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Andrei A. Sobolevsky
Iowa State University

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Product differentiation arising from genetically modified organisms: trade and welfare effects in the soybean complex

by

Andrei A. Sobolevsky

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GianCarlo Moschini, Major Professor
John Beghin
Domenico D'Alessandro
Arne Hallam
Harvey Lapan

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Graduate College
Iowa State University

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Andrei A. Sobolevsky

has met the dissertation requirements of Iowa State University

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

For the Major Program

This dissertation is dedicated to my wife Elvira

who believed in me and supported me all these years.

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ABSTRACT

The first biotechnology innovations in agriculture, such as herbicide resistant crops, took the form of cost reducing *process* innovations and were modeled as such. In recent years it became clear that these innovations are also *product* innovations in that they introduce altered, genetically modified final products to the market, and consumer preferences against the presence of GMOs in food drive the differentiation between products obtained using the conventional and biotechnology. I develop a new partial equilibrium four-region world trade model for the soybean complex comprising soybeans, soybean oil and soybean meal, in which 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 governments' 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 soybean varieties. The United States, Argentina, Brazil and the Rest of the World all gain from the introduction of biotechnology. Price support programs for U.S. farmers, despite hurting the United States, have the potential to further improve world's efficiency. Compared to the 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 Unites 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. 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 GMO-conscious consumers and elasticity of demands for conventional product varieties.

CHAPTER 1. INTRODUCTION

1.1. Rationale

Recent biotechnology innovations in agriculture led to the introduction of improved crop varieties that belong to the class of genetically modified organisms (GMOs). Genetic modification proved successful in seeds of such crops as corn/maize, soybeans, cotton, canola/rapeseed, and potato, and the growth rates of areas devoted to these transgenic crops have been very high in the last five years, as documented in James (1998, 2000). The advantage of genetically modified (GM) crops marketed to date lies in the fact that the new genes inserted in the seed make them either tolerant to specific types of herbicides that can later be applied in the field to eradicate weeds, or make them toxic to pests that can attack the crop during its growth. These attributes of biotech crops reduce weed and pest management costs and thus have the potential of providing sizeable efficiency gains.

In recent years it has become clear that, whereas genetic modification of seeds has brought about more cost-effective technology in the input market, it has also led some consumers to demand a choice between consuming biotech and nonbiotech final food products. In economic terms, this implies that biotechnology innovations that were originally thought to be just *process* innovations that do not introduce any new features to the final product – biotech foods have been determined to be "substantially equivalent" to their conventional counterparts by the U.S. Food and Drug Administration – turn out rather to be *product* innovations in light of the increasing public and political opposition to GMOs in Europe and elsewhere. Clearly, accommodation of this trend in subsequent research requires that we treat biotech innovations as product innovations, and the resulting product differentiation has important implications for modeling the economic impact of the diffusion of GMO crops.

Differentiated demands will not be met unless the supply chain is able to deliver biotech and nonbiotech product varieties separately to the consumer. To address this issue, most of the recent literature on agricultural biotechnology has already shifted the focus from the benefits of the new technology to the costs of keeping it segregated alongside its conventional counterpart as public and political opposition to importing grains produced using genetically modified seeds became widespread outside the United States, entered international regulatory bodies, and won a new legislation in the European Union explicitly aimed at regulating GMOs (Miller and Conko, 2000; Moschini and Corrigan, 1999). With GMOs being subject to labeling in Europe and soon in Australia, New Zealand, Japan and South Korea, the only way to provide consumers with a credible non-GMO alternative to a product that contains GMOs is to ensure that nonbiotech grain is properly separated in the supply chain using identity preservation (IP) or crop segregation techniques (Lin, Chambers and Harwood, 2000).

Several models have recently attempted to incorporate differentiated final product demands and the supply-side biotech versus nonbiotech crop separation costs. These models vary in their approaches and issues addressed, but can be roughly grouped in two categories. An example of the first category is a simple model of the world canola market developed by Linder *et al.* (2001), with homogeneous farmers described by a two-input constant returns to scale, constant elasticity of substitution production function and heterogeneous consumers with constant elasticity demands. While being useful for analyzing welfare implications of introduction of GM product and various levels of segregation costs for consumers, producers and the world in general, such model, by being a one-good one-sector type model, cannot say anything about price, trade and welfare effects of the new technology in different parts of the world, and it is not very useful for common policy analysis. In short, the models in the first category are very aggregated.

Examples of the second category are Nielsen and Anderson (2000) and Nielsen, Thierfelder and Robinson (2001). They build their analysis based on the global economy-wide general equilibrium model and database – with the most recent data for 1995 – known as GTAP. GTAP splits the world in 45 regions and has 50 product sectors that can be aggregated if necessary. Although GTAP provides an exceptional richness of price, production and trade detail when analyzing a split of production into GM and GM-free lines or various policy actions, its existing applications have only one representative household in each region, which does not allow the analyst to separate consumer and producer welfare, and also makes it impossible to introduce differentiated demands. Nielsen, Thierfelder and

Robinson (2001), however, model consumer attitudes towards GM products by introducing a change in preferences, but this rules out standard welfare analysis.[1] Also, by assuming perfect competition, GTAP does not treat realistically the market structure typical for most products affected by biotechnology.

The limitations of existing models represent serious impediments to correctly capturing the crucial features of present agricultural markets and addressing the types of questions that are of interest to policymakers. First, welfare analysis, and not only the analysis of price, production and trade dynamics, is extremely important for supporting arguments in the discussion of the pros and cons of biotechnology in agriculture. To make it possible, as explained earlier, differentiated markets need to be introduced in the analysis consistently and not by means of preference changes.

Secondly, models that are too aggregated are not suitable for analyzing the effects of rather diverse attitudes toward GMOs in different parts of the world. While the U.S. regulatory system has chosen a hands-off approach to GM foods manifested in the "substantial equivalence" approach used by the U.S. Food and Drug Administration, European governments have relied on the "precautionary principle" that also found its way into the Biosafety Protocol that was agreed upon in January 2000 (Moschini, 2001). Although the precautionary principle, by postulating that the lack of scientific evidence should not delay taking such precautionary steps as banning the product with, say, uncertain health implications, may be at odds with the rules under which countries-members of the World Trade Organization (WTO) must operate, it tends to be widely adopted by European policymakers and has already led to actual bans of some GM crops. Clearly, this leaves the United States concerned with the consequences of EU biotechnology regulation.

Finally, biotechnology innovations, having been developed by the private sector, are proprietary. The intellectual property rights (IPRs) for these innovations are protected by patents that give innovators a limited monopoly power that affects the provision of genetically modified seeds to farmers. This power translates into higher prices charged by biotech seed companies for transgenic seeds and subsequent monopoly profits. For example,

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[1] Standard welfare calculations are meaningful only under the hypothesis of unchanged preferences (Hicks, 1940).

the price markup on the Roundup Ready soybean seed – the so called "technology fee" – has been kept at around $6.50/bag during the last few years, representing approximately a 40 percent markup on the price of conventional soybean seeds. Such monopolistic market structure in the input market cannot be ignored in the welfare analysis because, as Moschini and Lapan (1997) demonstrate, it would lead to overestimation of welfare gains due to innovation. The correct approach is to introduce the structure of the input market into a model and add the innovator-monopolist's profits in the input market to consumer and producer surplus measured in the output market in order to obtain correct welfare measure.

With chances of the emergence of sizable differentiated markets for grains becoming increasingly high, there is a clear need for a research framework that avoids the shortcomings of the existing models. Table 1.1 shows the results of a recent survey of a representative sample of 16,000 citizens of the European Union conducted on behalf of their member governments in order to assess the extent of consumer opposition to GM foods. These results overwhelmingly confirm the existence of a sizeable customer base with differentiated preferences. Fifty-five percent of those polled disagree that genetically modified food is not dangerous and fifty-nine percent believe that it can negatively impact the environment. Also, ninety-five 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.

Table 1.1. **Results of the 2001 Opinion Poll Conducted by the 15 EU Member States**

Would you say that you are more inclined to agree or disagree with each of the following propositions on genetically modified foods? (% EU 15)	Inclined to Agree	Inclined Not to Agree	Did Not Know
I want to have the right to choose	94.6	2.5	2.8
I want to know more about this kind of food before eating it	85.9	9.3	4.8
They should only be introduced if it is scientifically proven that they are harmless	85.8	8.0	6.1
I do not want this type of food	70.9	16.9	12.2
They could have negative effects on the environment	59.4	11.9	28.7
The dangers have been exaggerated by the media	33.1	44.3	22.6
This kind of food does not present any particular danger	14.6	54.8	30.6

Source: Eurobarometer (2001).

New research being carried out in this direction includes Desquilbet and Bullock (2001), who provide preliminary analysis of potential adoption of GM rapeseed with non-GMO market segregation in the European Union. Their model looks at individual consumers, crop handlers and farmers who differentiate between biotech and nonbiotech varieties to build up market supply and demand functions. This approach allows the researches to circumvent the problem of insufficient data for aggregate demand and supply calibrations. The model splits the world in two regions and is expected to be useful for answering welfare and policy questions.

Another example is Lapan and Moschini (2002), who 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 biotech and nonbiotech products, develops a new GM crop and adopts it, and 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) that has the ability to impose regulations and/or protectionist policies to limit its exposure to GMOs. This model is free of the three identified above major drawbacks of other existing research studies and provides analytical answers to questions about welfare impacts of introduction of GM products and subsequent protective policies of an importing country.

In this dissertation I develop a four-region world trade model that can also provide answers to most vital questions in conjunction with continuing production of GM crops in differentiated and segregated markets. The model is specifically tailored to the world soybean industry, which allows it to offer concrete estimates of the impacts of biotechnology in the market for soybeans and soybean products. 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 biotech. Unlike in Desquilbet and Bullock (2001), producer and consumer decisions are modeled explicitly in each region using aggregate demand and supply specifications. Linear regional demands are allowed to be differentiated or not depending on the region-specific consumer preferences, and the two varieties of a product are produced and delivered separately to consumers using costly segregation technology. The adoption rate of biotech product by its producers is determined endogenously in each region and not fixed by assumption as in most other studies[2]. One of the inputs in biotech production process is noncompetitively supplied by the innovator-monopolist residing in one of the regions. Both spatial and vertical equilibrium conditions are used to complete the model. The model is then calibrated, solved and simulated to study various policy scenarios. The restrictions on the particular parameter values used at the calibration stage are studied through an extensive sensitivity analysis.

The questions that can be addressed by the model include the direction of price changes and trade flows in biotech and nonbiotech markets, associated welfare distribution in different parts of the world and among consumers, producers and innovator-monopolist, and 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. A more detailed description of the model and scenarios that will be studied using it is provided in the next section. A brief overview of the world market for soybeans and soybean products is offered first in order to illustrate the main issues facing the soybean complex and relate them to modeling choices.

1.2. Research Focus: The Soybean Complex

Soybeans are one of the major oilseed crops along with cottonseed, rapeseed (canola), and sunflowerseed. 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 (see Table 1.2). Although the United States has always maintained the leading position in the world soybean markets, its share of global soybean and soybean product exports has steadily diminished in the past two decades, according to USDA statistics. One of the reasons for that is the emergence of the countries of South America, particularly Brazil and Argentina, as the second and third largest soybean producers in the world. In 1998-1999 crop year, Brazil produced 31 million metric tons (MT) of soybeans, Argentina – 20 million MT, and the United States – almost 75 million. Brazil and Argentina represent more than 90

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[2] In Lapan and Moschini (2002), the adoption in the importing country is set to zero, which in the language of this model is equivalent to the special case of the production ban on the GM product in the importing region.

Table 1.2. **Soybean Production and Utilization, 1998-1999** (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).

percent of the 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 in the form of seed, on-farm dairy feed and direct food uses such as tofu. A relatively larger share is exported to the Rest of the World consisting of the European Union, China, Japan, Mexico and other, smaller importing countries, with the EU being the world's single largest soybean importer. But for the most part soybeans are crushed to extract the soybean oil and meal.

Soybean oil constitutes approximately 18-19 percent of the soybean's weight and has both food and industrial uses. It accounts for about two-thirds of the vegetable oils and animal fat consumed in the United States, and is used mainly in salad and cooking oil, bakery shortening, and margarine. As in the case with soybeans, the United States, Argentina and Brazil are the three leading producers of soybean oil (see Table 1.3). Most of it is consumed at home but some – around 20 percent of worldwide production – is imported by the Rest of the World. Notably, the European Union is self-sufficient in soybean oil production, but many other countries import oil, including China and the countries of the Middle East and North Africa.

Table 1.3. **Soybean Oil Production and Utilization, 1998-1999** (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).

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 (U.S. Department of Agriculture, 2002b). About 98 percent of soybean meal consumption is used for livestock feed, and the remainder is used in human foods such as bakery ingredients and meat substitutes. As illustrated by Table 1.4, 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 Rest of the World.

Table 1.4. **Soybean Meal Production and Utilization, 1998-1999** (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).

In summary, the world's soybean market consists of the 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 of this dissertation. The main players in the soybean complex in terms of their production and trading status are the United States, South America, and the Rest of the World.

Soybeans have been among the first crops that took advantage of agricultural biotechnology. Since their commercial introduction in 1996, herbicide-tolerant Roundup Ready soybeans gained rapid acceptance among U.S. and Argentine farmers (see Table 1.5). In the 1998-1999 marketing year, the adoption rate was 36% 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 America, Brazil and Argentina took different paths with respect to adopting Roundup Ready soybeans due to 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 Rest of the World, the present model distinguishes the regions that I call Brazil and Argentina. Brazil region includes the countries of Brazil and Paraguay, while Argentina region includes all other countries of

Table 1.5. **Acreage and Adoption of RR Soybeans** (Million Ha)

	1997	1998	1999	2000	Adoption Rate 1998-1999[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

[a] Marketing year (September – August)

Source: James (1998, 2000)

South America. This ensures that Brazil and Argentina regions cover all of South America, while the Rest of the World represents European and Asian markets.

Some of the groundwork for the forthcoming analysis has been already done by Moschini, Lapan and Sobolevsky (2000), who developed a model to evaluate the welfare effects of the Roundup Ready (RR) technology for soybean production. That analysis was carried out under the assumption – unsatisfactory in light of the present discussion – that RR soybeans represented a process innovation and therefore conventional and RR soybean, soybean oil and soybean meal varieties were perfect substitutes in consumption. By dividing the world into three regions, the United States, South America and the Rest of the World, they estimated welfare effects – properly accounting for the proprietary nature of the RR technology – for different adoption patterns and market structures.

The goal of this dissertation is to capitalize on the Moschini, Lapan and Sobolevsky model and take it to the next level by increasing its dimensionality, introducing differentiated linear demands in the Rest of the World, providing a modeling capability to have differentiated linear demands in the other three regions as well, and simulating a series of relevant policy scenarios. In the model, product differentiation applies only to soybeans and soybean oil because, to date, there is no empirical evidence of biotech-based product differentiation in the soybean meal sector as almost none of it is used in the production of human food. 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 so that while at equal prices both varieties are still consumed, the demand for the RR variety vanishes as its price exceeds the price of the conventional counterpart. As such, the RR product represents a peculiar type of product innovation – one that is simultaneously cost-reducing to farmers and carrying a *negative* value in the product's characteristics space of some consumers.

