tag{B.2}$$

$$b_0 = -\frac{\hat{\varepsilon}^{00}\hat{k}\hat{Q}(1-\hat{\sigma})}{\hat{p}} \tag{B.3}$$

$$b_1 = \frac{\hat{Q}}{\hat{p}}\left[-\frac{(1-\hat{k}\hat{\sigma})^2\hat{\varepsilon}^{00}}{\hat{k}(1-\hat{\sigma})} - \hat{\varepsilon}^{UU}\right] \tag{B.4}$$

$$c = -\frac{(1-\hat{k}\hat{\sigma})\hat{\varepsilon}^{00}\hat{Q}}{\hat{p}} \tag{B.5}$$

The requirements that all parameters are strictly positive, and that $b_0 > c$ and $b_1 > c$ to satisfy curvature conditions, translate into the following restrictions on parameters $\hat{k}, \hat{\sigma}, \hat{\varepsilon}^{UU}, \hat{\varepsilon}^{00}$:

$$\hat{k} > 1;\ \hat{\sigma} < 1;\ \hat{k}\hat{\sigma} < 1;\ \hat{\varepsilon}^{00} > \frac{(1-\hat{\sigma})\hat{k}}{(1-\hat{k}\hat{\sigma})(\hat{k}-1)}\hat{\varepsilon}^{UU}. \tag{B.6}$$

Given that we estimate that $\hat{\varepsilon}_{j,i}^{UU} = -0.4$ in all regions *i* and for all products *j* and assume that $\hat{k}_{j,i} = 1.05$ and $\hat{\sigma}_{j,i} = 0.5$ in differentiated markets for soybeans and soybean oil (*j* = B, O), $\hat{\varepsilon}_{j,i}^{00}$ must satisfy $-8.842 < \hat{\varepsilon}_{j,i}^{00} < 0$. Therefore, for the model that produced results shown in Tables C.1–C.15 in Appendix C, we choose the value for $\hat{\varepsilon}_{j,i}^{00}$ approximately in the middle of the interval (B.7), that is at -4.5.

It may be instructive to see how this assumption affects the elasticity of scale ε^T for beans and oil in differentiated markets. Evaluated at $p^0 = p^1 = \hat{p}$, it equals

$$\hat{\varepsilon}^T \equiv \varepsilon^T\Big|_{p^0=p^1=\hat{p}} = \frac{1}{\hat{k}}\left[\hat{\varepsilon}^{UU} + \hat{\varepsilon}^{00}\frac{(\hat{k}-1)^2}{(1-\hat{\sigma})\hat{k}}\right] \xrightarrow[\hat{k}\to 1]{} \hat{\varepsilon}^{UU}\,. \tag{B.8}$$

When $\hat{\varepsilon}^{00} = -4.5$ and other parameters are as set above, $\hat{\varepsilon}^{T} = -0.4014$. This exercise demonstrates that our differentiated demand system—the way it is calibrated here and in the neighborhood of the reference year's prices and quantities—permits sufficiently elastic individual differentiated demands while the total demand remains inelastic with respect to uniform changes in both varieties' prices, similar to current behavior of undifferentiated demands for commodity soybeans and oil.

Appendix C. Results

TABLE C.1. Economic impact of Roundup Ready technology (no-LDP scenario): changes from pre-innovation equilibrium, production, and exports (mil U.S.$; mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Soybean Supply		Export (Equiv.)[a]		Export Meal[b]
						Conv.	RR	Conv.	RR	
Pre-innovation										
US	0.00					70.1	.	26.9	.	2.3
BR	0.00					35.6	.	18.8	.	5.1
AR	0.00					21.1	.	15.3	.	0.9
ROW	0.00					32.3	.	-60.9	.	-8.3
No segregation technology										
US	1.00	323	-117	830.8	1036.5	.	69.3	.	24.8	3.2
BR	1.00	120	72	.	191.7	.	35.9	.	18.6	5.5
AR	1.00	43	47	.	89.3	.	21.2	.	15.2	1.0
ROW	1.00	125	121	.	246.6	.	32.6	.	-58.6	-9.7
World		611	123	830.8	1564.1					
Segregation cost: $19.8/mt										
US	0.95	310	-95	806.8	1021.2	3.7	65.8	3.7	21.3	3.2
BR	1.00	116	83	.	199.0	0.0	35.9	0.0	18.6	5.5
AR	1.00	41	53	.	94.4	0.0	21.3	0.0	15.3	1.0
ROW	1.00	131	132	.	262.8	0.0	32.6	-3.7	-55.2	-9.7
World		597	173	806.8	1577.3					
Segregation cost: $13.2/mt										
US	0.90	301	-83	784.4	1002.9	7.0	62.5	7.0	18.1	3.1
BR	1.00	112	90	.	201.7	0.0	36.0	0.0	18.7	5.5
AR	1.00	40	57	.	96.9	0.0	21.3	0.0	15.3	1.0
ROW	1.00	145	138	.	282.7	0.0	32.6	-7.0	-52.0	-9.7
World		598	201	784.4	1584.2					
Segregation cost: $6.6/mt										
US	0.70	275	-46	690.3	919.1	20.9	48.8	20.9	4.6	2.9
BR	1.00	97	109	.	206.0	0.0	36.1	0.0	18.9	5.4
AR	1.00	36	69	.	104.0	0.0	21.3	0.0	15.4	1.0
ROW	1.00	198	155	.	353.1	0.0	32.7	-20.9	-38.9	-9.2
World		606	286	690.3	1582.2					
Zero segregation cost										
US	0.62	169	120	651.1	939.8	27.0	43.6	27.0	0.0	2.3
BR	0.99	116	61	.	176.7	0.3	35.5	0.3	18.3	5.4
AR	1.00	43	40	.	82.8	0.0	21.2	0.0	15.2	1.0
ROW	1.00	399	111	.	510.9	0.0	32.5	-27.3	-33.5	-8.7
World		727	332	651.1	1710.2					

[a] Exports of beans, oil, and meal measured in bean equivalent required to support them. This representation is due to the model's inability to distinguish individual trade flows (see eq. (48)).

[b] Meal exports, additional to those imbedded in previous two columns. This separate figure arises from the fact that domestic crush to meet domestic oil demand usually produces excess domestic supply of meal (see eq. (49)).