The specification of supply is based on Moschini, Lapan and Sobolevsky (2000) and is extended to account for costs of separating RR and conventional soybeans along the supply chain. It is assumed that this separation is achieved by a constant-cost segregation technology. RR soybean seed is sold by an innovator-monopolist at a premium. Also, 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), which have become quite important in the last few years.

The model is 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, and is solved for several scenarios. First, there is a free trade scenario with no government intervention in any region. This scenario provides estimates of worldwide RR adoption rates that are based on private economic decisions and shows how welfare of agents changes with the introduction of the RR technology. Also, it serves as a point of comparison for the regional production and import policy scenarios and allows to evaluate their economic efficiency.

The second scenario looks at the case of a production subsidy in the United States. The interest in this scenario is not purely theoretical because, as explained in Chapter 3, this subsidy has been sizable over the past several years and provided a boost to the soybean acreage in the United States. Taking the form of LDPs, the subsidy has the objective of providing a revenue floor to farmers and is expected to offer the same price to both conventional and RR soybean producers. This provides an incentive to U.S. farmers to grow only less costly RR soybeans and can in theory lead to immiserizing growth.

The next three scenarios look at production bans on RR soybeans and soybean products in the Rest of the World and Brazil individually and together. The Rest of the World region includes the countries of the European Union, Japan and several others 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. Similarly, Brazil to date has not adopted RR soybeans despite their wide popularity in the neighboring Argentina and is seen as trying to differentiate itself from other soybean exporting nations by establishing itself as a biotech-free soybean region and thus avoiding segregation costs. Therefore, these ban scenarios represent the reality of today's soybean industry and the question of interest is whether these policies are justified from an economic point of view and what is their impact on the United States.

Not only can the Rest of the World impose a production ban, but it can also choose to ban consumption of RR products altogether. This may happen, for example, in response to a

GMO scare similar to the infamous StarLink fiasco, when a GM corn variety not approved for human consumption found its way into food products because of a failed segregation procedure. Or, imports of the RR variety may cease because of prohibitively expensive mandatory labeling requirements imposed by the Rest of the World's regulators. In any case, the implications of an import ban in the Rest of the World must be severe for such exporting regions as the United States and Argentina, as they will have to divest themselves from optimally high levels of adoption of the RR technology. I consider two scenarios with the import ban in the Rest of the World: one with Brazil implementing the simultaneous RR production ban and one without.

The rest of the dissertation is organized as follows. A short survey of the literature on modeling product differentiation along with detailed specification of the demand function used in the present model is provided in Chapter 2. Supply side discussion is provided in Chapter 3. Chapter 4 analyzes the trade and market equilibrium conditions. Calibration of the model's parameters is discussed in Chapter 5, and analysis of results in different policy scenarios is offered in Chapter 6. Sensitivity analysis of major findings is provided in Chapter 7, followed by conclusions in Chapter 8. Appendices and references conclude the dissertation.

CHAPTER 2. THE MODEL: DEMAND

Introducing a product innovation in the agricultural trade model requires specifying its aggregate demand system (a.d.s.) so that two separate downward-sloping demands – for conventional and RR varieties – exist in the post-innovation period both for soybeans and soybean oil. Also, the pre-innovation demand for the conventional variety and the post-innovation demand for the *de facto* RR variety in the world with no segregation technology should satisfy the same preferences to permit welfare calculations. Thus, in this model the demand specification will rely on standard approaches used in modeling new and differentiated goods.

2.1. New and Differentiated Products

A conceptual difficulty with analyzing the welfare implications of new products lies in the fact that such analysis requires comparing pre- and post-innovation states of the world that have different dimensions in product space. This issue has received the closest attention in the literature concerning proper measurement of the cost-of-living index in the face of new or disappearing goods (e.g., Feenstra 1994, Hausman 1999). Oi (1997) traces back the roots of the proposed solution to works of Fisher and Shell (1968), who showed that new products can 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.

The two distinguished types of product differentiation are *horizontal* and *vertical.* If two products can be described by a set of characteristics, then they are horizontally differentiated when the first contains more of some characteristics and less of the others relative to the second product, so that rational consumers may like more the first or the second product depending on what characteristics are relatively more valuable to them. The two products are vertically differentiated when the first contains more of some or all characteristics relative to the second product, so that rational consumers, *ceteris paribus*, would always select the first.

The two leading groups of models that are used in studying product differentiation are the *product characteristics* models (e.g., Hotelling, 1929; Lancaster, 1979; see also Helpman and Krugman, 1989) and the *traditional consumer-theory* models (e.g., Dixit and Stiglitz, 1977; see also Helpman and Krugman, 1989). The models can also be distinguished by whether consumers are considered to be *heterogeneous* or *homogeneous*. Consumer heterogeneity is modeled by introducing a statistical distribution either over income or some parameter describing the individual consumers' preference towards a product characteristic. Both vertical and horizontal differentiation can be modeled with either specification of consumers.

Whereas product characteristics models usually require quite detailed modeling of individual consumer preferences, traditional consumer-theory models of product differentiation tend to be too symmetric to realistically represent substitution patterns among product varieties (Hausman, 1997). As such, they are not suitable for most aggregate-level models of differentiated markets. In the latter models, one would like to specify an aggregate demand system that meets some particular research agenda and not bother with the details of individual agents' behavior. A relevant question in that case is whether the chosen a.d.s. specification is consistent with a preference structure that describes particular consumer behavior in a differentiated market. Anderson, de Palma and Thisse (1989) attempt to answer this question by investigating conditions under which an aggregate demand system for differentiated products can be derived from a characteristics model with heterogeneous consumers. They consider the a.d.s. that satisfy gross substitutes property and successfully show that the systems with aggregate demands that (i) are functions of price differences, or (ii) are derived from the CES utility, or (iii) have the form $Q_i = f_i(p_i)/\sum f_j(p_j)$, where $f_i(\cdot) > 0$, can be reconciled with some characteristics model with heterogeneous consumers. Unfortunately, they cannot say anything about a.d.s. of other forms, including linear. Therefore, when the linear demand system is introduced below, direct references to an underlying preference structure of a representative consumer will be made.

2.2. Demand Specification

GMO labeling requirements introduced by the European Union and other countries, coupled with the availability of technology to test for GMO content, an increasing interest by food companies in identity preservation of genetically unmodified food ingredients (Ballenger, Bohman and Gehlhar, 2000; Gachet *et al.*, 1999; Lin, Chambers and Harwood, 2000), and the apparent existence of a large mass of consumers conscious about consuming GM foods (Table 1.1) generate conditions for the emergence of separate demands for conventional and RR soybeans and soybean products. Underlying that, of course, is the presumption that some consumers are willing to pay to access foods that are free of genetically modified ingredients. As discussed earlier, consumers are likely to have such a preference because of health risk concerns about GM foods, because of concerns for the environment (for example, worsened biodiversity), and because of ethical reservations about genetically manipulated living organisms. Hence, the reasonable conclusion is that, at present, RR soybeans and soybean products are perceived in differentiated markets as imperfect and weakly inferior substitutes to the conventional varieties.

To understand better the notion of weakly inferior substitutes, let $Q^0(p^0,p^1)$ be the aggregate demand for good 0 and $Q^1(p^0,p^1)$ be the aggregate demand for good 1, with p^0 and p^1 denoting their respective prices. Note that Lapan and Moschini (2002) provide a clear discussion of what is meant by "weakly inferior," and define the aggregate demands $Q^0(p^0,p^1)$ and $Q^1(p^0,p^1)$ from a population of consumers with heterogeneous tastes and quasilinear preferences. In what follows, good 0 represents the conventional (traditional) soybean product of interest, and good 1 represents the corresponding RR soybean product. Assuming that these goods are measured in the same physical units, if goods 0 and 1 were perfect substitutes their indifference curve would be a straight 45-degree line illustrated in Figure A1, Appendix A. Were these goods to be imperfect substitutes, on the other hand, the indifference curve would look like that in Figure A2, reflecting the notion that, as more and more of one good is consumed, the consumer would be willing to give up an increasing amount of that good in exchange for a unit of the second good (at a fixed level of utility), i.e., the marginal rate of substitution is decreasing. An important feature of the general substitution case is that both goods are typically consumed at the relevant prices.

When goods are imperfect substitutes, but ceteris paribus good 0 is always preferred to good 1, the indifference curve of the representative consumer may be represented as in Figure A3. Note that in this case preferences are strictly convex (reducing consumption of good 0 by a unit always requires more than one unit increase in consumption of good 1 to keep the utility constant). For the consumer to demand a positive quantity of the new product, therefore, it must be that $p^1 < p^0$. And, as illustrated by the associated demand curve represented in Figure A4, demand for the new product vanishes at $p^1 = p^0$. Whereas the presentation of preferences in Figures A3-A4 can be consistent with our prior beliefs on the structure of GM and non-GM food demand, it is perhaps overly restrictive. For example, if we think of the aggregated demands $Q^0(p^0, p^1)$ and $Q^1(p^0, p^1)$ arising from a population of consumers with heterogeneous attitudes towards GMOs, the foregoing structure would seem to rule out that some consumers may be perfectly indifferent between good 0 and good 1 as long as $p^1 = p^0$. To allow for this possibility we can modify the preference ordering of the representative consumer as in Figure A5, where the flat region on the indifference curve allows for a portion of demand to be indifferent in the sense just discussed. As the associated demand curve in Figure A6 makes clear, some nonzero demand for the new good is possible at $p^1 = p^0$, although demand for the new product vanishes if $p^1 > p^0$.

Based on the foregoing discussion, I specify a 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 (without wealth effects) 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:

$$\text{(2.1)} \quad \left.\begin{aligned} Q^0 &= a_0 - b_0 p^0 + c p^1 \\ Q^1 &= a_1 - b_1 p^1 + c p^0 \end{aligned}\right\} \; \textit{if } p^0 > p^1$$

where all parameters are strictly positive. Note that the symmetry condition is maintained, such that this demand system is integrable into well defined (quasi-linear) preferences, a condition that will become important when making welfare evaluations. The total demand that is implied by this structure is:

$$Q^T = (a_0 + a_1) - (b_0 - c)p^0 - (b_1 - c)p^1 \tag{2.2}$$

Note that the curvature conditions associated with (2.1), $b_0 > c$ and $b_1 > c$, imply that the total demand is non-increasing in either price. Also, note that at $p^0 = p^1$ (2.1) 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 conventional variety. Therefore:

$$\left.\begin{array}{l} Q^0 \in \{a_0 - (b_0 - c)p, (a_0 + a_1) - (b_0 + b_1 - 2c)p\} \\ Q^1 \in \{0, a_1 - (b_1 - c)p\} \end{array}\right\} \quad \text{if } p \equiv p^0 = p^1 \tag{2.3}$$

With $p^0 < p^1$ demand for Q^1 vanishes, and:

$$\left.\begin{array}{l} Q^0 = (a_0 + a_1) - (b_0 + b_1 - 2c)p^0 \\ Q^1 = 0 \end{array}\right\} \quad \text{if } p^0 < p^1 \tag{2.4}$$

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

$$V(p^0, p^1, I) = I - \left(a_0 p^0 + a_1 p^1 - \frac{1}{2} b_0 (p^0)^2 - \frac{1}{2} b_1 (p^1)^2 + c p^0 p^1 \right) \tag{2.5}$$

where I is income and the price of the numeraire good is normalized to one.

A graphic illustration of the system (2.1) – (2.4) is given in Figures A7 and A8, Appendix A. Bold lines in Figure A7 trace the demand for the conventional variety when RR price is fixed at a particular level p^1 marked on vertical axes. For a higher $\tilde{p}^1$, conventional demand traces a dashed $\tilde{Q}^0$. Similarly, the demand for the RR variety in

Figure A8 traces the bold lines when conventional price is fixed at marked level p^0, and dashed lines ($\tilde{Q}^1$) when conventional price goes up to $\tilde{p}^0$.

Following the standard approach of dealing with new products discussed in Chapter 2.1, the specification in equation (2.4) will be used to describe the differentiated market before the introduction of RR products, with RR reservation price implicitly set above p^0 (i.e., we imagine that 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 (I 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 $\bar{p}^0 \equiv (a_0 + cp^1)/b_0$ drives the demand for conventional product to zero. Therefore:

$$(2.6) \quad \left.\begin{aligned} &Q^0 = 0 \\ &Q^1 = a_1 + \frac{ca_0}{b_0} - \left(b_1 - \frac{c^2}{b_0}\right)p^1 \end{aligned}\right\} \quad if\ p^0 \geq \bar{p}^0$$

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 (2.1) – (2.4) for all prices in the nonnegative quadrant of $\Re^2$ is represented in Figures A9 and A10. 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 A10.

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

$$(2.7) \quad \varepsilon^{11} = -b_1\frac{p^1}{Q^1}, \quad \varepsilon^{10} = c\frac{p^0}{Q^1}, \quad \varepsilon^{00} = -b_0\frac{p^0}{Q^0}, \text{ and } \varepsilon^{01} = c\frac{p^1}{Q^0}.$$

It may also 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:

$$(2.8) \quad \varepsilon^{T} = \frac{\partial Q^{T}\left(tp^{0}, tp^{1}\right)}{\partial t} \frac{t}{Q^{T}} \bigg|_{t=1} = \frac{-\left(b_{0}-c\right)p^{T} - \left(b_{1}-c\right)p^{T}}{Q^{T}\left(p^{0}, p^{1}\right)}$$

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

$$(2.9) \quad Q^{U}(p) = a - bp$$

where p is either the own price of undifferentiated soybean meal or the price of the cheaper or the only available variety (could be a conventional variety) in a region inhabited by consumers who do not have differentiated tastes. The own price elasticity of the demand (2.9) is defined as:

$$(2.10) \quad \varepsilon^{UU} = -b\,p/Q^{U}\,.$$

CHAPTER 3. THE MODEL: 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 below, and its extensions necessary for the analysis of scenarios concerned with in this dissertation are discussed next.

3.1. Undifferentiated and Non-segregated Market

Moschini, Lapan and Sobolevsky (2000) assume 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 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).[3] 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:

$$(3.1) \qquad \pi(p_B, r, w) = \max_{z,x}\{p_B f(z,x) - r \cdot z - wx\}$$

is written in the additive form:

$$(3.2) \qquad \pi(p_B, r, w) = \tilde{\pi}(p_B, r) - \delta w$$

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

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:

$$(3.3)\qquad \frac{\partial \pi(p_B,r,w)}{\partial p_B}=\frac{\partial \tilde{\pi}(p_B,r)}{\partial p_B}\equiv y(p_B,r)$$

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:

$$(3.4)\qquad L=L(\pi)$$

Thus, total supply of soybeans is written as:

$$(3.5)\qquad Y_B=L(\tilde{\pi}(p_B,r)-\delta w)\cdot y(p_B,r)$$

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:

$$(3.6)\qquad \tilde{\pi}^1(p_B,r)>\tilde{\pi}^0(p_B,r)$$

Specifically, the two per-hectar profit functions are parameterized as follows:

$$(3.7)\qquad \pi^0=A+\frac{G}{1+\eta}p_B^{1+\eta}-\delta w \qquad \text{for the conventional technology, and}$$

$$(3.8)\quad \pi^1 = A + \alpha + \frac{(1+\beta)G}{1+\eta} p_B^{1+\eta} - \delta w(1+\mu) \qquad \text{for the RR technology,}$$

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

$$(3.9)\quad \Delta\pi = \alpha + \frac{\beta G}{1+\eta} p_B^{1+\eta} - w\delta\mu$$

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.

Moschini, Lapan and Sobolevsky (2000) make no attempt to model the innovator-monopolist's optimizing behavior and the new technology's diffusion process leading to a complete adoption of RR soybeans in this non-segregated market setting. Instead, they rely on the observed behavior of agents and set RR seed markup and adoption rates exogenously.

Thus, for an exogenously 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:

$$(3.10)\quad \bar{\pi} = A + \rho\alpha + \frac{(1+\rho\beta)G}{1+\eta} p_B^{1+\eta} - \delta w(1+\rho\mu)$$

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:

$$(3.11)\quad L = \lambda\bar{\pi}^\theta$$

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 more convenient to express θ in terms of more readily observed elasticity of land supply with respect to soybean prices ψ:

$$(3.12)\quad \theta = \frac{\pi}{p_B y}\psi = r\psi,$$

where *r* is the farmer's rent share in unit revenue. Finally, the aggregate supply of soybeans in a non-segregated market is written as:

$$(3.13)\quad Y_B = \lambda\left[A + \rho\alpha + \frac{(1+\rho\beta)G}{1+\eta}p_B^{1+\eta} - \delta w(1+\rho\mu)\right]^{\theta}(1+\rho\beta)Gp_B^{\eta}$$

As was mentioned before, this model is based on the assumption that farmers are homogeneous. Clearly, this assumption is a simplification. Although recent analysis by OECD (1999) confirms that this modeling approach is appropriate in that the RR technology seems to benefit farmers by reducing costs and, to a lesser extent, by increasing yields, which is often offset by the technology fees paid to seed companies, this general result is subject to high variation on a farm level, and as Nielsen and Anderson (2000) point out, adoption of RR soybeans should be explained, at least in part, by heterogeneity of farm characteristics, preference for simplifying the production process and expectation of advantages of early adoption due to learning. To keep analysis tractable and the scope of the dissertation manageable, these considerations are not developed further in what follows.

3.2. The Market with Differentiated Products and Segregation Costs

The requirement to maintain two distinct – conventional ("nonbiotech") and RR ("biotech") – varieties of soybeans in order to serve differentiated soybean product markets gives rise to additional production and marketing costs associated mainly with the nonbiotech variety – the costs that would not exist otherwise. While it is possible that producers of biotech soybeans may be required to bear some additional cost, for example the cost of mandatory labeling, it is obvious that soybean consumers who do not have differentiated tastes (or, equivalently, regard the biotech and nonbiotech products as perfect substitutes) will be indifferent between consuming nonbiotech and biotech varieties. Consequently, it will be the production and marketing chain of nonbiotech soybeans that will bear most of the additional cost, as only GMO-conscious consumers will demand certification that the product they consume is free from genetically modified material at a particular tolerance level (Golan and Kuchler, 2000).[4]

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 Lapan and Moschini (2002) point out in their paper, mandatory labeling that imposes an additional, wasteful cost on the biotech market segment cannot be ruled out completely because it is actually being implemented in the European Union, possibly as a protectionist measure. In what follows, however, I do not model explicitly the impact of additional regulatory costs that can be imposed on RR soybean and soybean product imports. Indirectly, these costs can be accounted for in the model by appropriately adjusting the estimated profit advantage of the RR technology in the exporting regions, but quantifying them is a difficult task at present as data is scarce. In the event of prohibitively high regulatory costs the biotech exports will simply cease, which will be equivalent to an import ban discussed at length in Chapter 6. Thus, the model's attention is focused on the cost of separating GM-free products in the supply and marketing chain.

Separation of nonbiotech soybeans can be accomplished by either crop segregation or identity preservation (Lin, Chambers and Harwood, 2000). Crop segregation requires separation of nonbiotech beans at all levels of production and 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 biotech content

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[4] There exists a theoretical possibility that in regions with low levels of adoption of RR technology biotech soybean producers and the marketing chain will be mandated to bear most of the additional cost of ensuring their product's separation from the nonbiotech varieties. However, the successful practical implementation of such mandate and its enforcement that would instill the desired confidence in the purity of conventional soybeans seems very unlikely.

at various points in the marketing system. Identity preservation is a more stringent system that typically involves containerized shipping.

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 nonbiotech soybeans, which may be expected to reduce farmers' transportation costs. For as much as 95% of U.S. elevators, separating nonbiotech 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 nonbiotech crop, as well as costs of "storing air" will fall per ton of nonbiotech soybeans if its quantity were to increase. Economies of scale in shipping, especially if it is containerized, may be less evident unless shipments of nonbiotech 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.

Given these considerations, unit segregation cost φ in general should be a non-increasing function of conventional soybean supply Y_B^0:

$$(3.14)\quad \varphi = f(Y_B^0), \quad f'(\cdot) \le 0$$

For the purposes of the present model, however, given that there is little factual information on the extent of the economies scale and their relationship with the share of nonbiotech soybean supply in the total soybean production, it is assumed that the segregation technology is described by a constant cost function:

$$(3.15)\quad \varphi = \begin{cases} \text{constant}, & \rho > 0 \\ 0, & \rho = 0 \end{cases}$$

In what follows, we will consider segregation costs only to the extent they arise between the moment a farmer sells his crop to the elevator and the moment soybeans reach the domestic user or are prepared to be shipped to the final consumer or crusher overseas. In other words, φ represents a wedge between the producer and 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 (3.7), (3.8) are defined as follows:

(3.16) $\pi^0 = A + \frac{G}{1+\eta}\left(p_B^0 - \varphi\right)^{1+\eta} - \delta w$ for conventional technology,

(3.17) $\pi^1 = A + \alpha + \frac{(1+\beta)G}{1+\eta}(p_B^1)^{1+\eta} - \delta w(1+\mu)$ for RR technology,

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 $p_B^0 - \varphi$.

Whereas in Chapter 3.1 we assumed that the adoption rate ρ is determined exogenously, here 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., $\pi^0 = \pi^1$. Theoretically, this is guaranteed by the implicit optimal choice of μ, the markup charged by the monopolist selling the RR seed that appears in the definition of π^1. The problem of this monopolistic seed producer is to maximize his overall profit in all countries where RR seed is sold, subject to farmers' incentive compatibility constraint $\pi^1 \geq \pi^0$ in each country. As pointed out in Moschini, Lapan and Sobolevsky (2000), this optimization problem must incorporate equilibrium in other markets, in particular the soybean market, such that $\mu = \mu(p_{B,i}^0, p_{B,i}^1, r_i, ...)$, where *i* denotes regions and *r* is the vector of other than seed input prices. As explained earlier, the equilibrium in the soybean market with both varieties produced rules out a non-binding incentive compatibility constraint.

In what follows we again do not solve for the optimal choice of the monopolist and the model relies instead on observed behavior for the parameter μ that measures the markup on RR seed prices. Definitions (3.16) and (3.17) 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 (3.11) as a function of average land rents, but now:

$$\bar{\pi} = \begin{cases} \pi^0, & \rho = 0 \\ (1-\rho)\pi^0 + \rho\pi^1 = \pi^0 = \pi^1, & \rho \in (0,1) \\ \pi^1, & \rho = 1 \end{cases} \tag{3.18}$$

The region's adoption rate ρ or, equivalently, the land allocation between conventional and RR soybeans is endogenously determined in equilibrium. Endogenizing inter-variety land allocation represents a major difference in modeling supply relative to Moschini, Lapan and Sobolevsky (2000).

Given the definition of ρ, RR and conventional soybeans will have ρL and $(1-\rho)L$ hectares of land allocated to them, respectively, and since soybean supply is the product of allocated land and yield, the aggregate supply of each soybean variety in each region can be written in equilibrium due to (3.18) as:

$$Y_B^0 = \lambda\left[A + \frac{G}{1+\eta}(p_B^0 - \varphi)^{1+\eta} - \delta w\right]^\theta (1-\rho)G(p_B^0 - \varphi)^\eta \tag{3.19}$$

$$Y_B^1 = \lambda\left[A + \alpha + \frac{G(1+\beta)}{1+\eta}(p_B^1)^{1+\eta} - \delta w(1+\mu)\right]^\theta \rho(1+\beta)G(p_B^1)^\eta \tag{3.20}$$

3.3. U.S. Price Support Policies

The above supply equations were obtained under the assumption of no government intervention in the soybean sector. In reality, there exists a large number of countries in the world that pursue high price support policies to encourage agricultural production, with some of them simultaneously offering export subsidies to expand exports (Murphy, Furtan, and Schmitz, 1993). A question that arises in the context of the present model, then, concerns the effect that such price distortions have on the benefit that the world and individuals regions derive from biotechnology innovations resulting in technological change. As the following review of the literature shows, the adverse effects of price distortions can be quite high and even lead to immiserizing growth, with their actual size being an empirical question.

With rare exceptions, the early research on benefits of R&D used closed models or trade models where agricultural price supports were absent, and reported impressive returns to R&D. A number of more recent articles, summarized and generalized in Alston and Martin (1995), explain how price-distorting policies may affect the size and distribution of returns to research, while Murphy, Furtan, and Schmitz (1993) even demonstrate the possibility of immiserizing technical change. In fact, the latter finding is not very new, as Johnson (1967) and Bhagwati (1968) have demonstrated a long time ago that growth may be welfare-reducing due to various trade policy distortions and terms-of-trade effects caused by market power in trade. For example, when domestic producers in the large exporting country enjoy a fixed price support, the research-induced supply shift, no matter parallel or pivotal,[5] has a range of implications. The welfare-reducing implications are the leftward shift in the rest of the world's excess demand due to the spillover of new technology overseas and the increase in export subsidy bill at home caused by higher exports and lower world price. The welfare-enhancing implications are the increase in producer and consumer surplus at home and overseas.[6] Murphy, Furtan, and Schmitz (1993) show that taking most of these effects

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[5] Whether the supply shift is parallel or pivotal matters for the producer surplus in home country. Alston and Martin (1995) show that with inelastic demand pivotal supply shift always makes producers worse off, while with parallel shift they are necessarily better off. In the present model, because of nonlinearities the supply shift may be seen as a mixture of a parallel shift and a pivot.

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

into account – they assume domestic consumers are locked into high support price 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 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.

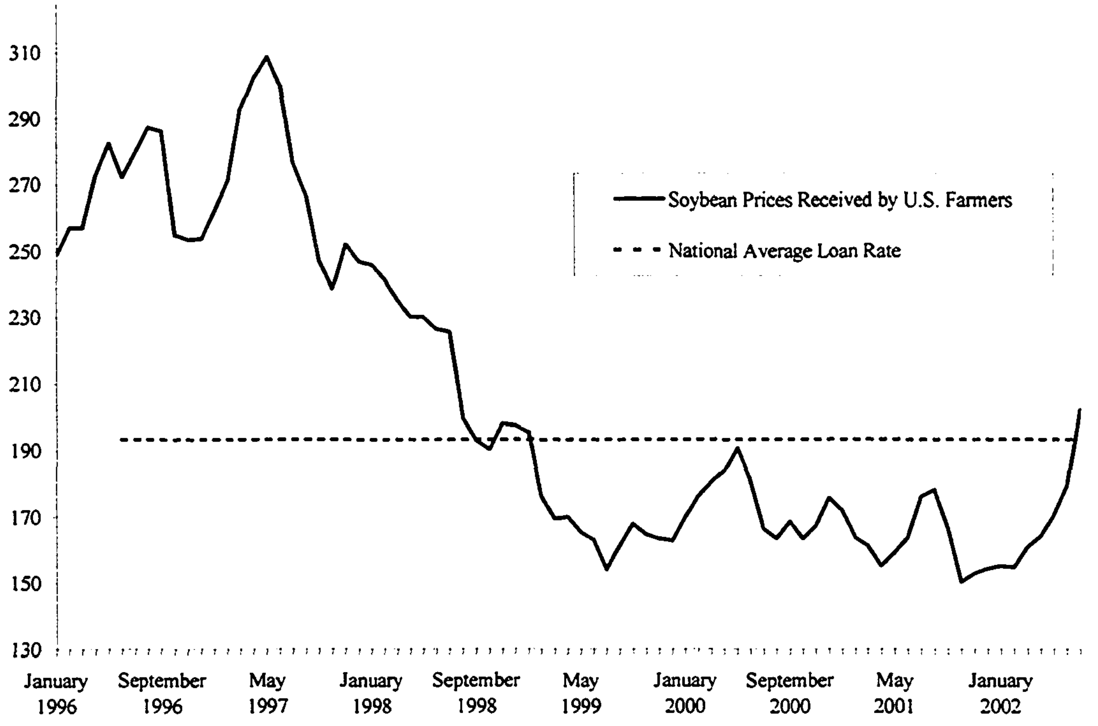
Given such importance of price distortions for welfare analysis, we will explicitly model them in the region where they appear to be most apparent and relevant – the United States. The United States soybean farmers benefit from the Federal Agriculture Improvement and Reform Act of 1996, which established that nonrecourse marketing assistance loans and loan deficiency payments (LDPs) will be administered for the 1996 through 2002 crops (U.S. Department of Agriculture, 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 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% of the simple average price received by producers during the marketing years for the immediately preceding 5 crops, excluding the highest and lowest prices, but no less than $4.92 per bushel ($180.76 per metric ton) and no more than $5.26 per bushel ($193.25 per metric ton). The 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 PCP is higher than that combined amount. If PCP is lower than the loan rate plus interest, the loan is repaid by paying just 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 PCP if the latter is lower at the requested date. Thus, price support programs give farmers the following options:

- sell the crop for cash and take an LDP;

- take an LDP, store the crop, and lock in a futures price;
- take a loan, wait for favorable market conditions, sell the crop and repay the loan;
- take a loan, then realize a marketing loan gain by repaying it at lower PCP;
- take a loan and deliver the collateral crop to the CCC at maturity.

Note that since the fifth option is likely to require a prior sale of the crop at the price close to PCP, and the third option seems rather unlikely (Hayes and Babcock, 1998), the opportunities to receive a price greater than the loan rate are presented only in the second and forth options. In what follows, the second option is assumed away for simplicity.

Figure 3.1 offers a glimpse at the extent of the impact this price support program has had on U.S. soybean farmers in recent years. Whereas the 1996 and 1997 soybean crops did not benefit from LDPs, the 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



Source: U.S. Department of Agriculture (2000a, 2001)

Figure 3.1. **U.S. Soybean Prices and Price Support Rates, 1996-2002** ($/MT)

2002. Only in the summer of 2002 did the 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 can continue to do so if prices decline again. As the analysis in Chapter 5 suggests, U.S. farmers took full advantage of LDPs as soon as they became available during the 1998-1999 crop year. Disregarding this policy in the present model would therefore be a gross mistake.

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 (3.19) and (3.20) for the United States may be rewritten as

$$(3.21)\quad Y_B^0 = \lambda\left[A + \frac{G}{1+\eta}(\overline{p}_B^0)^{1+\eta} - \delta w\right]^\theta (1-\rho)G(\overline{p}_B^0)^\eta$$

$$(3.22)\quad Y_B^1 = \lambda\left[A + \alpha + \frac{G(1+\beta)}{1+\eta}(\overline{p}_B^1)^{1+\eta} - \delta w(1+\mu)\right]^\theta \rho(1+\beta)G(\overline{p}_B^1)^\eta,$$

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

CHAPTER 4. TRADE AND MARKET EQUILIBRIUM

As explained in Chapter 1, the world economy in this model is divided into four regions: the United Stated (subscripted U), Brazil (subscripted Z, includes Brazil and Paraguay), Argentina (subscripted A, includes all other countries of South America), and the Rest of the World (subscripted R, abbreviated ROW). 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. It allows learning whether different regions are affected differently by the RR technology. In addition, it allows us to model possible future region-specific policy actions 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 in each product, each variety and in 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.