TABLE C.2. Equilibrium consumption and prices (No-LDP scenario) (mil mt; $/mt)

		Bean Price		Oil Price		Meal	Bean Demand		Oil Demand		Meal
Region	**ρ**	**Conv.**	**RR**	**Conv.**	**RR**	**Price**	**Conv.**	**RR**	**Conv.**	**RR**	**Demand**
Pre-innovation											
US	0.00	181.9		480.2		143.6	5.4		6.8		27.9
BR	0.00	171.9		470.2		133.6	1.5		2.8		7.0
AR	0.00	171.9		470.2		133.6	0.8		0.9		3.0
ROW	0.00	211.9		540.2		173.6	16.3		13.9		69.8
No segregation technology											
US	1.00		174.5		444.8	142.3		5.5		7.1	28.0
BR	1.00		164.5		434.8	132.3		1.6		2.8	7.1
AR	1.00		164.5		434.8	132.3		0.9		0.9	3.1
ROW	1.00		204.5		504.8	172.3		15.7		13.6	70.0
Segregation cost: $19.8/mt											
US	0.95	200.4	174.8	586.7	445.5	142.5	0.0	5.5	0.0	7.1	28.0
BR	1.00		164.8		435.5	132.5	0.0	1.6	0.0	2.8	7.1
AR	1.00		164.8		435.5	132.5	0.0	0.9	0.0	0.9	3.1
ROW	1.00	230.4	204.8	616.4	505.5	172.5	3.7	12.4	0.0	13.6	69.9
Segregation cost: $13.2/mt											
US	0.90	194.0	175.0	551.7	447.0	142.4	0.0	5.5	0.0	7.1	28.0
BR	1.00		165.0		437.0	132.4	0.0	1.6	0.0	2.8	7.1
AR	1.00		165.0		437.0	132.4	0.0	0.9	0.0	0.9	3.1
ROW	1.00	224.0	205.0	611.7	507.0	172.4	4.8	11.3	0.4	13.3	69.9
Segregation cost: $6.6/mt											
US	0.70	187.9	175.5	522.8	454.5	141.4	0.0	5.5	0.0	7.0	28.1
BR	1.00		165.5		444.5	131.4	0.0	1.6	0.0	2.8	7.1
AR	1.00		165.5		444.5	131.4	0.0	0.9	0.0	0.9	3.1
ROW	1.00	217.9	205.5	582.8	514.5	171.4	6.0	10.2	2.7	11.1	70.1
Zero segregation cost											
US	0.62	183.6	177.9	502.9	471.1	140.5	0.0	5.4	0.0	6.9	28.2
BR	0.99	173.6	164.2	492.9	440.7	130.5	0.0	1.6	0.0	2.8	7.1
AR	1.00		164.2		440.7	130.5	0.0	0.9	0.0	0.9	3.1
ROW	1.00	213.6	204.2	562.9	510.7	170.5	6.6	9.8	3.8	10.2	70.2

Note: Prices are consumer prices; the price received by producers of conventional soybeans is lower by the amount of segregation cost.

TABLE C.3. Economic impact of Roundup Ready technology (LDP scenario): changes from pre-innovation equilibrium, production and exports (mil U.S.$; mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ in Subsidy	Δ W Total	Bean Supply		Export (Equiv.)[a]		Export Meal[b]
							Conv.	RR	Conv.	RR	
Pre-innovation[c]											
US	0.00						74.0	.	30.3	.	2.3
BR	0.00						34.4	.	17.5	.	5.2
AR	0.00						20.5	.	14.6	.	0.9
ROW	0.00						31.8	.	-62.3	.	-8.4
No Segregation technology											
US	1.00	478	429	859.4	859.8	906.6	.	75.7	.	30.3	3.2
BR	1.00	169	-51	.	.	117.2	.	34.0	.	16.4	5.6
AR	1.00	62	-27	.	.	35.2	.	20.3	.	14.2	1.0
ROW	1.00	472	7	.	.	479.4	.	31.7	.	-60.9	-9.9
World		1181	358	859.4	859.8	1538.3					
Segregation cost = $19.8/mt											
US	1.00	461	429	849.7	829.8	909.8	0.0	75.7	0.0	30.4	3.2
BR	0.91	163	-38	.	.	125.4	3.1	31.0	3.1	13.3	5.6
AR	1.00	60	-19	.	.	41.1	0.0	20.3	0.0	14.2	1.0
ROW	1.00	460	20	.	.	479.7	0.0	31.8	-3.1	-57.9	-9.9
World		1144	392	849.7	829.8	1556.0					
Segregation cost = $13.2/mt											
US	1.00	455	429	846.0	818.5	911.1	0.0	75.7	0.0	30.4	3.2
BR	0.87	161	-33	.	.	128.5	4.3	29.8	4.3	12.2	5.6
AR	1.00	59	-16	.	.	43.3	0.0	20.3	0.0	14.2	1.0
ROW	1.00	470	25	.	.	494.1	0.0	31.8	-4.3	-56.8	-9.9
World		1144	405	846.0	818.5	1577.0					
Segregation cost = $6.6/mt											
US	1.00	428	429	815.5	777.2	895.5	0.0	75.7	0.0	30.6	3.0
BR	0.60	149	-14	.	.	134.6	13.9	20.4	13.9	2.9	5.5
AR	1.00	55	-4	.	.	50.6	0.0	20.4	0.0	14.3	1.0
ROW	1.00	474	42	.	.	516.3	0.0	31.8	-13.9	-47.8	-9.6
World		1106	452	815.5	777.2	1597.0					
Zero segregation cost											
US	1.00	396	429	771.5	726.8	869.5	0.0	75.7	0.0	30.9	2.8
BR	0.51	129	15	.	.	144.3	17.1	17.4	17.1	0.0	5.4
AR	0.50	50	9	.	.	59.3	10.3	10.2	10.3	4.2	1.0
ROW	1.00	552	63	.	.	615.2	0.0	31.9	-27.4	-35.0	-9.1
World		1127	517	771.5	726.8	1688.2					

[a] See footnote a, Table C.1.

[b] See footnote b, Table C.1.

[c] The value of the pre-innovation subsidy is $1.2 billion.

TABLE C.4. Equilibrium consumption and prices (LDP scenario) (mil mt; $/mt)

Region	**ρ**	**Bean Price**		**Oil Price**		**Meal Price**	**Bean Demand**		**Oil Demand**		**Meal Demand**
		Conv.	**RR**	**Conv.**	**RR**		**Conv.**	**RR**	**Conv.**	**RR**	
Pre-innovation											
US	0.00	176.6		468.7		139.5	5.5		6.9		28.2
BR	0.00	166.6		458.7		129.5	1.6		2.8		7.1
AR	0.00	166.6		458.7		129.5	0.9		0.9		3.1
ROW	0.00	206.6		528.7		169.5	16.4		14.1		70.4
No segregation technology											
US	1.00		165.6		425.4	135.5		5.6		7.2	28.5
BR	1.00		155.6		415.4	125.5		1.6		2.9	7.2
AR	1.00		155.6		415.4	125.5		0.9		0.9	3.1
ROW	1.00		195.6		485.4	165.5		16.0		13.9	71.0
Segregation cost: $19.8/mt											
US	1.00		166.0		426.3	135.8	0.0	5.6	0.0	7.2	28.5
BR	0.91	185.3	156.0	578.0	416.3	125.8	0.0	1.6	0.0	2.9	7.2
AR	1.00		156.0		416.3	125.8	0.0	0.9	0.0	0.9	3.1
ROW	1.00	225.3	196.0	599.0	486.3	165.8	3.1	13.1	0.0	13.9	71.0
Segregation cost: $13.2/mt											
US	1.00		166.2		426.6	135.9	0.0	5.6	0.0	7.2	28.5
BR	0.87	178.8	156.2	541.9	416.6	125.9	0.0	1.6	0.0	2.9	7.2
AR	1.00		156.2		416.6	125.9	0.0	0.9	0.0	0.9	3.1
ROW	1.00	218.8	196.2	599.3	486.6	165.9	4.3	12.1	0.0	13.8	71.0
Segregation cost: $6.6/mt											
US	1.00		166.7		432.0	135.4	0.0	5.6	0.0	7.2	28.5
BR	0.60	172.8	156.7	510.8	422.0	125.4	0.0	1.6	0.0	2.9	7.2
AR	1.00		156.7		422.0	125.4	0.0	0.9	0.0	0.9	3.1
ROW	1.00	212.8	196.7	580.8	492.0	165.4	5.5	11.0	1.5	12.4	71.1
Zero segregation cost											
US	1.00		167.4		439.5	134.5	0.0	5.6	0.0	7.1	28.6
BR	0.51	167.0	157.6	482.9	430.6	124.5	0.0	1.6	0.0	2.9	7.2
AR	0.50	167.0	157.4	482.9	429.5	124.5	0.0	0.9	0.0	0.9	3.1
ROW	1.00	207.0	197.4	552.9	499.5	164.5	6.6	9.9	3.7	10.3	71.2