4.1. Equilibrium Conditions

I 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 outlined in chapters 2 and 3 are as follows:

$$(4.1) \qquad \sum_{i=U,A,Z,R} Q^0_{B,i}(p^0_{B,i}, p^1_{B,i}) + \frac{1}{\gamma_O} \sum_{i=U,A,Z,R} Q^0_{O,i}(p^0_{O,i}, p^0_{O,i}) = \sum_{i=U,A,Z,R} Y^0_{B,i}(p^0_{B,i}, \rho_i)$$

$$(4.2)\quad Q^{0}_{B,i}(p^{0}_{B,i},p^{1}_{B,i})+\frac{1}{\gamma_O}Q^{0}_{O,i}(p^{0}_{O,i},p^{1}_{O,i})=Y^{0}_{B,i}(p^{0}_{B,i},\rho_i),\quad i\in I^0\subset\{U,A,Z,R\}$$

$$(4.3)\quad \sum_{i=U,A,Z,R}Q^{1}_{B,i}(p^{0}_{B,i},p^{1}_{B,i})+\frac{1}{\gamma_O}\sum_{i=U,A,Z,R}Q^{1}_{O,i}(p^{0}_{O,i},p^{1}_{O,i})=\sum_{i=U,A,Z,R}Y^{1}_{B,i}(p^{1}_{B,i},\rho_i)$$

$$(4.4)\quad Q^{1}_{B,i}(p^{0}_{B,i},p^{1}_{B,i})+\frac{1}{\gamma_O}Q^{1}_{O,i}(p^{0}_{O,i},p^{1}_{O,i})=Y^{1}_{B,i}(p^{1}_{B,i},\rho_i),\quad i\in I^1\subset\{U,A,Z,R\}$$

$$(4.5)\quad \frac{1}{\gamma_M}\sum_{i=U,A,Z,R}Q_{M,i}(p_{M,i})=\frac{1}{\gamma_O}\left(\sum_{i=U,A,Z,R}Q^{0}_{O,i}(p^{0}_{O,i},p^{1}_{O,i})+\sum_{i=U,A,Z,R}Q^{1}_{O,i}(p^{0}_{O,i},p^{1}_{O,i})\right)$$

$$(4.6)\quad p^{0}_{B,i}+m_i=\gamma_M p_{M,i}+\gamma_O p^{0}_{O,i},\quad i\in I^0\cup I^2, I^2\subset\{U,A,Z,R\}\setminus I^0$$

$$(4.7)\quad p^{1}_{B,i}+m_i=\gamma_M p_{M,i}+\gamma_O p^{1}_{O,i},\quad i\in I^1\cup I^3, I^3\subset\{U,A,Z,R\}\setminus I^1$$

$$(4.8)\quad \begin{array}{lll} \pi^0_i(p^0_{B,i})=\pi^1_i(p^1_{B,i}) & \text{if} \quad \rho_i\in(0,1) & \\ \pi^0_i(p^0_{B,i})\geq\pi^1_i(p^1_{B,i}) & \text{if} \quad \rho_i=0 & i=U,A,Z,R \\ \pi^0_i(p^0_{B,i})\leq\pi^1_i(p^1_{B,i}) & \text{if} \quad \rho_i=1 & \end{array}$$

$$(4.9)\quad \left|p^0_{B,i}-p^0_{B,j}\right|\leq t^0_{B,ij},\ i,j=U,A,Z,R,\ i\neq j$$

$$(4.10)\quad \left|p^1_{B,i}-p^1_{B,j}\right|\leq t^1_{B,ij},\ i,j=U,A,Z,R,\ i\neq j$$

$$(4.11)\quad \left|p^0_{O,i}-p^0_{O,j}\right|\leq t^0_{O,ij},\ i,j=U,A,Z,R,\ i\neq j$$

$$(4.12)\quad \left|p^1_{O,i}-p^1_{O,j}\right|\leq t^1_{O,ij},\ i,j=U,A,Z,R,\ i\neq j$$

$$(4.13)\quad \left|p_{M,i}-p_{M,j}\right|\leq t_{M,ij},\ i,j=U,A,Z,R,\ i\neq j$$

Equations (4.1) and (4.3) are market clearing equations requiring that the total world soybean demand for direct use and processing equals world supply in each variety. Equations (4.2) and (4.4) 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 (4.1), the number of elements in I^0 should not exceed 3. The same applies to I^1. Equation (4.5) ensures that the soybean equivalents of oil and meal demands are the same on aggregate.

Equations (4.6) and (4.7) 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). Due to 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 (4.6) 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 (4.7) 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 (4.8) 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 (4.9) through (4.13) define the spatial configuration of prices. Because differentiated markets for biotech and nonbiotech 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 Rest of the World, between Brazil and the Rest of the World, and between Argentina and the Rest of the World, but whether this is the case in differentiated markets will be determined by equilibrium. $t^k_{m,ij}$ denote price differentials (transportation costs) that are assumed symmetric for each pair of regions.[7] Whenever trade between two regions in a particular product variety exists, the corresponding inequality becomes the equality; otherwise the inequality must be strict. An assumption about direction of trade is necessary to replace absolute values by an appropriate sign.

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[7] See Chapter 5 on calibration and Table 5.2 for more information on price differentials.

The existence and uniqueness of equilibrium is guaranteed by the normal shape of demand and supply curves as defined in Chapters 2 and 3 (Samuelson, 1952). It must be realized, however, that the uniqueness property is subject to the continuity of the segregation cost function (3.15). The general positive-constant-cost specification of (3.15) becomes ambiguous at a corner solution, i.e., it may be difficult to justify a constant non-zero segregation cost in a region that fully specializes in growing conventional soybeans. The rationale for having a non-zero segregation cost in such region must be a risk of losing its full-specialization status, thus requiring continued testing and other procedures, which still does not justify the imposition of the cost that would be reasonable, for example, at a 20% adoption rate. In what follows, it is assumed – without any loss of generality – that a region producing only conventional soybeans pays no segregation cost.

I now assume that the soybean and soybean oil demands in the Rest of the World are the only differentiated demands in the system, while the U.S., Argentine and Brazilian consumers remain indifferent as 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 (4.1)-(4.13) more explicitly, in line with definitions of Chapter 2:

$$\begin{aligned}
& Q^0_{B,i}(p^0_{B,i}, p^1_{B,i}) \equiv 0, \quad i = U, A, Z \\
& Q^0_{O,i}(p^0_{O,i}, p^1_{O,i}) \equiv 0, \quad i = U, A, Z \\
(4.14) \quad & Q^1_{B,i}(p^0_{B,i}, p^1_{B,i}) \equiv Q^U_{B,i}(p^1_{B,i}), \quad i = U, A, Z \\
& Q^1_{O,i}(p^0_{O,i}, p^1_{O,i}) \equiv Q^U_{O,i}(p^1_{B,i}), \quad i = U, A, Z \\
& Q_{M,i}(p_{M,i}) \equiv Q^U_{M,i}(p_{M,i}), \quad i = U, A, Z, R
\end{aligned}$$

Were we to assume that all four regions have differentiated demands in soybeans and soybean oil, only the last of the five identities in (4.14) would apply.

A limitation of the equilibrium system (4.1) – (4.13) is that it does not allow one to recover 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 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 inter-regional 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:

$$(4.15)\quad ES^j_{B,i} = Y^j_{B,i} - Q^j_{B,i} - \frac{1}{\gamma_O} Q^j_{O,i} \qquad i = U, A, Z, R; \quad j = 0,1$$

We can call $ES^j_{B,i}$ 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:

$$(4.16)\quad ES_{M,i} = \frac{1}{\gamma_O}\left(Q^0_{O,i} + Q^1_{O,i}\right)\gamma_M - Q_{M,i} \quad i = U, A, Z, R$$

$ES_{M,i}$ is reported under the "Meal Exports" heading in the results tables available in the appendix.

4.2. Solution Algorithm

Given this setting, we are faced with the task of solving the spatial four-region three-good equilibrium model. The literature on spatial equilibrium models can be traced back to Samuelson (1952), who showed that in the partial-equilibrium (one commodity) context the problem of finding competitive equilibrium among spatially separated markets could be converted mathematically into a maximum problem. Defining the net social payoff function as the sum of areas under all regions' excess demand curves minus total transportation cost, Samuelson proved 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 suggested 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 made it easy to produce rigorous qualitative comparative statics predictions, but also showed how to actually solve some spatial equilibrium models in an era of limited computing resources. Takayama and Judge (1964, 1970) extended Samuelson's work to a multiple-commodity competitive equilibrium case and demonstrated that the problem, under the assumption of linear aggregate regional demand and supply functions, can be converted to a conventional quadratic programming problem[8] and solved using the available simplex methods. Takayama and Judge (1970, 1971) also showed that their approach would work not only for linear demand specifications that satisfy symmetry conditions (the type of the demand system used in (2.1)), but also for spatial models with asymmetric demand coefficients, and that the model can still be solved using 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 was just too high to justify nonlinear specifications. They provide an example of the Japan Ministry of Agriculture that started using the agricultural modeling

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[8] The problem of maximizing the quadratic function subject to linear inequality constraints.

system with general nonlinear functions in 1970's but had to scrap it eventually due to its high costs.

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, due to 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 the spatial equilibrium model defined earlier in this chapter directly, using available numerical techniques of solving the $N \times N$ systems of nonlinear equations.

The model (4.1) – (4.13) is solved using GAUSS, the software equipped with *eqSolve* procedure that solves $N \times N$ systems of nonlinear equations by inverting the system's Jacobian while iterating until convergence. Needless to say, all equations must be binding. In our case, however, the number of binding equations in (4.1) – (4.13) 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, which are discussed in detail in Appendix E. For example, when differentiated markets exist only in the Rest of the World, the size of the binding portion of (4.1) – (4.13) can be anywhere from N=5 to N=21.

GAUSS provides no capability to change the dimensions of the system of equations as it is being solved. Thus, in the case when differentiated markets exists only in the Rest of the World, the solution algorithm looks for the equilibrium by repeatedly solving the fluctuating-in-size binding portion of the system (4.1) – (4.13) over all possible combinations of the following assumptions:

- a region specializes in conventional soybeans, or in RR soybeans, or does not specialize – for each region;
- there is no trade in RR beans/oil;
- there is only one RR trade flow involving a pair of regions, in either direction, for all possible region pairs;

- 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);
- 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 (4.1) – (4.13). When a differentiated market equilibrium satisfying the system (4.1) – (4.13) is found, the model solves the benchmark pre-innovation undifferentiated equilibrium and computes consumer and producer surpluses, innovator-monopolist's profit, and subsidy to U.S. farmers.

A more detailed discussion of the solution algorithm and its implementation is provided in Appendix E.

CHAPTER 5. 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 1.2 – 1.4 in Chapter 1. The history of world adoption rates for RR soybeans is provided in Table 1.5 in Chapter 1, with adoption rates used in calibration shown in the last column of the table. Price data are in Table 5.1 below. U.S. prices for soybeans, oil and meal were taken to be

Table 5.1. **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							
US farm price[b]	233	205	263	274	230	176	230
US 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							
US (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							
US (Decatur)[c]	596	605	550	504	571	441	534
US (Decatur)[b]	595	606	545	496	569	438	531
US 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.[e]	539	608	537	514	608	452	544
Argentina, f.o.b.[c]	545	625	540	517	617	456	551
Argentina, f.o.b.[e]	543	623	533	515	614	453	548
Rotterdam, f.o.b.[c]	580	642	575	536	633	483	574

[a] Fiscal years (October to September)
[b] Source: U.S. Department of Agriculture
[c] Source: Oil World (2000)
[d] Percentage refers to protein content
[e] Source: Safras and Mercad

equal $176, $441 and $145 per MT, respectively. In the United States, the producer (farmer) price for soybeans was different from $176/MT due to LDPs; see Chapter 5.4 below. 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 Rest of the World being a net importer of soybeans and all soybean products, the spatial price differentials were taken at the levels used in Moschini, 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' f.o.b. prices for soybeans and soybean products are very close to each other (see Table 5.1). 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 rest of the World and at least a $10/MT U.S. transportation cost advantage over Argentina and Brazil due to distance and higher insurance costs. See Table 5.2 for individual transportation cost values.

5.1. Demand

The assumption is that, in a region with heterogeneous preferences with respect to biotech and nonbiotech crops, soybean demand will be differentiated. As far as soybean oil

Table 5.2. **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

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

is concerned, detection of GMOs in it depends on the degree of its refinement. Still, some concerned food manufacturers, such as baby food and EU 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 those regions where differentiation takes place. The current situation with soybean meal is the one where countries have no legislation concerning genetically modified 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 nonbiotech soybeans at present. However, feed labeling legislation is being drafted at least in the EU and can be imposed in the near future. For the time being, 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 no mass segregation of RR and conventional soybeans has taken place in the 1998-99 reference year, we can assume, as discussed in Chapter 2, that in that year $Q^0 = 0$ and $Q^1 = a_1 + c\bar{p}^0 - b_1 p^1$. Hence, for the observed total quantity demanded $\hat{Q}$ and price $\hat{p}$, it must be that:

$$(5.1) \quad \hat{Q} = a_1 + \frac{ca_0}{b_0} - \left(b_1 - \frac{c^2}{b_0}\right)\hat{p}$$

Now, consider the case when p^0 falls from the choke level $\bar{p}^0$ 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:

$$(5.2) \quad \frac{a_1 - (b_1 - c)\hat{p}}{(a_0 + a_1) - (b_0 + b_1 - 2c)\hat{p}} = \hat{\sigma}$$

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

$$(5.3) \quad a_0 + a_1 - (b_0 + b_1 - 2c)\hat{p} = \hat{k}\hat{Q}, \quad \hat{k} \geq 1 .$$

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

$$(5.4) \quad \hat{\varepsilon}^{UU} = -\left(b_1 - \frac{c^2}{b_0}\right)\frac{\hat{p}}{\hat{Q}}$$

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

$$(5.5) \quad \hat{\varepsilon}^{00} = -b_0 \frac{\hat{p}}{a_0 - (b_0 - c)\hat{p}}$$

The solution of the system (5.1)-(5.5) and the resulting restrictions on the parameters of the demand system are discussed in Appendix B.

Undifferentiated demand's parameters are calibrated as follows:

$$(5.6) \quad a = \hat{Q}(1 - \hat{\varepsilon}^{UU}), \quad b = -\hat{\varepsilon}^{UU}\frac{\hat{Q}}{\hat{p}} .$$

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 explanation). $\hat{\varepsilon}^{UU} = -0.4$ in all regions and for all products (Moschini, Lapan and Sobolevsky, 2000, p. 45-46).

5.2. 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 (3.7) - (3.13).

In line with Moschini, Lapan and Sobolevsky (2000), the unit seed cost $\delta\omega$ is set at $\{45, 40, 40, 40\}$[9]. The $45/ha U.S. cost comes from Table 5.3. In Argentina (see Table 5.4), conventional soybean seeds sold for $8-10/bag in 1998. In per-hectar terms, it's at most $30

Table 5.3. **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
	$/hectar		8.90	22.49

Source: Author's adaptation of Iowa State University Extension budgets (ISU Weed Science 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).

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

Table 5.4. **Soybean Seed Prices per 50 lb Bag, Before Taxes[a], 1998**

	Conventional Seeds	Roundup Ready Seeds
United States	$13-17	$20-23[b]
Argentina	$8-10	$12-15

Source: U.S. Government Accounting Office (2000)

[a] No taxes on seed purchases are levied in Illinois and Iowa; Argetine farmers' net tax burden is about 12%.

[b] Includes technology fee.

before taxes or $36 after the 21% 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, I set $\delta\omega = 40$ in Argentina and Brazil and assume the same for the Rest of the World.

RR seed monopolist's markup is set to $\mu = \{0.4, 0.2, 0.2. 0.2\}$. The 0.4 U.S. estimate is the result of the $6 per bag technology fee charged by Monsanto (see Table 5.3). 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 5.5, one would conservatively assume that at least 50% of soybean seed planted in Argentina is not commercially purchased, implying that the average markup in Argentina is at best $\mu = 0.2$. IPR protection will unlikely be better in Brazil or the Rest of the World, and therefore I set $\mu = 0.2$ in these two regions as well.

The cost saving due to RR technology parameter $\Delta\pi$ has been revised to $15/ha for the United States. As Table 5.3 illustrates, following the introduction of competitively priced Roundup Ready weed control systems, the prices for competing herbicides, especially those used for conventional soybeans, have declined over the last two years in the U.S. For 2000, it is estimated that the cost saving of using RR technology lies between $8.90 and $22.49 per hectar and therefore I 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 RR seed markup

Table 5.5. **Sources of Soybean Seeds, 1998**

Source of Seeds	Estimated Percentage of Total Soybean Acreage Planted 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)

coefficient is twice lower in Brazil and Argentina than 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 (3.9)). 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 RR seed markup coefficient in the Rest of the World is twice lower than 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 5.6.

The elasticity of land supply with respect to soybean prices ψ remains 0.8 in the United States and 0.6 in the Rest of the World (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 has 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}.

Table 5.6. **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

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.

5.3. Segregation Costs

Lin, Chambers and Harwood (2000) extended the segregation cost estimates available for specialty crops grown in the United States in 1998 (Bender *et al.*, 1999) to nonbiotech soybeans and projected that for U.S. grain handlers segregating nonbiotech soybeans may cost from $6.60 to $19.80/MT, depending on whether handling process patterns that used for HOC (high oil corn) or the one used for STS soybeans.[10] 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 nonbiotech soybeans to elevators near 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.

5.4. Marketing Assistance Loans and 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 5.7. While in 1997-98 crop year only 10% of soybean production enjoyed price support, in 1998-

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[10] 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.

Table 5.7. **Loan Deficiency Payments and Price Support Loan Activity, 1997-1999**

		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

1999 support covered 90% of the crop, of which 78 percentage points received LDPs, 0.5 percentage points was delivered to the CCC on loan's maturity and 11.5 percentage points used to realize marketing loan gains. The share of the aforementioned option four (Chapter 3.3, page 30) was negligible. This means that approximately 90% 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% 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.

5.5. 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 (4.1) – (4.14) is provided in Table 5.8. Some parameter values are borrowed from Moschini, Lapan and Sobolevsky (2000) who estimated 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 in this chapter, and several new parameters were added.

Table 5.8. **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	0.0	0.0	0.0
		6.6	6.6	6.6	6.6
		13.2	13.2	13.2	13.2
		19.8	19.8	19.8	19.8

[a] See Chapter 5.1 for details.

CHAPTER 6. RESULTS

The model described by equations (4.1) – (4.14) was solved numerically using Gauss software for several parameter values and policy scenarios. As stipulated by equation (4.14), only the Rest of the World 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, I study the implications of introducing the RR technology in the soybean complex that is free of any government intervention. Regional adoption rates, prices, production and consumption patterns, trade flows and welfare associated with this equilibrium are discussed in Chapter 6.1 (Scenario 1). 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. As explained in Chapter 3.3, this scenario is important because the Unites States has a history of providing sizable price support to its soybean producers. Such price distortions can in theory lead to immiserizing growth and deserve due attention in research.

Scenario 3 is the first in the series of government ban scenarios considered next. It simulates the situation in which the Rest of the World introduces a ban on RR soybean production at home. The Rest of the World region includes the countries of European Union, Japan and several others 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 the neighboring Argentina and is seen as trying to differentiate itself from other soybean exporting nations by establishing itself as a biotech-free soybean region. Next two scenarios are variations on the same theme. Scenario 5 investigates the effects of simultaneous RR production bans in Brazil and the Rest of the World, and Scenario 6 adds an import ban on RR products in the Rest of the World in addition to production bans. Finally, in Chapter 6.7 I discuss a separate question of 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, I obtain a solution for the full adoption scenario (ρ_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 (2.6) and (2.9), and supply functions satisfy (3.11). The benchmark for all welfare calculations is the pre-innovation scenario in which the RR soybean is not yet available (ρ_i=0, i = U, A, Z, R), such that demands are described by equations (2.4) and (2.9), while supplies are described by (3.11). 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 (4.1)-(4.14) 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):

$$(6.1) \quad \Delta CS_{j,i} = -\int_{\hat{p}^1_{j,i}}^{\tilde{p}^1_{j,i}} Q^1_{j,i}(\hat{p}^0_{j,i}, p^1_{j,i})dp^1_{j,i} - \int_{\hat{p}^0_{j,i}}^{\tilde{p}^0_{j,i}} Q^0_{j,i}(p^0_{j,i}, \tilde{p}^1_{j,i})dp^0_{j,i}$$

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

$$(6.2) \quad \Delta CS_{j,i} = \int_{\tilde{p}^1_{j,i}}^{\hat{p}^1_{j,i}} Q^U_{j,i}(p)dp$$

Now, let $\hat{\bar{\pi}}_i$ be the pre-innovation equilibrium average unit profit that satisfies (3.10), and $\tilde{\bar{\pi}}_i$ be the differentiated market equilibrium average unit profit that satisfies (3.18). Then the change in producer surplus between pre-innovation and differentiated market scenarios is:

$$(6.3) \quad \Delta PS_i = \int_{\hat{\bar{\pi}}_i}^{\tilde{\bar{\pi}}_i} L_i(v)dv$$

where L_i is the land allocation function (3.11). The innovator-monopolist's profit is computed simply as

$$(6.4) \quad \Pi^M = \sum_{i=U,S,R} \tilde{\rho}_i L_i(\tilde{\bar{\pi}}_i)\mu_i \delta w_i$$

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

$$(6.5) \quad \begin{aligned} \Delta W_U &= \sum_{j=B,O,M} \Delta CS_{j,U} + \Delta PS_U + \Pi^M \\ \Delta W_i &= \sum_{j=B,O,M} \Delta CS_{j,i} + \Delta PS_i \quad i = A, Z, R \end{aligned}$$

There is one important result that is common to all scenarios that will be discussed in the subsequent sections of this chapter. 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 Rest of the World 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 tables in Appendix C.

6.1. Scenario 1: No LDPs[11] *in the United States*

Absent any government intervention, the soybean complex is subject to the only market distortion that comes from the U.S.-based monopolist selling RR seed to all regions. I find a unique equilibrium solution for this scenario for each of the four selected levels of segregation costs. Equilibrium adoption rates, consumer, producer, monopolist's and total welfare changes, as well as production and trade flow results are provided in Table C1 of Appendix C. Equilibrium price and consumption data for soybeans and soybean oil of both varieties, as well as soybean meal, are provided in Table C2.

As the world moves to the full adoption of the cost-saving RR technology, U.S. soybean prices fall by 4%, oil – by 7%, and meal – by 1%, and prices in all other regions decline as well, as shown in the "No segregation technology" set of results in Table C1. 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, but other regions' supply grows. Consumption increases in all regions but the Rest of the World, 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 worldwide efficiency gain estimated at $1,564 million. This is 25% lower than the worldwide gain estimated using the Moschini, Lapan and Sobolevsky (2000) soybean model with this dissertation's parametric assumptions. The lower welfare gain is explained by the negative value RR soybeans generate for the Rest of the World consumers who prefer the conventional variety. Consumers capture 39% of the welfare gain, while the innovator-monopolist – another 53%. 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 Rest of the World gain despite the baseline assumption that 50% 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

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[11] Here and elsewhere in the text the term "LDPs" is used to refer both to loan deficiency payments and market loans received by U.S. farmers.

effect of GMO-conscious consumers losing from prohibitively high prices for conventional products and GMO-indifferent consumers benefiting from lower prices.

Depriving the Rest of the World 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% 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%. In other words, the costs of segregation "burn" most of the additional gain due to conventional product availability.

The high-segregation-cost equilibrium, the likely 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% in worldwide production and 23% 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 and not the ROW that has the GMO-conscious consumers produces conventional soybeans 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 nonbiotech soybeans. In equilibrium, the U.S. adoption rate for RR soybeans is 95%. Compared to the pre-innovation benchmark, RR prices fall, conventional producer prices fall, too, but conventional consumer prices increase due to segregation costs.

Let's now 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 C2, conventional consumer prices fall and conventional producer prices increase as segregation costs decline. This benefits ROW consumers and U.S. producers who increase their share of conventional soybean production to 30% when segregation costs are low. The United States remains the only producer of the conventional variety, with the worldwide share of the conventional soybean market growing to 13%. As more production shifts toward conventional soybeans, the world's RR supply decreases causing RR prices to increase.

Therefore, producer surplus improves in all four regions and consumer surplus in the United States, Brazil and Argentina, where only RR products are consumed, reduces.

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%. Brazil finds it profitable to grow conventional soybeans but allocates only 1% of total soybean land to them. The U.S. adoption rate is a low 62% and the region finds itself in an autarky equilibrium in the RR market, exporting only the conventional variety to the ROW. As a result, RR prices in the other regions fall compared to the low-segregation-cost scenario 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. The seed monopolist, on the contrary, benefits the least in this scenario due to a large worldwide share of conventional soybean production and captures 38% 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 lower-segregation-cost equilibria.

6.2. Scenario 2: LDPs in the United States

Assume now that U.S. farmers receive LDPs in the amount of $193/MT both in the counterfactual market equilibria and the pre-innovation benchmark (supply equations (3.21), (3.22) apply in this case). Results are shown in Tables C3 and C4 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% of its soybean land to the conventional variety and does not export RR beans and oil. Argentina, too, dedicates 50% 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 in Chapter 3.3 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% 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 its farmers. However, its overall effect on U.S. and world welfare can be negative. The results in Tables C1 and C3 can be subtracted from each other to show how welfare changes when LDPs are introduced in the soybean complex with differentiated tastes and potentially segregated markets. These welfare changes are presented in Table C5, Appendix C.

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% 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 innovator-monopolist's profit that creates an externality, LDPs would hurt world's welfare for all levels of segregation costs. Thanks to that profit, however, 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 under-adoption and puts the industry in the second-best equilibrium.

6.3. Scenario 3: Production Ban on RR Products in the ROW

In this and the next two sections I 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 Rest of the World region have currently in place – the ban on production of RR soybeans and products. Results in Table C6 of Appendix C are provided both for the LDP and no-LDP scenarios in the United States. They show that under the medium and high segregation costs the Rest of the World 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 Rest of the World. 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% 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 as a result 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 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 Rest of the World consumers willing to buy it.

Comparison to unregulated production scenarios from Tables C1 and C3 is provided in Table C7, Appendix C. It shows that RR production ban in the Rest of the World 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 Rest of the World holds both in the no-LDP and LDP scenarios. Whenever the ban benefits the Rest of the World, it also benefits Brazil and Argentina but hurts the Unites States, reducing its welfare by \$80-90 million, primarily because of the forgone innovator-monopolist profit.

6.4. Scenario 4: Production Ban on RR Products in Brazil

To date, Brazil has not adopted RR soybeans due to 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 Rest of the World. Results for this ban scenario are summarized in Tables C8 and C9, 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 its 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 Rest of the World that 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 cost 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 of 52%. 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 C9. 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 (see Chapter 7.3 for more on this issue) 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 as a result 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.

6.5. Scenario 5: Production Bans on RR Products in Brazil and the ROW

What if the Rest of the World and Brazil were to ban RR production simultaneously? This logical extension of Scenarios 3 and 4 is summarized in Tables C10 and C11, Appendix C. My results suggest that such simultaneous production bans are welfare reducing for both regions implementing it, 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 Rest of the World are forced to produce only conventional soybeans, with Brazil exporting to the ROW, and the United States and Argentina both 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 Rest of the World, with 17% 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.

The welfare comparison between the ban and no-ban scenarios is provided in Table C11. 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 Rest of the World 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 Rest of the World. Brazil loses approximately $260 million, while the ROW may lose between $80 and $170 million depending on the level of segregation costs.

6.6. Scenario 6: Production and Import Bans on RR Products in the ROW

Depending on the severity of GMO aversion in the European Union and other countries manifested in their official government regulations, the Rest of the World 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 C12, Appendix C. Results for the scenario when, in addition to ROW bans, Brazil bans RR production are provided in Table C13. The welfare changes between the ban and no-ban scenarios in both cases are shown in Table C14. In all tables, the effects of the import ban are illustrated using the no-LDP scenario only.

First, let's 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, U.S. adoption rate for RR technology is 62-67%, Brazilian – 49-52%, and Argentine – 28-30%. 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 unavailability of 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 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 Rest of the World, 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.

6.7. Economic Benefits of RR 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's 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 whether observed behavior is optimal and whether optimal behavior is attainable.

To address these questions, I provide solutions to the soybean trade model described by equations (4.1) – (4.14) for the three levels of monopolist's RR seed markup: $\mu=\{0, 0, 0, 0\}$, $\mu=\{0.4, 0.4, 0.4, 0.4\}$, and μ that maximizes 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 C15, Appendix C, 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 Rest of the World simultaneously.

The $\mu=\{0, 0, 0, 0\}$ case represents the competitive provision of RR technology worldwide. As shown in Table C15, 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 C1). However, U.S. rate of adoption increases from 90% to 95% because RR soybeans become more attractive, and U.S. welfare gain is $400 million smaller as it is being re-allocated to other regions. Overall, the world welfare gain increases by only 1%. Adoption rates in the simultaneous Brazil/ROW RR production ban do not change as the United States and Argentina already have 100% adoption rates.

If the innovator-monopolist was able to enforce IPRs equally in all parts of the world, the new technology could be sold at a markup μ={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 $1,133 million, 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 C15 shows it for the scenario when both Brazil and the Rest of the World impose a production ban on RR soybeans, which is the closest representation of the current situation in the soybean complex. Here I assume that the markup remains at 20% in Argentina where the enforcement of intellectual property rights by Monsanto had little success. When segregation cost is $13.2/MT, the estimated optimal markup is μ={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% 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 farm level. If segregation costs were zero, the optimal markup would be μ={0.73, 0.0, 0.2, 0.0}, thirty-three 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 μ={0.4, 0.2, 0.2, 0.2} that is based on currently observed monopolist's 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.

CHAPTER 7. SENSITIVITY ANALYSIS

The results discussed in Chapter 6 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 Rest of the World: the share of "indifferent" demand $\hat{\sigma}$, the coefficient of 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 soybean, oil and 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 will most likely 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 if the model's parameter values were different. 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 in this chapter.