Note: Prices are consumer prices. RR producer prices in the U.S. are $193/mt in all scenarios. The price received by producers of conventional soybeans in other regions is lower by the amount of segregation cost.

TABLE C.5. Economic impact of loan deficiency payments (changes from no-LDP scenario) (mil U.S.$)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ in Subsidy	Δ W Total
No segregation technology						
US	1.00	155	546	28.6	859.8	-129.9
BR	1.00	49	-123			-74.5
AR	1.00	19	-74			-54.1
ROW	1.00	347	-114			232.8
World		570	235	28.6	859.8	-25.8
Segregation cost: $19.8/mt						
US		151	524	42.9	829.8	-111.4
BR		47	-121			-73.6
AR		19	-72			-53.3
ROW		329	-112			216.9
World		547	219	42.9	829.8	-21.3
Segregation cost: $13.2/mt						
US		154	512	61.6	818.5	-91.8
BR		49	-123			-73.2
AR		19	-73			-53.6
ROW		325	-113			211.4
World		546	204	61.6	818.5	-7.2
Segregation cost: $6.6/mt						
US		153	475	125.2	777.2	-23.6
BR		52	-123			-71.4
AR		19	-73			-53.4
ROW		276	-113			163.2
World		500	166	125.2	777.2	14.8
Zero segregation cost						
US		227	309	120.4	726.8	-70.3
BR		13	-46			-32.4
AR		7	-31			-23.5
ROW		153	-48			104.3
World		400	185	120.4	726.8	-22.0

TABLE C.6. Economic impact of the Roundup Ready production ban in the Rest of the World (no-LDP and LDP scenarios), changes from pre-innovation equilibrium, production, and exports (mil U.S.$; quantities in mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ in Subsidy	Δ W Total	Bean Supply		Export (Equiv.)[a]		Export Meal[b]
							Conv.	RR	Conv.	RR	
						No-LDP Scenario					
Segregation cost = positive											
US	1.00	239	9	674.9	0.0	922.2	0.0	70.0	0.0	26.0	2.6
BR	1.00	81	137	.	.	217.7	0.0	36.2	0.0	19.2	5.3
AR	1.00	30	85	.	.	115.6	0.0	21.4	0.0	15.5	1.0
ROW	0.00	277	41	.	.	317.6	32.4	0.0	0.0	-60.7	-8.9
World		626	272	674.9	0.0	1573.0					
Zero segregation cost											
US	0.96	230	22	658.5	0.0	910.5	2.5	67.6	2.5	23.7	2.6
BR	1.00	77	144	.	.	220.8	0.0	36.3	0.0	19.2	5.3
AR	1.00	29	89	.	.	118.4	0.0	21.4	0.0	15.5	1.0
ROW	0.00	298	10	.	.	308.2	32.3	0.0	-2.5	-58.5	-8.8
World		634	266	658.5	0.0	1557.9					
						LDP Scenario					
Any segregation cost											
US	1.00	360	429	703.9	665.8	827.2	0.0	75.7	0.0	31.0	2.7
BR	1.00	119	36	.	.	155.5	0.0	34.6	0.0	17.2	5.4
AR	1.00	45	26	.	.	71.1	0.0	20.5	0.0	14.5	1.0
ROW	0.00	537	-27	.	.	510.0	31.7	0.0	0.0	-62.7	-9.0
World		1061	464	703.9	665.8	1563.7					

[a] See footnote a, Table C.1.

[b] See footnote b, Table C.1.

TABLE C.7. Economic impact of the Roundup Ready production ban in the Rest of the World: (changes from no-ban scenario) (mil U.S.$)

	No-LDP Scenario				**LDP Scenario**				
Region	**Δ CS Total**	**Δ PS Total**	**$\Delta\Pi^M$**	**Δ W Total**	**Δ CS Total**	**Δ PS Total**	**$\Delta\Pi^M$**	**Δ in Subsidy**	**Δ W Total**
Segregation cost: $19.8/mt									
US	-71	104	-132	-99	-101	0	-146	-164	-83
BR	-35	54		19	-44	74			30
AR	-11	32		21	-15	45			30
ROW	146	-91		55	77	-47			30
World	29	99	-132	-4	-83	72	-146	-164	8
Segregation cost: $13.2/mt									
US	-62	92	-110	-81	-95	0	-142	-153	-84
BR	-31	47		16	-42	69			27
AR	-10	28		19	-14	42			28
ROW	132	-97		35	67	-52			16
World	28	71	-110	-11	-83	59	-142	-153	-13
Segregation cost: $6.6mt									
US	-36	55	-15	3	-68	0	-112	-111	-68
BR	-16	28		12	-30	50			21
AR	-6	16		12	-10	30			21
ROW	79	-114		-36	63	-69			-6
World	20	-14	-15	-9	-45	12	-112	-111	-33
Zero segregation cost									
US	61	-98	7	-29	-36	0	-68	-61	-42
BR	-39	83		44	-10	21			11
AR	-14	49		36	-5	17			12
ROW	-101	-101		-203	-15	-90			-105
World	-93	-66	7	-152	-66	-53	-68	-61	-125