The six parameters and their base and suggested alternative values that form this chapter's analysis are summarized in Table 7.1. To keep the scope of the analysis manageable, I 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 all ban scenarios discussed in Chapter 6.3 through Chapter 6.6. Increases and decreases in each parameter value are implemented *ceteris paribus* (that is,

Table 7.1. **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
$\hat{\varepsilon}^{OO}$	0.5	Base Value × ⅔	Base Values × 1⅓

holding all other parameters at their base values). In the tables, the model's results for the base values of parameters are also shown for the ease of comparison. One ancillary outcome of the sensitivity analysis that I 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, I 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 don't have differentiated tastes. I show that it is possible that they choose to import RR products in equilibrium, although this would probably not be allowed as it violates the purpose of production ban.

7.1. 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 Table D1, Appendix D. 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% of the total welfare gain, the halved elasticity would imply that they reaped 49%. 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% 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 3-6, Chapter 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 Rest of the World 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 their home, but overall Brazil loses while the Rest of the World gains again thanks to lower conventional prices relative to the free trade equilibrium. Simultaneous RR production bans in Brazil and the Rest of the World, 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 D2, Appendix D, 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 when ψ is halved – vice versa. Innovator-monopolist's profit shows more sensitivity as supply elasticity changes but is still very robust as its deviation is within 1% of the base value. Again, none of the qualitative results of the ban scenarios change.

The model's results appear quite sensitive to the change in the yield increase parameter due to 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 the farmers' economic decisions, 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 reasons 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% yield edge. In what follows, I assume a more moderate yield gain of $\beta=0.02$ (2%) and provide results in Table D3, Appendix D.

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 $\beta=0.02$ all prices are lower, which leads to the reallocation of welfare gains between consumers and producers. In this equilibrium, the United States has the 88% adoption rate versus the 90% 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 $\beta=0.02$. 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 Rest of the World 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 Chapter 6 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 innovator-monopolist, which remains essentially unaffected by these parametric changes.

7.2. 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 both in the soybean and the soybean oil differentiated demand functions and is set to 0.5 (50%) for both products in the base-values scenario. In other words, at a particular price level, with prices of both varieties the same, 50% of consumers demand conventional variety and 50% are indifferent as to which one to consume.

This assumption appears to be quite reasonable when applied to the Rest of the World and in particular to the European Union. A recent survey of 16,000 EU citizens (Eurobarometer, 2001) found that 56.5% 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, I select alternative values of $\hat{\sigma}$=0.333 and $\hat{\sigma}$=0.667 (the same for soybeans and soybean oil) and report results in Table D4, Appendix D.

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 not trivial. 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 the 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 ones.

Judging by the free trade results in Table D4, the Unites States remains the only producer of both varieties under different values of $\hat{\sigma}$, with adoption rate of 87% at low values and 93% at high values. Variation in $\hat{\sigma}$ mainly affects the welfare of the Rest of the World 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% less than in the base-values scenario, and when $\hat{\sigma}$ is high they gain 120% more.

Whereas simulating the RR production ban in the Rest of the World under low $\hat{\sigma}$ does not produce new outcomes, the results for the high $\hat{\sigma}=0.667$ suggest that the Rest of the World does not benefit from the ban. The low share of GMO-conscious consumers in the region makes the Rest of the World 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% 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 Rest of the World consumers, too. In addition, as the results in Chapter 6 show, it benefited Brazilian producers who switched to producing 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 tradeoff stops working in their favor and Brazilian farmers lose under the production ban at home relative to the no-ban scenario.

Another situation when 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 Rest of the World. Under the base and the high values of $\hat{\sigma}$, the world produces more than the GMO-conscious consumers demand in the Rest of the World and therefore a portion of conventional products is used to meet undifferentiated demand in Brazil and indifferent demand in the Rest of the World (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 Rest of the World benefits from the ban when compared with the free trade scenario because of the combination of really favorable conditions under the ban and really 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% 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 D5 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) and the model's sensitivity results with respect to these values are provided in Table D6 of Appendix D.

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 one. 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% in the free trade case), whereas in the high-elasticity equilibrium this share is lower than in the base-values scenario (2% versus 4% 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% when $\hat{\varepsilon}^{00}$=-3.0 compared to the 90% rate in the base-values scenario and the 95% rate when $\hat{\varepsilon}^{00}$=-6.0. Similarly to what we have already seen in the sensitivity analysis for $\hat{\sigma}$, the gains to the Rest of the World consumers vary greatly depending on the value of $\hat{\varepsilon}^{00}$ but remain positive. Also, when the Rest of the World 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 Rest of the World 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 Chapter 6. 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 Rest of the World 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 Rest of the World benefits from 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 Rest of the World 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 are more likely to hold can clearly be the subject of speculation in the present environment because differentiated markets for soybean products are in their infancy, but some thoughts on that will be offered in the concluding Chapter 8.

7.3. The Possibility of Multiple Equilibria and the Effect of Low Brazil-Argentina Transortation Costs

There are two more results that have surfaced in Chapter 6 discussions that are subject to change under alternative parametric assumptions. The first one is the uniqueness of the market and trade equilibrium described by equations (4.1) – (4.13). The segregation cost function described by equations (3.12) – (3.13) 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 D7, Appendix D.

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 in Table D7 is characterized by the 61% rate of adoption of RR technology in the United States and 73% in Brazil, with Argentina and the Rest of the World 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 dissertation). In it, the Rest of the World 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 Rest of the World. 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 (Chapter 6.4) – the RR production ban in Brazil. The unique equilibrium solution for this scenario (see Table C8, Appendix C) 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 Rest of the World (see Table 5.2 in Chapter 5). Because at present the 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 Rest of the World, the equilibrium results would be as shown in Table D8, Appendix D.

Table D8 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 will 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 Rest of the World. 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 should probably 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.

CHAPTER 8. CONCLUSIONS

In this dissertation I have developed a new partial equilibrium four-region world trade model for the soybean complex comprising soybeans, soybean oil and soybean meal, to study some of the economic questions arising from the large-scale adoption of genetically modified soybeans. The distinctive feature of the model is that consumers in one of the four regions – the Rest of the World – view genetically modified Roundup Ready soybeans, and products derived from them, as weakly inferior to their conventional counterparts. The model provides as close a representation of the world soybean market as 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 demand and supply characteristics. Finally, the restrictions on the particular parameter values used at the calibration stage were evaluated through an extensive sensitivity analysis.

My 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. I 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, continued leading U.S. position in world soybean exports, and welfare gains to all regions and all economic agents (producers, consumers, and innovator-monopolist selling RR seed) except U.S. farmers.

Moving on to the case where segregation technology is available at a positive cost, my analysis shows that, absent any government production and trade regulations, the Unites States emerges as the only region producing both RR and conventional soybeans and 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 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 profit 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 Rest of the World, 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 Rest of the World and Brazil impose production bans on RR products is that the Rest of the World 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, my results suggest that the Rest of the World 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 Rest of the World, 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 Rest of the World 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. My analysis also shows that, whenever beneficial to the Rest of the World, 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 is subject to speculation. If the model's baseline assumption of a 50 percent share of GMO-conscious consumers in the Rest of the World is accurate, then we would have welfare gains to these regions.

The last important result of this dissertation is the robust welfare losses to all regions as the result of the introduction of an import ban on RR products in the Rest of the World. 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 Roundup Ready 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.