TABLE C.8. Economic impact of the Roundup Ready production ban in Brazil (no-LDP and LDP scenarios), changes from pre-innovation equilibrium, production and exports (mil U.S.$; quantities in mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ in Subsidy	Δ W Total	Bean Supply		Export (Equiv.)[a]		Export Meal[b]
							Conv.	RR	Conv.	RR	
						No-LDP Scenario					
Segregation cost = $19.8/mt or $13.2/mt											
US	1.00	326	-124	712.4	0.0	914.1	0.0	69.3	0.0	24.8	3.1
BR	0.00	-94	188	.	.	93.1	36.6	0.0	20.4	0.0	4.7
AR	1.00	43	45	.	.	87.2	0.0	21.2	0.0	15.2	1.0
ROW	1.00	291	118	.	.	409.2	0.0	32.6	-20.4	-40.0	-8.8
World		565	226	712.4	0.0	1503.6					
Segregation cost = $6.6/mt											
US	0.99	321	-116	706.9	0.0	911.3	0.9	68.5	0.9	24.0	3.1
BR	0.00	-90	178	.	.	87.6	36.6	0.0	20.3	0.0	4.7
AR	1.00	42	47	.	.	88.9	0.0	21.2	0.0	15.3	1.0
ROW	1.00	289	122	.	.	410.5	0.0	32.6	-21.2	-39.2	-8.8
World		561	230	706.9	0.0	1498.2					
Zero segregation cost											
US	0.77	231	23	609.7	0.0	863.4	15.9	54.2	15.9	10.3	2.7
BR	0.00	-17	12	.	.	-5.7	35.6	0.0	19.0	0.0	4.9
AR	1.00	30	90	.	.	119.1	0.0	21.4	0.0	15.5	1.0
ROW	1.00	292	187	.	.	479.5	0.0	32.8	-34.9	-25.8	-8.6
World		536	311	609.7	0.0	1456.2					
						LDP Scenario					
Segregation cost >=$6.6/mt											
US	1.00	511	429	746.6	917.7	768.5	0.0	75.7	0.0	30.3	3.2
BR	0.00	-61	81	.	.	19.2	34.9	0.0	18.5	0.0	4.7
AR	1.00	66	-42	.	.	23.7	0.0	20.2	0.0	14.1	1.0
ROW	1.00	686	-17	.	.	669.0	0.0	31.6	-18.5	-44.3	-9.0
World		1201	451	746.6	917.7	1480.4					
Zero Segregation Cost											
US	1.00	421	429	715.3	766.5	798.5	0.0	75.7	0.0	30.7	2.9
BR	0.00	-21	-3	.	.	-23.6	34.4	0.0	17.7	0.0	4.9
AR	0.52	54	-2	.	.	52.2	9.8	10.6	9.8	4.6	1.0
ROW	1.00	597	46	.	.	643.5	0.0	31.8	-27.5	-35.2	-8.8
World		1051	471	715.3	766.5	1470.7					

[a] See footnote a, Table C.1.

[b] See footnote b, Table C1.

TABLE C.9. Economic impact of the Roundup Ready production ban in Brazil: (changes from no-ban scenario) (mil U.S.$)

	No-LDP Scenario				LDP Scenario				
Region	**Δ CS Total**	**Δ PS Total**	**$\Delta\Pi^M$**	**Δ W Total**	**Δ CS Total**	**Δ PS Total**	**$\Delta\Pi^M$**	**Δ in Subsidy**	**Δ W Total**
Segregation cost: $19.8/mt									
US	16	-29	-94	-107	50	0	-103	88	-141
BR	-210	105		-106	-224	119			-106
AR	2	-8		-7	6	-23			-17
ROW	160	-14		146	226	-37			189
World	-32	53	-94	-74	57	59	-103	88	-76
Segregation cost: $13.2/mt									
US	25	-41	-72	-89	56	0	-99	99	-143
BR	-206	98		-109	-222	114			-109
AR	3	-12		-10	7	-26			-20
ROW	146	-20		127	216	-42			175
World	-33	25	-72	-81	57	46	-99	99	-97
Segregation cost: $6.6mt									
US	46	-70	17	-8	83	0	-69	141	-127
BR	-187	69		-118	-210	95			-115
AR	6	-22		-15	11	-38			-27
ROW	91	-33		57	212	-59			153
World	-45	-56	17	-84	95	-1	-69	141	-117
Zero segregation cost									
US	62	-97	-41	-76	25	0	-56	40	-71
BR	-133	-49		-182	-150	-18			-168
AR	-13	50		36	4	-11			-7
ROW	-107	76		-31	45	-17			28
World	-191	-21	-41	-254	-76	-46	-56	40	-218

TABLE C.10. Economic impact of the simultaneous Roundup Ready production bans in Brazil and the Rest of the World (no-LDP and LDP scenarios), changes from pre-innovation equilibrium, production and exports (mil U.S.$; quantities in mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ in Subsidy	Δ W Total	Bean Supply Conv.	Bean Supply RR	Export (Equiv.)[a] Conv.	Export (Equiv.)[a] RR	Export Meal[b]
					No-LDP Scenario						
Any segregation cost											
US	1.00	113	215	563.6	0.0	890.9	0.0	71.1	0.0	27.6	2.3
BR	0.00	35	-96	.	.	-60.7	35.0	0.0	18.1	0.0	5.2
AR	1.00	14	148	.	.	162.1	0.0	21.7	0.0	15.9	0.9
ROW	0.00	271	-87	.	.	183.4	32.0	0.0	-18.1	-43.5	-8.4
World		432	180	563.6	0.0	1175.7					
					LDP Scenario						
Any segregation cost											
US	1.00	158	429	591.6	313.6	865.4	0.0	75.7	0.0	31.7	2.3
BR	0.00	49	-128	.	.	-78.8	33.6	0.0	16.5	0.0	5.2
AR	1.00	19	122	.	.	141.9	0.0	21.1	0.0	15.1	0.9
ROW	0.00	379	-119	.	.	260.5	31.4	0.0	-16.5	-46.8	-8.4
World		606	305	591.6	313.6	1188.9					

[a] See footnote a, Table C.1.

[b] See footnote b, Table C.1.

Table C.11. Economic impact of the simultaneous Roundup Ready production bans in Brazil and the Rest of the World (changes from no-ban scenario) (mil U.S.$)

	No-LDP Scenario				LDP Scenario				
Region	**Δ CS Total**	**Δ PS Total**	**$\Delta\Pi^M$**	**Δ W Total**	**Δ CS Total**	**Δ PS Total**	**$\Delta\Pi^M$**	**Δ in Subsidy**	**Δ W Total**
Segregation cost: $19.8/mt									
US	-197	310	-243	-130	-303	0	-258	-516	-44
BR	-81	-179		-260	-114	-90			-204
AR	-27	95		68	-41	141			101
ROW	140	-219		-79	-81	-139			-219
World	-165	7	-243	-402	-538	-87	-258	-516	-367
Segregation cost: $13.2/mt									
US	-188	298	-221	-112	-297	0	-254	-505	-46
BR	-77	-186		-262	-112	-95			-207
AR	-26	91		65	-40	138			99
ROW	126	-225		-99	-91	-144			-234
World	-166	-21	-221	-409	-538	-100	-254	-505	-388
Segregation cost: $6.6mt									
US	-162	261	-127	-28	-270	0	-224	-464	-30
BR	-62	-205		-267	-100	-114			-213
AR	-22	79		58	-36	126			91
ROW	73	-242		-170	-95	-161			-256
World	-174	-106	-127	-407	-500	-147	-224	-464	-408
Zero segregation cost									
US	-56	95	-88	-49	-238	0	-180	-413	-4
BR	-81	-157		-237	-80	-143			-223
AR	-29	108		79	-31	113			83
ROW	-128	-198		-328	-173	-182			-355
World	-295	-152	-88	-535	-521	-212	-180	-413	-499

TABLE C.12. Economic impact of the Roundup Ready production and import ban in the Rest of the World (no-LDP scenario), changes from pre-innovation equilibrium, production and exports (mil U.S.$; quantities in mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Soybean Supply		Export (Equiv.)[a]		Export Meal[b]
						Conv.	RR	Conv.	RR	
Segregation cost: $19.8/mt										
US	0.67	429	-256	396.3	569.6	23.0	45.6	23.0	0.0	4.3
BR	0.52	245	-130		115.3	16.7	18.1	16.7	0.0	6.2
AR	0.30	83	-77		6.6	14.4	6.2	14.4	0.0	1.3
ROW	0.00	-1487	533		-954.1	33.8	0.0	-54.0	0.0	-11.8
World		-730	71	396.3	-262.6					
Segregation cost: $13.2/mt										
US	0.65	353	-149	391.2	594.5	24.1	45.1	24.1	0.0	3.8
BR	0.51	208	-76		132.0	17.2	17.8	17.2	0.0	6.0
AR	0.30	72	-45		27.0	14.6	6.2	14.6	0.0	1.2
ROW	0.00	-1021	363		-658.2	33.3	0.0	-56.0	0.0	-11.0
World		-389	93	391.2	95.4					
Segregation cost: $6.6/mt										
US	0.64	277	-40	386.1	622.8	25.3	44.5	25.3	0.0	3.2
BR	0.50	171	-21		150.6	17.8	17.6	17.8	0.0	5.8
AR	0.29	61	-12		48.4	14.9	6.1	14.9	0.0	1.1
ROW	0.00	-552	196		-355.5	32.9	0.0	-57.9	0.0	-10.1
World		-43	123	386.1	466.3					
Zero segregation cost										
US	0.62	202	71	381.0	654.6	26.4	43.9	26.4	0.0	2.7
BR	0.49	135	36	.	171.0	18.3	17.4	18.3	0.0	5.5
AR	0.28	49	21	.	70.7	15.1	6.0	15.1	0.0	1.0
ROW	0.00	-79	33	.	-46.2	32.4	0.0	-59.9	0.0	-9.3
World		307	162	381.0	850.1					

[a] See footnote a, Table C.1.

[b] See footnote b, Table C.1.

TABLE C.13. Economic impact of the simultaneous Roundup Ready production bans in Brazil and the Rest of the World and import ban in the Rest of the World (no-LDP scenario), changes from pre-innovation equilibrium, production and exports (mil U.S.$; quantities in mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Soybean Supply Conv.	Soybean Supply RR	Export (Equiv.)[a] Conv.	Export (Equiv.)[a] RR	Export Meal[b]
Segregation cost: $19.8/mt										
US	0.70	638	-569	343.5	413.2	20.3	46.5	20.3	0.0	4.9
BR	0.00	-178	422		244.0	37.9	0.0	21.9	0.0	4.5
AR	0.32	111	-171		-59.4	13.7	6.4	13.7	0.0	1.3
ROW	0.00	-1069	378		-691.3	33.4	0.0	-56.0	0.0	-10.8
World		-497	60	343.5	-93.6					
Segregation cost: $13.2/mt										
US	0.67	498	-371	337.4	464.3	22.3	45.7	22.3	0.0	4.2
BR	0.00	-124	284		160.1	37.1	0.0	21.0	0.0	4.7
AR	0.31	92	-112		-20.0	14.2	6.2	14.2	0.0	1.3
ROW	0.00	-727	256		-471.3	33.0	0.0	-57.4	0.0	-10.2
World		-261	57	337.4	133.1					
Segregation cost: $6.6/mt										
US	0.65	359	-166	331.3	523.6	24.2	44.9	24.2	0.0	3.5
BR	0.00	-70	152		81.1	36.4	0.0	20.0	0.0	4.8
AR	0.30	72	-50		21.8	14.6	6.1	14.6	0.0	1.2
ROW	0.00	-388	137		-251.0	32.7	0.0	-58.8	0.0	-9.6
World		-28	72	331.3	375.4					
Zero segregation cost										
US	0.63	219	47	325.1	591.1	26.1	44.1	26.1	0.0	2.9
BR	0.00	-17	24	.	6.9	35.7	0.0	19.1	0.0	5.0
AR	0.29	52	14	.	66.0	15.1	6.0	15.1	0.0	1.1
ROW	0.00	-52	21	.	-30.6	32.4	0.0	-60.3	0.0	-8.9
World		203	106	325.1	633.5					

[a] See footnote a, Table C.1.

[b] See footnote b, Table C.1.

TABLE C.14. Economic Impact of the simultaneous production and import bans (no-LDP scenario), changes from no-ban scenario (mil U.S.$)

Region	RR Production and Import Ban in the ROW				RR Production Bans in Brazil and ROW and Import Ban in ROW			
	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total
Segregation cost: $19.8/mt								
US	119	-161	-411	-452	328	-474	-463	-608
BR	129	-213		-84	-294	339		45
AR	42	-130		-88	70	-224		-154
ROW	-1618	401		-1217	-1200	246		-954
World	-1327	-102	-411	-1840	-1094	-113	-463	-1671
Segregation cost: $13.2/mt								
US	52	-66	-393	-408	197	-288	-447	-539
BR	96	-166		-70	-236	194		-42
AR	32	-102		-70	52	-169		-117
ROW	-1166	225		-941	-872	118		-754
World	-987	-108	-393	-1489	-859	-144	-447	-1451
Segregation cost: $6.6mt								
US	2	6	-304	-296	84	-120	-359	-396
BR	74	-130		-55	-167	43		-125
AR	25	-81		-56	36	-119		-82
ROW	-750	41		-709	-586	-18		-604
World	-649	-163	-304	-1116	-634	-214	-359	-1207
Zero segregation cost								
US	33	-49	-270	-285	50	-73	-326	-349
BR	19	-25		-6	-133	-37		-170
AR	6	-19		-12	9	-26		-17
ROW	-478	-78		-557	-451	-90		-542
World	-420	-170	-270	-860	-524	-226	-326	-1077

TABLE C.15. Economic impact of Roundup Ready technology in alternative market structures (no-LDP scenario), changes from pre-innovation and μ={0.4,0.2,0.2,0.2} equilibria (mil U.S.$)