APPENDIX A. DEMAND SPECIFICATION

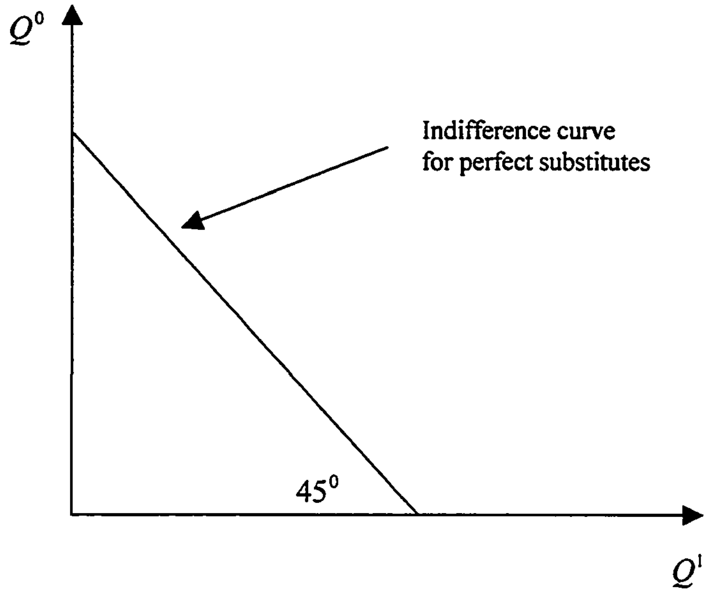

Figure A1. **Indifference curve for perfect substitutes**

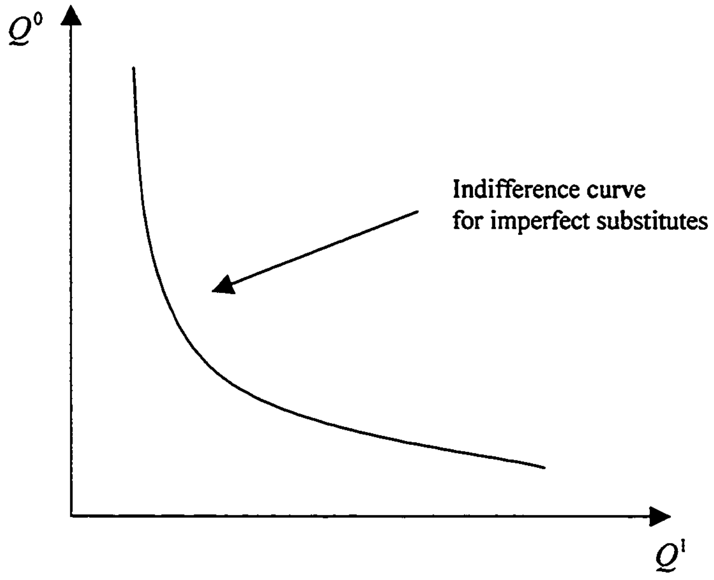

Figure A2. **Indifference curve for imperfect substitutes**

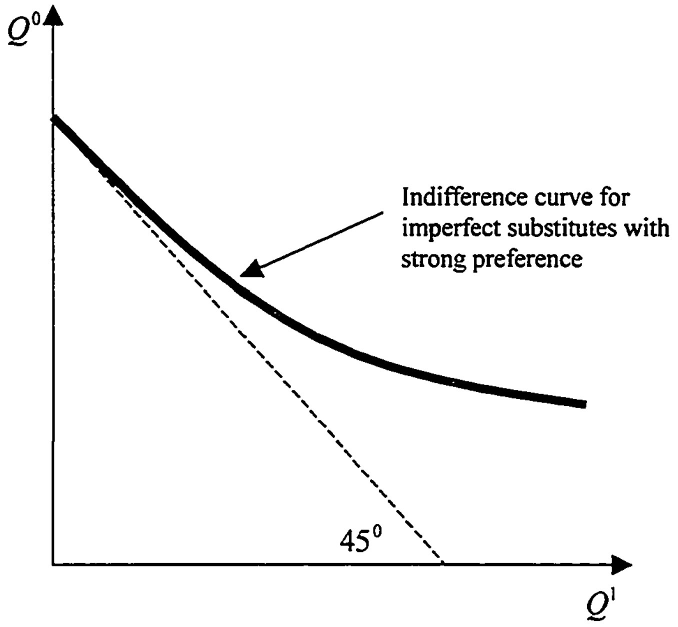

Figure A3. **Indifference curve with good 0 always preferred to good 1**

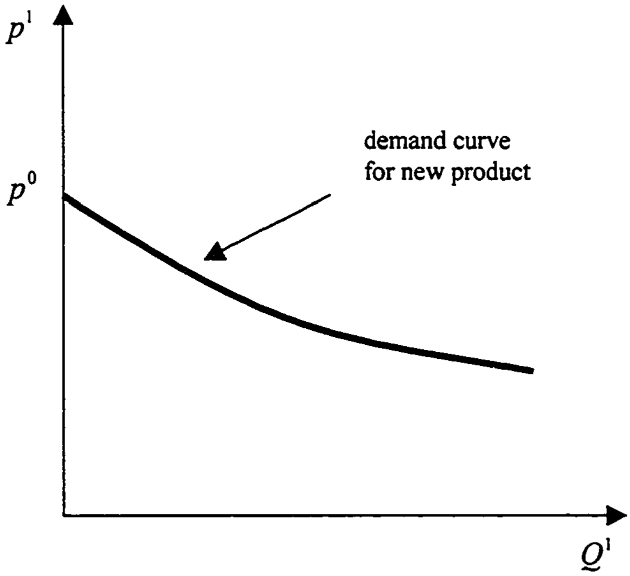

Figure A4. **Demand curve for inferior good 1**

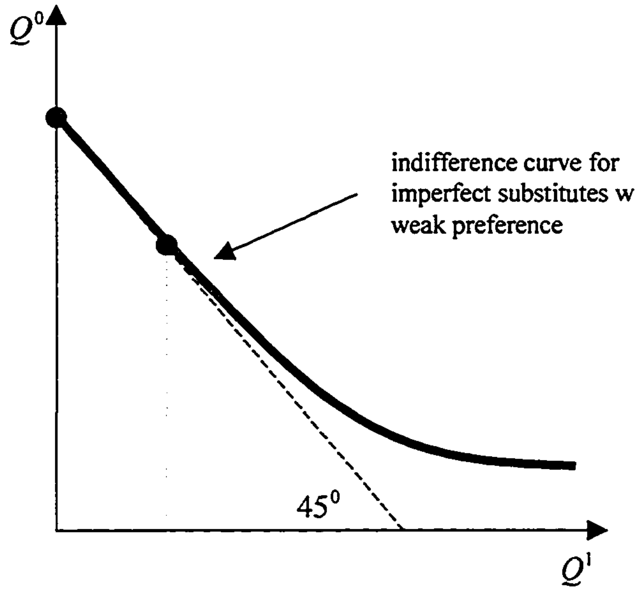

Figure A5. **Indifference curve with good 0 weakly preferred to good 1**

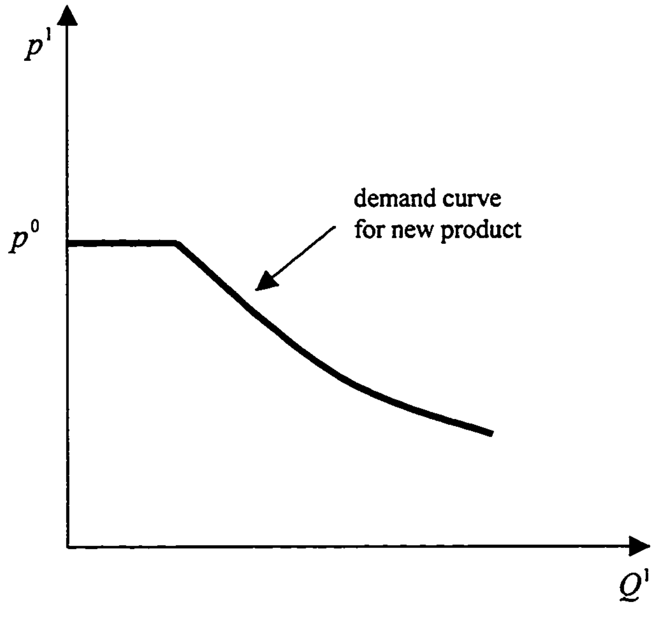

Figure A6. **Demand curve for weakly inferior good 1**

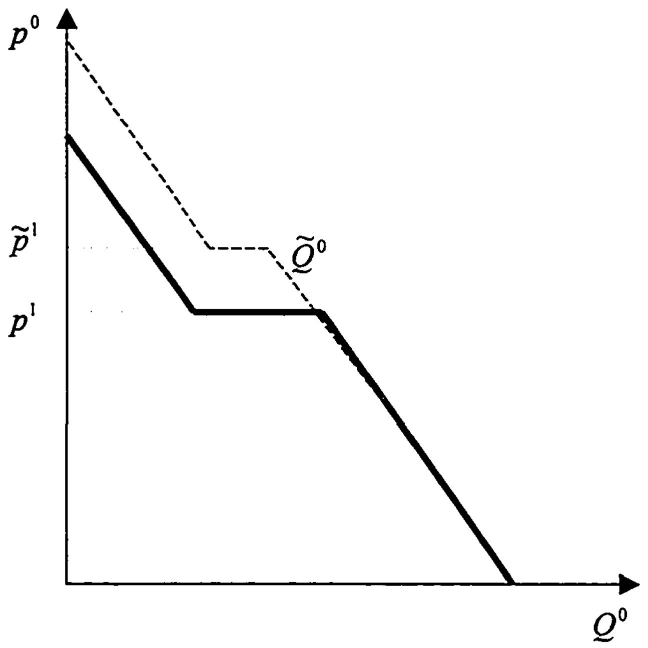

Figure A7. **Demand curve for conventional soybeans**

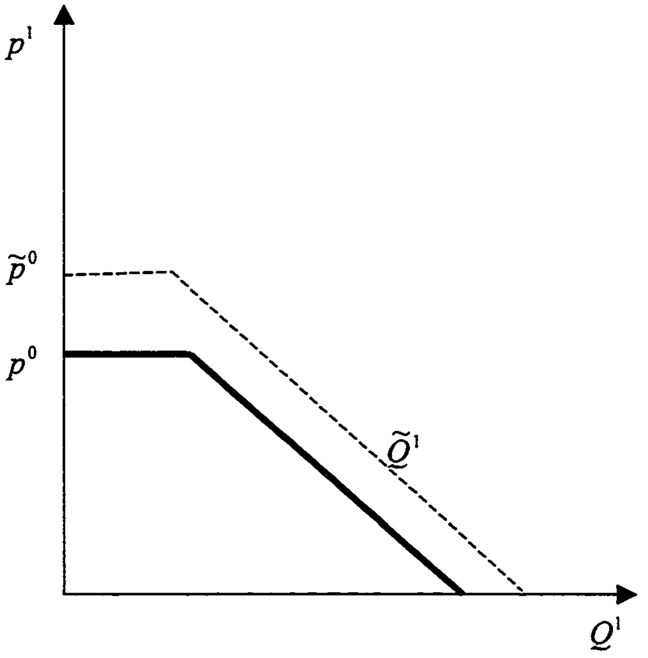

Figure A8. **Demand curve for Roundup Ready soybeans**

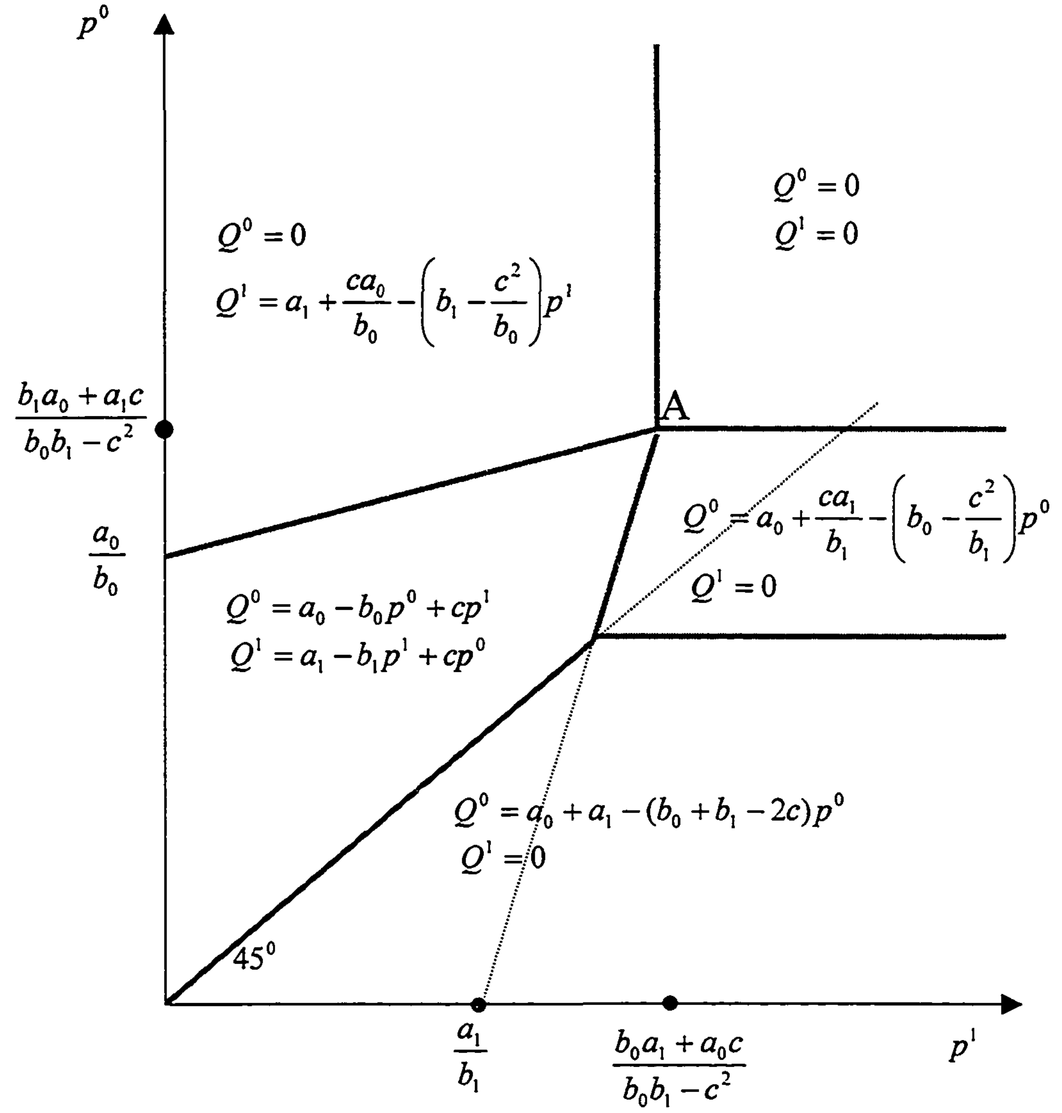

Figure A9. **Differentiated Demand System (2.1) – (2.4) where point A satisfies** $\frac{b_1 - c}{a_1} > \frac{b_0 - c}{a_0}$

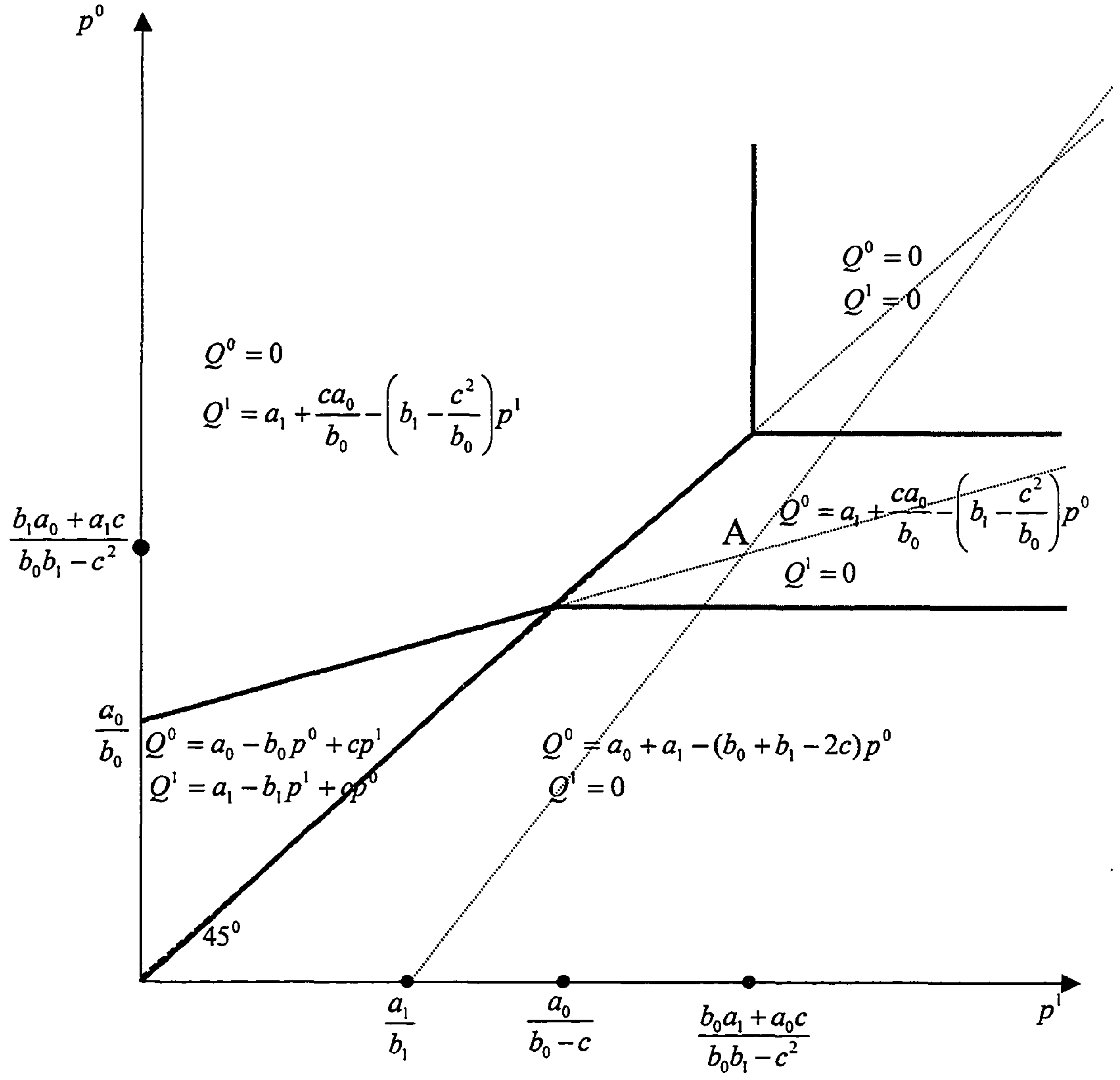

Figure A10. **Differentiated Demand System (2.1) – (2.4) where point A satisfies** $\frac{b_1 - c}{a_1} < \frac{b_0 - c}{a_0}$

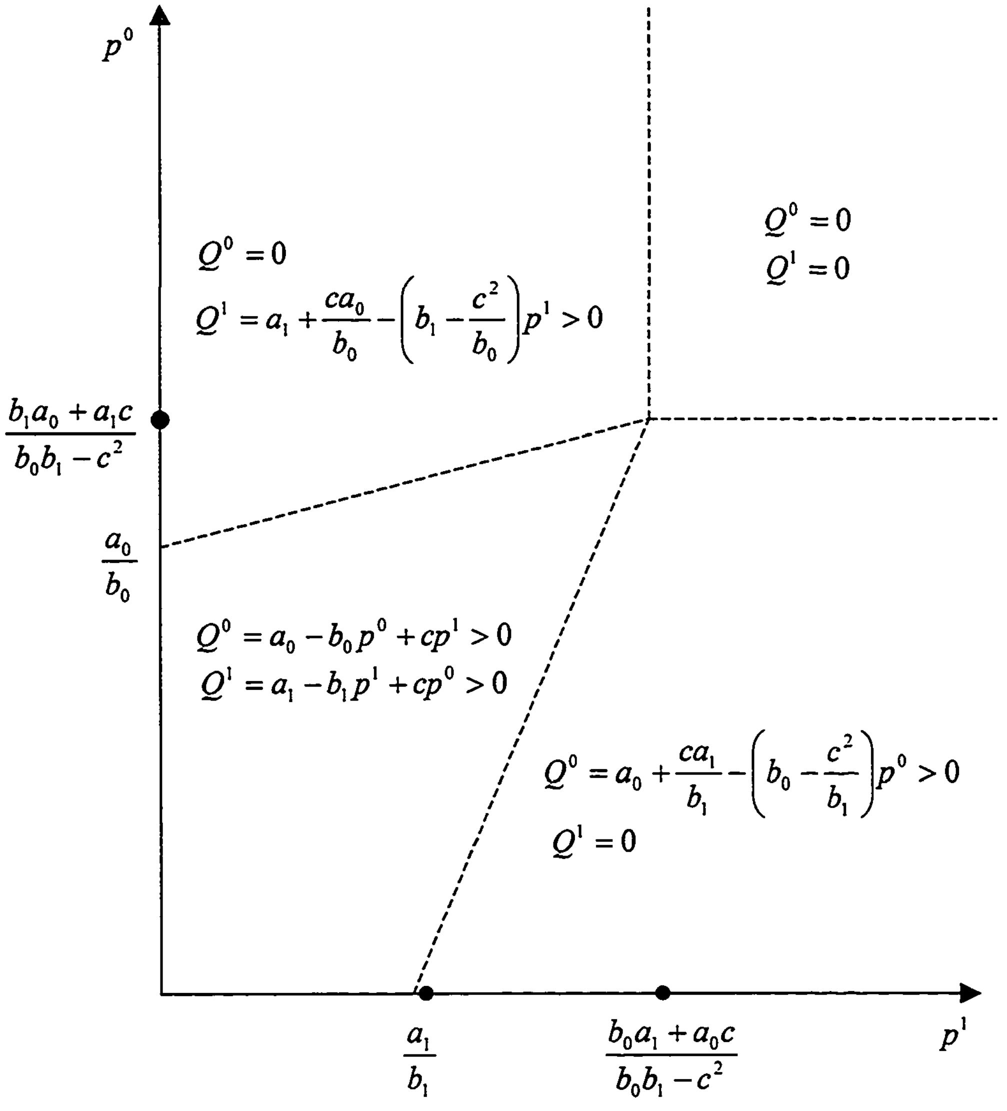

Figure A11. **A general two-good demand system**

APPENDIX B. DEMAND CALIBRATION

The analytical solution to the system (5.1) – (5.5) of equations that are used to calibrate the parameters of the demand system is as follows:

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

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

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

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

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

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

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

Given that we estimate that $\hat{\varepsilon}^{UU}_{j,i} = -0.4$ 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), $\hat{\varepsilon}^{00}_{j,i}$ must satisfy:

$$\text{(B.7)} \quad -8.842 < \hat{\varepsilon}^{00}_{j,i} < 0$$

Therefore, for the model that produced results shown in tables C1 – C15 in Appendix C, we choose the value for $\hat{\varepsilon}^{00}_{j,i}$ approximately in the middle of the interval (B.7), at -4.5.

This is about the best we can do given that we know that goods 0 and 1 are close substitutes but have no factual knowledge of their elasticities because differentiated demands have not materialized yet.