		Vs. Pre-Innovation Equilibrium				Vs. μ = {0.4,0.2,0.2,0.2} Equilibrium			
Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total
Markup μ = {0,0,0,0}									
Segregation cost: $13.2/mt; free trade									
US	0.95	459	141	0.0	600.4	158	224	-784	-402.5
BR	1.00	162	74	.	236.7	50	-16		35.0
AR	1.00	59	50	.	109.0	19	-7		12.1
ROW	1.00	481	179	.	659.6	336	41		376.9
World		1162	443	0.0	1605.7	564	242	-784	21.5
Segregation cost: $13.2/mt; RR production bans in BR and ROW									
US	1.00	214	536	0.0	750.4	101	321	-564	-140.5
BR	0.00	66	-180	.	-113.6	31	-84		-52.9
AR	1.00	26	168	.	194.7	12	20		32.6
ROW	0.00	514	-165	.	349.5	243	-78		166.1
World		822	359	0.0	1181.0	390	179	-564	5.3
Markup μ = {0.4,0.4,0.4,0.4}									
Segregation cost: $13.2/mt; free trade									
US	0.90	247	8	1133.4	1387.8	-54	91	349	384.9
BR	1.00	95	18	.	113.4	-17	-72		-88.3
AR	1.00	33	14	.	46.6	-7	-43		-50.3
ROW	1.00	17	18	.	35.0	-128	-120		-247.7
World		392	58	1133.4	1582.8	-206	-143	349	-1.4
Segregation cost: $13.2/mt; RR production bans in BR and ROW									
US	1.00	100	236	635.1	971.4	-13	21	72	80.5
BR	0.00	31	-85	.	-54.0	-4	11		6.7
AR	1.00	12	82	.	94.7	-2	-66		-67.4
ROW	0.00	240	-78	.	162.9	-31	9		-20.5
World		384	156	635.1	1174.9	-48	-24	72	-0.8
Monopolist profit maximizing markup; RR production bans in BR and ROW									
Segregation cost: $13.2/mt; markup μ = {1.498,0.0,0.2,0.0}									
US	1.00	-149	-655	1794.4	990.4	-262	-870	1231	99.5
BR	0.00	-46	129	.	83.3	-81	225		144.0
AR	1.00	-18	287	.	269.0	-32	139		106.9
ROW	0.00	-357	117	.	-240.4	-628	204		-423.8
World		-571	-122	1794.4	1102.2	-1003	-302	1231	-73.5
Zero segregation cost; markup μ = {0.733,0.0,0.2,0.0}									
US	1.00	36	-61	955.6	931.3	-77	-276	392	40.4
BR	0.00	11	-31	.	-19.7	-24	65		41.0
AR	1.00	4	188	.	192.8	-10	40		30.7
ROW	0.00	87	-28	.	58.7	-184	59		-124.7
World		139	69	955.6	1163.1	-293	-111	392	-12.6

Appendix D. Sensitivity Analysis

TABLE D.1. Model's sensitivity to demand elasticities ε^{YY} : welfare effects (mil U.S.$)

	Base Values × ½					Base Values					Base Values × 2				
Region	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
Free Trade															
US	0.90	359	-160	786	985	0.90	301	-83	784	1003	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	1599		598	201	784	1584		514	273	785	1571
RR Production Ban in ROW															
US	1.00	278	-50	675	902	1.00	239	9	675	922	1.00	233	19	675	927
BR	1.00	98	107		206	1.00	81	137		218	1.00	85	142		228
AR	1.00	36	68		104	1.00	30	85		116	1.00	31	88		119
ROW	0.00	366	4		370	0.00	277	41		318	0.00	238	50		289
World		778	128	675	1581		626	272	675	1573		588	300	675	1562
RR Production Ban in Brazil															
US	1.00	374	-192	712	894	1.00	326	-124	712	914	1.00	311	-101	713	923
BR	0.00	-71	154		83	0.00	-94	188		93	0.00	-86	188		103
AR	1.00	50	24		75	1.00	43	45		87	1.00	41	51		93
ROW	1.00	373	87		460	1.00	291	118		409	1.00	251	129		379
World		726	73	712	1512		565	226	712	1504		517	267	713	1498
RR Prod. Bans in Brazil and ROW															
US	1.00	131	185	565	881	1.00	113	215	564	891	1.00	135	181	562	878
BR	0.00	41	-111		-71	0.00	35	-96		-61	0.00	51	-112		-60
AR	1.00	16	139		156	1.00	14	148		162	1.00	18	138		156
ROW	0.00	315	-101		214	0.00	271	-87		183	0.00	295	-102		193
World		503	111	565	1179		432	180	564	1176		500	105	562	1167
RR Prod. and Import Ban in ROW															
US	0.64	340	-131	385	593	0.65	353	-149	391	595	0.68	420	-246	407	581
BR	0.49	203	-67		137	0.51	208	-76		132	0.54	241	-125		117
AR	0.29	70	-39		31	0.30	72	-45		27	0.32	83	-74		9
ROW	0.00	-1063	373		-690	0.00	-1021	363		-658	0.00	-877	316		-561
World		-450	135	385	70		-389	93	391	95		-133	-129	407	145

TABLE D.1. Continued.

Region	Base Values × ½					Base Values					Base Values × 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
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
US	0.65	487	-361	330	455	0.67	498	-371	337	464	0.71	567	-458	354	462
BR	0.00	-128	293		165	0.00	-124	284		160	0.00	-94	236		142
AR	0.30	90	-108		-19	0.31	92	-112		-20	0.33	103	-138		-35
ROW	0.00	-754	262		-491	0.00	-727	256		-471	0.00	-606	213		-393
World		-305	85	330	110		-261	57	337	133		-30	-147	354	177

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

TABLE D.2. Model's sensitivity to supply elasticities ψ : welfare effects (mil U.S.$)

	Base Values × ½					Base Values					Base Values × 2				
Region	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**
Free Trade															
US	0.90	281	-49	792	1024	0.90	301	-83	784	1003	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	1586		598	201	784	1584		670	143	772	1585
RR Production Ban in ROW															
US	1.00	204	71	684	958	1.00	239	9	675	922	1.00	267	-39	659	887
BR	1.00	70	164		234	1.00	81	137		218	1.00	89	118		207
AR	1.00	26	103		129	1.00	30	85		116	1.00	34	71		105
ROW	0.00	185	74		259	0.00	277	41		318	0.00	359	7		366
World		484	411	684	1579		626	272	675	1573		750	157	659	1565
RR Production Ban in Brazil															
US	1.00	308	-95	725	938	1.00	326	-124	712	914	1.00	336	-136	692	891
BR	0.00	-110	220		111	0.00	-94	188		93	0.00	-74	145		71
AR	1.00	41	54		95	1.00	43	45		87	1.00	44	39		83
ROW	1.00	231	131		363	1.00	291	118		409	1.00	346	112		458
World		470	311	725	1506		565	226	712	1504		651	160	692	1502
RR Prod. Bans in Brazil and ROW															
US	1.00	87	264	572	924	1.00	113	215	564	891	1.00	131	175	549	855
BR	0.00	27	-72		-45	0.00	35	-96		-61	0.00	41	-116		-75
AR	1.00	11	160		171	1.00	14	148		162	1.00	16	142		158
ROW	0.00	209	-67		143	0.00	271	-87		183	0.00	315	-104		212
World		334	285	572	1191		432	180	564	1176		504	97	549	1149
RR Prod. and Import Ban in ROW															
US	0.64	366	-174	393	585	0.65	353	-149	391	595	0.69	344	-130	390	604
BR	0.52	212	-84		128	0.51	208	-76		132	0.49	205	-72		132
AR	0.30	74	-51		23	0.30	72	-45		27	0.29	71	-41		29
ROW	0.00	-997	347		-650	0.00	-1021	363		-658	0.00	-1037	383		-653
World		-345	39	393	87		-389	93	391	95		-417	140	390	113

TABLE D.2. Continued.

	Base Values × ½					Base Values					Base Values × 2				
Region	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**
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
US	0.65	505	-391	339	453	0.67	498	-371	337	464	0.72	502	-357	337	481
BR	0.00	-123	271		148	0.00	-124	284		160	0.00	-123	300		178
AR	0.30	93	-114		-22	0.31	92	-112		-20	0.31	92	-114		-22
ROW	0.00	-718	248		-470	0.00	-727	256		-471	0.00	-715	261		-454
World		-244	14	339	109		-261	57	337	133		-244	91	337	184

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

TABLE D.3. Model's sensitivity to the yield increase parameter β: welfare effects (mil U.S.$)

	Base Values					β = 0.02				
Region	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**
Free Trade										
US	0.90	301	-83	784	1003	0.88	411	-288	770	893
BR	1.00	112	90		202	1.00	146	-6		140
AR	1.00	40	57		97	1.00	53	3		56
ROW	1.00	145	138		283	1.00	409	51		459
World		598	201	784	1584		1019	-240	770	1548
RR Production Ban in ROW										
US	1.00	239	9	675	922	1.00	333	-171	669	832
BR	1.00	81	137		218	1.00	110	55		165
AR	1.00	30	85		116	1.00	42	39		81
ROW	0.00	277	41		318	0.00	498	-28		470
World		626	272	675	1573		984	-105	669	1547
RR Production Ban in Brazil										
US	1.00	326	-124	712	914	1.00	419	-300	707	825
BR	0.00	-94	188		93	0.00	-69	115		46
AR	1.00	43	45		87	1.00	54	-1		53
ROW	1.00	291	118		409	1.00	507	44		551
World		565	226	712	1504		910	-142	707	1476
RR Prod. Bans in Brazil and ROW										
US	1.00	113	215	564	891	1.00	180	82	561	823
BR	0.00	35	-96		-61	0.00	56	-153		-97
AR	1.00	14	148		162	1.00	22	116		138
ROW	0.00	271	-87		183	0.00	432	-139		293
World		432	180	564	1176		690	-94	561	1157
RR Prod. and Import Ban in ROW										
US	0.65	353	-149	391	595	0.65	392	-239	386	539
BR	0.51	208	-76		132	0.50	223	-122		101
AR	0.30	72	-45		27	0.30	79	-71		7

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

TABLE D.4. Model's sensitivity to demand parameter $\hat{\sigma}$: welfare effects (mil U.S.$)

	Base Values × ⅔					Base Values					Base Values × 1⅓				
Region	**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**
Free Trade															
US	0.87	335	-132	768	971	0.90	301	-83	784	1003	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	1391		598	201	784	1584		768	206	801	1775
RR Production Ban in ROW															
US	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	1455		626	272	675	1573		706	244	679	1629
RR Production Ban in Brazil															
US	1.00	391	-221	710	880	1.00	326	-124	712	914	1.00	264	-30	717	952
BR	0.00	-99	222		123	0.00	-94	188		93	0.00	-46	77		30
AR	1.00	53	15		68	1.00	43	45		87	1.00	34	74		108
ROW	1.00	202	73		275	1.00	291	118		409	1.00	386	163		549
World		546	90	710	1346		565	226	712	1504		638	283	717	1638
RR Prod. Bans in Brazil and ROW															
US	1.00	219	48	559	826	1.00	113	215	564	891	1.00	113	215	564	891
BR	0.00	13	-32		-19	0.00	35	-96		-61	0.00	35	-95		-61
AR	1.00	29	97		127	1.00	14	148		162	1.00	14	148		162
ROW	0.00	239	-29		209	0.00	271	-87		183	0.00	270	-87		183
World		500	84	559	1143		432	180	564	1176		431	181	564	1176
RR Prod. and Import Ban in ROW															
US	0.65	384	-196	391	580	0.65	353	-149	391	595	0.65	355	-152	392	594
BR	0.51	227	-99		128	0.51	208	-76		132	0.51	209	-77		132
AR	0.30	77	-59		18	0.30	72	-45		27	0.30	72	-46		27
ROW	0.00	-975	342		-633	0.00	-1021	363		-658	0.00	-1017	362		-656
World		-286	-12	391	93		-389	93	391	95		-381	86	392	97

TABLE D.4. Continued.

	Base Values × ⅔					Base Values					Base Values × 1⅓				
Region	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**
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
US	0.67	530	-418	337	449	0.67	498	-371	337	464	0.67	500	-373	338	464
BR	0.00	-105	261		156	0.00	-124	284		160	0.00	-124	283		160
AR	0.31	97	-126		-29	0.31	92	-112		-20	0.31	92	-112		-20
ROW	0.00	-680	234		-446	0.00	-727	256		-471	0.00	-724	255		-470
World		-157	-49	337	131		-261	57	337	133		-256	53	338	134

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

TABLE D.5. Model's sensitivity to demand parameter $\hat{k}$: welfare effects (mil U.S.$)

	$\hat{k} = 1.025$					Base Values					$\hat{k} = 1.075$				
Region	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
Free Trade															
US	0.90	298	-76	784	1006	0.90	301	-83	784	1003	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	1581		598	201	784	1584		717	87	785	1590
RR Production Ban in ROW															
US	1.00	259	-19	672	913	1.00	239	9	675	922	1.00	249	-8	677	918
BR	1.00	94	123		216	1.00	81	137		218	1.00	87	129		216
AR	1.00	34	77		111	1.00	30	85		116	1.00	32	81		113
ROW	0.00	302	24		326	0.00	277	41		318	0.00	301	33		334
World		688	205	672	1566		626	272	675	1573		669	234	677	1580
RR Production Ban in Brazil															
US	1.00	335	-135	711	912	1.00	326	-124	712	914	1.00	346	-157	714	904
BR	0.00	-87	179		92	0.00	-94	188		93	0.00	-82	172		90
AR	1.00	44	41		86	1.00	43	45		87	1.00	46	35		81
ROW	1.00	295	113		409	1.00	291	118		409	1.00	334	103		437
World		588	198	711	1497		565	226	712	1504		644	153	714	1511
RR Prod. Bans in Brazil and ROW															
US	1.00	147	166	561	874	1.00	113	215	564	891	1.00	112	217	566	895
BR	0.00	55	-119		-64	0.00	35	-96		-61	0.00	34	-95		-61
AR	1.00	19	133		153	1.00	14	148		162	1.00	14	149		163
ROW	0.00	315	-109		206	0.00	271	-87		183	0.00	271	-87		184
World		537	71	561	1168		432	180	564	1176		431	184	566	1181
RR Prod. and Import Ban in ROW															
US	0.66	386	-190	395	591	0.65	353	-149	391	595	0.64	354	-157	388	585
BR	0.52	228	-97		132	0.51	208	-76		132	0.50	208	-80		129
AR	0.30	78	-57		20	0.30	72	-45		27	0.29	72	-47		25
ROW	0.00	-966	343		-624	0.00	-1021	363		-658	0.00	-1027	360		-666
World		-274	-1	395	119		-389	93	391	95		-392	76	388	72

TABLE D.5. Continued.