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

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

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 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. TABLES OF RESULTS

Table C1. **Economic Impact of RR Technology (No-LDP scenario): Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US $; millions of MT)

		ΔCS	ΔPS	$\Delta\Pi^M$	ΔW	Soybean Supply		Export (Equiv.)[a]		Export
Region	ρ	Total	Total		Total	Conv.	RR	Conv.	RR	Meal[b]
Pre-innovation										
USA	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										
USA	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										
USA	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										
USA	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										
USA	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										
USA	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 Chapter 4, eq. (4.15)).

[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 (eq. (4.16)).

Table C2. **Equilibrium Consumption and Prices**[a] **(No-LDP scenario)** (millions of 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											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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

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[a] Consumer prices. The price received by producers of conventional soybeans is lower by the amount of segregation cost.

Table C3. **Economic Impact of RR Technology (LDP scenario): Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US $; millions of MT)

Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	Δ in Subsidy	ΔW Total	Bean Supply Conv.	Bean Supply RR	Export (Equiv.)[a] Conv.	Export (Equiv.)[a] RR	Export Meal[b]
Pre-innovation[c]											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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 C1.

[b] See footnote (b), Table C1.

[c] The value of pre-innovation subsidy is $1,205 million.

Table C4. **Equilibrium Consumption and Prices**[a] **(LDP scenario)** (millions of 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											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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

[a] Consumer prices. RR producer prices in US 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 C5. **Economic Impact of LDPs: Changes from No-LDP Scenario** (millions of US $)

Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	Δ in Subsidy	ΔW Total
No segregation technology						
USA	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						
USA		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						
USA		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						
USA		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						
USA		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 C6. **Economic Impact of the RR Production Ban in the ROW. No-LDP and LDP Scenarios: Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US $; quantities in millions of MT)

		ΔCS	ΔPS	$\Delta\Pi^M$	Δ in	ΔW	Bean Supply		Export (Equiv.)[a]		Export
Region	ρ	Total	Total		Subsidy	Total	Conv.	RR	Conv.	RR	Meal[b]
No-LDP Scenario											
Segregation cost = positive											
USA	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											
USA	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											
USA	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 C1.

[b] See footnote (b), Table C1.

Table C7. **Economic Impact of the RR Production Ban in the ROW: Changes from No-Ban Scenario** (millions of US $)

	No LDP Scenario				LDP Scenario				
Region	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	Δ in Subsidy	ΔW Total
Segregation cost: $19.8/MT									
USA	-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									
USA	-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									
USA	-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									
USA	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 C8. **Economic Impact of the RR Production Ban in Brazil. No-LDP and LDP Scenarios: Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US $; quantities in millions of MT)

		ΔCS	ΔPS	$\Delta\Pi^M$	Δ in	ΔW	Bean Supply		Export (Equiv.)[a]		Export
Region	ρ	Total	Total		Subsidy	Total	Conv.	RR	Conv.	RR	Meal[b]
No-LDP Scenario											
Segregation cost = $19.8/MT or $13.2/MT											
USA	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											
USA	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											
USA	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											
USA	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											
USA	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 C1.

[b] See footnote (b), Table C1.

Table C9. **Economic Impact of the RR Production Ban in Brazil: Changes from No-Ban Scenario** (millions of US $)

	No LDP Scenario				LDP Scenario				
Region	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	Δ in Subsidy	ΔW Total
Segregation cost: $19.8/MT									
USA	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									
USA	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									
USA	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									
USA	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 C10. **Economic Impact of the Simultaneous RR Production Bans in Brazil and the ROW. No-LDP and LDP Scenarios: Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US \$; quantities in millions of MT)

Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	Δ in Subsidy	ΔW Total	Bean Supply Conv.	Bean Supply RR	Export (Equiv.)[a] Conv.	Export (Equiv.)[a] RR	Export Meal[b]
No-LDP Scenario											
Any segregation cost											
USA	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											
USA	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 C1.

[b] See footnote (b), Table C1.

Table C11. **Economic Impact of the Simultaneous RR Production Bans in Brazil and the ROW: Changes from No-Ban Scenario** (millions of US $)

	No LDP Scenario				LDP Scenario				
Region	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	Δ in Subsidy	ΔW Total
Segregation cost: $19.8/MT									
USA	-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									
USA	-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									
USA	-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									
USA	-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 C12. **Economic Impact of the RR Production and Import Ban in the ROW. No-LDP Scenario: Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US $; quantities in millions of MT)

		ΔCS	ΔPS	$\Delta\Pi^M$	ΔW	Soybean Supply		Export (Equiv.)[a]		Export
Region	ρ	Total	Total		Total	Conv.	RR	Conv.	RR	Meal[b]
Segregation cost: $19.8/MT										
USA	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										
USA	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										
USA	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										
USA	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 C1.

[b] See footnote (b), Table C1.

Table C13. **Economic Impact of the Simultaneous RR Production Bans in Brazil and the ROW and Import Ban in the ROW. No-LDP Scenario: Changes from Pre-Innovation Equilibrium. Production and Exports** (millions of US $; quantities in millions of MT)

		ΔCS	ΔPS	$\Delta\Pi^M$	ΔW	Soybean Supply		Export (Equiv.)[a]		Export
Region	ρ	Total	Total		Total	Conv.	RR	Conv.	RR	Meal[b]
Segregation cost: $19.8/MT										
USA	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										
USA	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										
USA	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										
USA	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 C1.

[b] See footnote (b), Table C1.

Table C14. **Economic Impact of the Simultaneous Production and Import Bans. No-LDP Scenario: Changes from No-Ban Scenario** (millions of US $)

	RR Production and Import Ban in the ROW				RR Production Bans in Brazil and ROW and Import Ban in ROW			
Region	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Segregation cost: $19.8/MT								
USA	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								
USA	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								
USA	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								
USA	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 C15. **Economic Impact of RR Technology in Alternative Market Structures. No-LDP Scenario: Changes from Pre-Innovation and μ={0.4,0.2,0.2,0.2} Equilibria** (mil. $)

		Vs. Pre-Innovation Equilibrium				Vs. μ = {0.4,0.2,0.2,0.2} Equilibrium			
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Markup μ = {0,0,0,0}									
Segregation cost: $13.2/MT; free trade									
USA	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									
USA	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									
USA	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									
USA	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}									
USA	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}									
USA	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 TABLES

Table D1. **Model's Sensitivity to Demand Elasticities** ε^{UU} **: Welfare Effects**[a] (millions of US $)

	Base Values × ½					Base Values					Base Values × 2				
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Free Trade															
USA	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															
USA	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															
USA	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															
USA	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															
USA	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
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
USA	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

[a] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

Table D2. **Model's Sensitivity to Supply Elasticities ψ : Welfare Effects**[a] (millions of US $)

	Base Values × ½					Base Values					Base Values × 2				
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Free Trade															
USA	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															
USA	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															
USA	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															
USA	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															
USA	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
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
USA	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

[a] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

Table D3. **Model's Sensitivity to the Yield Increase Parameter β: Welfare Effects**[a] (millions of US $)

	Base Values					$\beta = 0.02$				
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Free Trade										
USA	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										
USA	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										
USA	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										
USA	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										
USA	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
ROW	0.00	-1021	363		-658	0.00	-893	320		-573
World		-389	93	391	95		-198	-113	386	75
RR Prod. Bans in Brazil and ROW and Import Ban in ROW										
USA	0.67	498	-371	337	464	0.66	523	-440	333	417
BR	0.00	-124	284		160	0.00	-111	247		137
AR	0.31	92	-112		-20	0.30	97	-131		-35
ROW	0.00	-727	256		-471	0.00	-626	222		-404
World		-261	57	337	133		-117	-102	333	114

[a] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

Table D4. **Model's Sensitivity to Demand Parameter $\hat{\sigma}$: Welfare Effects**[a] (millions of US $)

	Base Values × ⅔					Base Values					Base Values × 1⅓				
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Free Trade															
USA	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															
USA	1.00	301	-85	673	889	1.00	239	9	675	922	1.00	184	94	679	957
BR	1.00	114	89		203	1.00	81	137		218	1.00	57	181		238
AR	1.00	40	57		97	1.00	30	85		116	1.00	23	111		134
ROW	0.00	145	121		267	0.00	277	41		318	0.00	442	-142		300
World		600	182	673	1455		626	272	675	1573		706	244	679	1629
RR Production Ban in Brazil															
USA	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															
USA	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															
USA	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
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
USA	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

[a] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

Table D5. **Model's Sensitivity to Demand Parameter $\hat{k}$: Welfare Effects**[a] (millions of US $)

	$\hat{k}=1.025$					Base Values					$\hat{k}=1.075$				
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Free Trade															
USA	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															
USA	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															
USA	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															
USA	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															
USA	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
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
USA	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

[a] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

Table D6. **Model's Sensitivity to Demand Elasticities ε^{00}: Welfare Effects**[a] (millions of US \$)

	Demand Elasticities × ⅔					Base Values					Demand Elasticities × 1⅓				
Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total
Free Trade															
USA	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															
USA	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															
USA	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															
USA	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															
USA	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
RR Prod. Bans in Brazil and ROW and Import Ban in ROW															
USA	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

[a] Assuming the \$13.2/MT segregation cost in each region and no-LDP scenario

Table D7. **Possibility of Multiple Equilibria when Demand Elasticity $\hat{\varepsilon}^{00} = -1.0$: Welfare Changes from Pre-Innovation Equilibrium, Production, and Exports**[a] (millions of US $; quantities in millions of MT)

Region	ρ	ΔCS Total	ΔPS Total	$\Delta\Pi^M$	ΔW Total	Soybean Supply Conv.	Soybean Supply RR	Export (Equiv.)[b] Conv.	Export (Equiv.)[b] RR	Export Meal[c]
Pre-innovation										
USA	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										
USA	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										
USA	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					

[a] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

[b] See footnote (a), Table C1, Appendix C.

[c] See footnote (b), Table C1, Appendix C.

Table D8. **Model's Sensitivity to Transportation Costs[a] between Argentina and Brazil: Welfare Changes from Pre-Innovation Equilibrium, Quantities and Prices[b]** (millions of US $)

		ΔCS	ΔPS	$\Delta\Pi^{M}$	ΔW	Soybean Supply		Export (Equiv.)[c]		Export
Region	ρ	Total	Total		Total	Conv.	RR	Conv.	RR	Meal[d]
USA	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	Bean Demand		Oil Demand		Meal
	Conv.	RR	Conv.	RR	Price	Conv.	RR	Conv.	RR	Demand
USA	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

[a] Assuming transportation cost $t^{1}_{B,AZ} = 10, t^{1}_{O,AZ} = 17.5, t^{1}_{M,AZ} = 10$

[b] Assuming the $13.2/MT segregation cost in each region and no-LDP scenario

[c] See footnote (a), Table C1, Appendix C.

[d] See footnote (b), Table C1, Appendix C.

APPENDIX E. SOLUTION ALGORITHM

The model (4.1) – (4.13) is solved using GAUSS, the software equipped with *eqSolve* procedure that solves $N \times N$ systems of nonlinear equations by inverting the system's Jacobian (which is numerically computed within the procedure) while iterating until convergence. Needless to say, all equations must be binding. Thus the task is to apply *eqSolve* to the binding equations of the system (4.1) – (4.13).

In our case, the number of binding equations in (4.1) – (4.13) 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.

E.1. Trade Flows

As was explained earlier, the present model cannot distinguish between exports of soybean oil/meal to a region and exports of soybeans for crush in that region. That is why I consider only situations when, if exists, trade flow in soybeans (soybean oil) implies no trade or a trade flow in the same direction for soybean oil (soybeans), subject to bean and oil being of the same variety. In other words, I do not consider situations like the United States exporting RR soybeans to the Rest of the World and importing RR oil from that region. This allows to bring trade flow analysis up to the "variety type" level of aggregation, but with soybean meal considered separately.

Trade flow possibilities are numerous. However, what matters for the size of the system (4.1) – (4.13) is only the *number* of trade flows. For example, the maximum number of trade flows in the RR variety is three, and in that case equation (4.4) does not enter the model. If there is one trade flow, then there exist two regions that are in autarky and must satisfy (4.4). If there are no trade flows, then all four regions are in autarky and there are three equations (4.4), with equation (4.3) enforcing the autarky equilibrium in the fourth region. The same applies to the conventional variety.

The number of trade flows in each variety affects the number of crushing equations (4.6) and (4.7). For example, with three trade flows in the RR variety, there is one equation

(4.7) (any region – trading partner – may be chosen). With one trade flow there are three equations (4.7): two for autarky regions and one for one of the two trading regions. Similarly, with no RR trade flows there must be four equations (4.7).

E.2. Specialization in Production

Equation (4.8) specifies that land allocation decision between conventional and RR soybeans (expressed by means of the adoption rate ρ) depends on the incentive compatibility constraint which binds when a region does not specialize. Therefore, if a region does not specialize and ρ_i is determined by solving the system (4.1) – (4.13), the system gains one additional equation in the form of binding incentive compatibility constraint for that region *i*. If two regions produce both varieties, we gain two equations, and if four – four equations.

To summarize, the number of binding equations in (4.1) – (4.13) can vary. If there are three trade flows in each variety and in undifferentiated meal (so that all Brazilian, Argentine and the Rest of the World prices can be expressed through U.S. prices) and all regions specialize in growing some soybean variety, than we have a system of five equations (4.1), (4.3), (4.5), (4.6) and (4.7) in five unknowns: U.S. conventional and RR bean and oil prices and a meal price. This is the smallest size we can get for the system. The largest possible size with differentiated markets developed only in the Rest of the World is twenty-one: it arises when no region specializes in production and there is no trade in beans and oil of either variety.

E.3. Computer Implementation

GAUSS provides no capability to change the dimensions of the system of equations as it is being solved. Thus, in the case when differentiated markets exist only in the Rest of the World, the solution algorithm looks for the equilibrium by repeatedly solving the fluctuating-in-size binding portion of the system (4.1) – (4.13) over all possible combinations of the following assumptions:

- a region specializes in conventional soybeans, or in RR soybeans, or does not specialize – for each region;
- there is no trade in RR beans/oil;
- there is only one RR trade flow involving a pair of regions, in either direction, for all possible region pairs;
- 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);
- 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).

One of the above scenarios is the case of complete adoption of RR soybeans everywhere in the world, so the algorithm checks whether no differentiation is still an equilibrium. When each of the above scenarios is solved, the solution – if it exists – is checked against the remaining non-binding equations of the system (4.1) – (4.13). In particular, the non-binding incentive compatibility constraints are checked, actual trade flows are checked against the directions stipulated by (4.9) – (4.13), it is verified that trade takes place with a region with the lowest price (corrected for transportation costs), and demands and supplies are checked for being non-negative.

When a differentiated market equilibrium satisfying the system (4.1) – (4.13) is found, the model solves the benchmark undifferentiated equilibrium using the algorithm developed by Moschini, Lapan and Sobolevsky (2000), which is a simpler version of the algorithm described herein, and computes consumer and producer surpluses, innovator-monopolist's profit, and the subsidy to U.S. farmers.

The full automation of the search for the equilibrium over all possible combinations of the above-described trade and production assumptions is achieved using the vector programming properties of GAUSS, in which any function and any procedure may be defined for a vector of unknown size. When solution algorithm needs to solve the system (4.1) – (4.13) of a particular size, it passes appropriately sized vectors of the system's unknowns to the routines that “learn” through these vectors about a particular case of the system that must be solved.

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