	$\hat{k} = 1.025$					Base Values					$\hat{k} = 1.075$				
Region	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**
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
US	0.68	534	-412	340	462	0.67	498	-371	337	464	0.66	497	-379	335	454
BR	0.00	-107	261		154	0.00	-124	284		160	0.00	-121	283		162
AR	0.31	98	-124		-26	0.31	92	-112		-20	0.30	91	-114		-22
ROW	0.00	-675	235		-440	0.00	-727	256		-471	0.00	-731	254		-477
World		-151	-40	340	150		-261	57	337	133		-263	44	335	116

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

TABLE D.6. Model's sensitivity to demand elasticities ε^{00} : welfare effects (mil U.S.$)

	Demand Elasticities × ⅔					Base Values					Demand Elasticities × 1⅓				
Region	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
Free Trade															
US	0.71	309	-96	693	906	0.90	301	-83	784	1003	0.95	309	-94	806	1021
BR	1.00	118	83		201	1.00	112	90		202	1.00	115	84		199
AR	1.00	41	53		95	1.00	40	57		97	1.00	41	54		95
ROW	1.00	27	132		158	1.00	145	138		283	1.00	268	133		400
World		495	172	693	1361		598	201	784	1584		732	177	806	1716
RR Production Ban in ROW															
US	1.00	284	-60	674	898	1.00	239	9	675	922	1.00	231	21	675	927
BR	1.00	105	102		206	1.00	81	137		218	1.00	78	143		221
AR	1.00	37	64		102	1.00	30	85		116	1.00	29	89		118
ROW	0.00	217	120		337	0.00	277	41		318	0.00	331	-11		320
World		643	226	674	1543		626	272	675	1573		670	242	675	1587
RR Production Ban in Brazil															
US	1.00	410	-253	709	865	1.00	326	-124	712	914	1.00	298	-79	715	933
BR	0.00	-147	327		180	0.00	-94	188		93	0.00	-55	102		47
AR	1.00	55	5		60	1.00	43	45		87	1.00	39	58		98
ROW	1.00	252	58		309	1.00	291	118		409	1.00	333	139		473
World		569	136	709	1414		565	226	712	1504		615	221	715	1551
RR Prod. Bans in Brazil and ROW															
US	1.00	146	167	564	876	1.00	113	215	564	891	1.00	113	215	564	891
BR	0.00	55	-120		-65	0.00	35	-96		-61	0.00	35	-95		-61
AR	1.00	19	134		153	1.00	14	148		162	1.00	14	148		162
ROW	0.00	319	-109		210	0.00	271	-87		183	0.00	270	-87		183
World		539	71	564	1174		432	180	564	1176		432	181	564	1176
RR Prod. and Import Ban in ROW															
US	0.65	384	-195	391	580	0.65	353	-149	391	595	0.65	354	-151	391	594
BR	0.51	227	-99		128	0.51	208	-76		132	0.51	209	-77		132
AR	0.30	77	-59		18	0.30	72	-45		27	0.30	72	-45		27
ROW	0.00	-975	342		-633	0.00	-1021	363		-658	0.00	-1019	362		-657
World		-287	-11	391	93		-389	93	391	95		-384	89	391	96

TABLE D.6. Continued.

	Demand Elasticities × ⅔					Base Values					Demand Elasticities × 1⅓				
Region	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**
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
US	0.67	530	-418	337	449	0.67	498	-371	337	464	0.67	500	-373	338	464
BR	0.00	-105	261		156	0.00	-124	284		160	0.00	-124	284		160
AR	0.31	97	-126		-29	0.31	92	-112		-20	0.31	92	-112		-20
ROW	0.00	-680	234		-446	0.00	-727	256		-471	0.00	-725	255		-470
World		-159	-48	337	131		-261	57	337	133		-258	54	338	134

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

TABLE D.7. Possibility of multiple equilibria when demand elasticity $\hat{\varepsilon}^{00}$ = –1.0: welfare changes from pre-innovation equilibrium, production, and exports (mil U.S.$; quantities in mil mt)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^{M}$	Δ W Total	Soybean Supply		Export (Equiv.)[a]		Export Meal[b]
						Conv.	RR	Conv.	RR	
Pre-innovation										
US	0.00					70.3		27.5		1.8
BR	0.00					35.7		19.1		5.0
AR	0.00					21.1		15.4		0.9
ROW	0.00					32.4		-62.0		-7.6
Equilibrium #1										
US	0.61	186	95	619.6	900.6	27.4	43.4	27.4	0.0	2.1
BR	0.73	126	48		174.7	9.7	26.2	9.7	9.1	5.3
AR	1.00	45	33		78.2	0.0	21.2	0.0	15.3	1.0
ROW	1.00	-184	100		-84.3	0.0	32.6	-37.0	-24.4	-8.4
World		173	276	619.6	1069.2					
Equilibrium #2										
US	0.92	304	-96	635.9	843.8	5.3	64.5	5.3	20.5	2.5
BR	1.00	108	83		191.3	0.0	36.1	0.0	19.0	5.3
AR	1.00	39	53		92.8	0.0	21.3	0.0	15.4	0.9
ROW	0.00	-133	389		256.5	33.5	0.0	-5.3	-55.0	-8.7
World		319	429	635.9	1384.4					

Note: Assuming the $13.2/mt segregation cost in each region and no-LDP scenario.

[a] See footnote a, Table C.1, Appendix C.

[b] See footnote b, Table C.1, Appendix C.

TABLE D.8. Model's sensitivity to transportation costs between Argentina and Brazil: welfare changes from pre-innovation equilibrium, quantities and prices (millions of U.S.$)

Region	ρ	Δ CS Total	Δ PS Total	$\Delta\Pi^M$	Δ W Total	Soybean Supply		Export (Equiv.)[a]		Export Meal[b]
						Conv.	RR	Conv.	RR	
US	1.00	236	13	718.7	967.1	0.0	70.1	0.0	26.1	2.6
BR	0.00	-49	18		-31.0	35.7	0.0	34.1	-15.2	0.0
AR	1.00	30	86		116.0	0.0	21.4	0.0	15.5	6.3
ROW	1.00	300	182		482.0	0.0	32.8	-34.1	-26.4	-8.8
World		516	299	718.7	1534.1					

	Bean Price		Oil Price		Meal Price	Bean Demand		Oil Demand		Meal Demand
	Conv.	RR	Conv.	RR		Conv.	RR	Conv.	RR	
US	182.5	176.4	496.1	462.5	140.7	0.0	5.5	0.0	7.0	28.1
BR	172.5	176.4	486.1	470.0	140.7	1.5	0.0	0.0	2.8	6.9
AR	172.5	166.4	486.1	452.5	130.7	0.0	0.9	0.0	0.9	3.1
ROW	212.5	206.4	556.1	522.5	170.7	7.1	9.2	4.9	9.0	70.2

Notes: Transportation costs assume transportation cost $t^1_{B,AZ} = 10, t^1_{O,AZ} = 17.5, t^1_{M,AZ} = 10$. Prices assume the $13.2/mt segregation cost in each region and no-LDP scenario.

[a] See footnote a, Table C.1, Appendix C.

[b] See footnote b, Table C.1, Appendix C.

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