Roundup Ready ® Soybeans and Welfare Effects

in the Soybean Complex

Giancarlo Moschini
Harvey Lapan
Andrei Sobolevsky

September 1999 Staff Paper # 324

The authors are professor, professor, and research assistant, respectively, in the Department of Economics, Iowa State University. An earlier version of this paper was presented at the ICABR conference on "The Shape of the Coming Agricultural Biotechnology Transformation: Strategic Investment and Policy Approaches from an Economic Perspective," University of Rome Tor Vergata, June 1999. We thank Yoav Kislev and other conference participants for their constructive comments. The support of the U.S. Department of Agriculture, through a National Research Initiative grant, is gratefully acknowledged. This is Journal Paper No. J-18548 of the Iowa Agriculture and Home Economics Experiment Station, Project No. 3539. Send correspondence to: Giancarlo Moschini, Department of Economics, Iowa State University, Ames, IA 50011-1070 (Email: moschini@iastate.edu).

Roundup Ready ® Soybeans and Welfare Effects in the Soybean Complex

Abstract

A stylized three-region world model for the soybean complex is developed to evaluate the welfare effects of Roundup Ready (RR) soybean adoption. The innovation is modeled in a structural way that explicitly accounts for the incentives open to farmers as well as for the pricing of RR soybean seeds by a multinational firm that holds intellectual property rights. The model, calibrated on recent benchmark data, is solved for various scenarios to evaluate the production, price, and welfare impacts of RR soybean adoption. The United States gains substantially from the superior innovation, with the innovator capturing the larger share of the welfare gains. US farmers benefit in the base scenario, but would be adversely affected if the RR innovation were to increase yields. Spillover of the new technology to foreign competitors erodes the competitive position of domestic soybean producers, and export of the technology per se may not improve the welfare position of the innovating country. With strong overseas intellectual property rights protection, the innovator-monopolist could extract a substantial share of the efficiency gains, thus benefiting the home country. But with weaker international intellectual property protection, profits from foreign sales of the new technology just offset the loss of domestic producer welfare. Consumers in every region gain from the adoption of RR soybeans.

Key words: biotechnology, consumer surplus, genetically modified organisms, intellectual property rights, producer surplus, R&D spillovers, technology adoption, transgenic crops.

Introduction

Rapid increases in productivity have been a distinctive feature of agriculture throughout the twentieth century. Such productivity gains have been sustained by significant public and private investments in agricultural research and development (R&D) and have led to a number of important consequences, including declining real food prices and declining employment in agricultural production. Economic issues related to agricultural R&D and productivity have been the object of extensive research [Huffman and Evenson (1993); Alston, Norton, and Pardey (1995); Fuglie et al., (1996)]. A number of significant developments in the agricultural sector within the past decade, however, warrant new and increased research efforts in this area. In particular, the dawn of biotechnology is bringing to agriculture a new generation of innovations, such as transgenic crops, that have the potential to dramatically change the agri-food system. A distinctive feature of these innovations is that they are produced mostly from R&D efforts undertaken by the private sector, and they are typically protected by intellectual property rights (IPRs), such as patents (Rausser, Scotchmer and Simon, 1999). In developed countries IPRs give monopoly rights to the discoverer, with some limitation (Besen and Raskind, 1991). The exploitation of this institutionalized market power by innovators carries considerable implications for evaluating the welfare impact of agricultural innovations. Moschini and Lapan (1997) point out that the paradigm used by the vast majority of previous agricultural economic studies does not apply any longer, and illustrate the qualitative welfare implications of accounting for IPRs in the context of a closed economy.

The purpose of this paper is to extend the line of inquiry suggested by Moschini and Lapan (1997) to an open economy, and to apply the model to a specific case study. With the effective economies of scale that come about through technological improvements due to R&D, open access to world markets is increasingly important for maintaining the health and competitiveness of the US agricultural sector. Of particular significance in this setting are technological "spillovers" across national boundaries. This phenomenon has been documented extensively by recent research (e.g., Coe and Helpman, 1995; Park, 1995; Eaton and Kortum, 1999). The relevance of international spillovers of agricultural innovations is increased by the onset of biotechnology for two reasons. First, biotechnology innovations may be adapted to different environments much faster than traditional agronomic innovations, for which location-specificity typically plays an important role (e.g., Maredia, Ward, and Byerlee, 1996). Second, as discussed earlier, biotechnology innovations are typically produced by multinational firms that are ideally positioned for worldwide marketing of such innovations. In this context, a relevant question to be addressed is how exports of US technology affect US agricultural producers and US welfare. Sales by US multinationals of the latest technology to countries that export competitive products increases profitability for these firms, but undermines US competitiveness in exports of the final product. Though private gains may accrue to multinationals from these sales, the impact on US welfare may be ambiguous as prices of US exports decline and market share may be lost.

This ambiguity is related to Bhagwati's (1958) possibility of "immiserizing growth": under conditions of perfect competition and free trade, innovations in one country, while increasing world efficiency, may impoverish that country. However, in the presence of an appropriate trade policy, the growth must be welfare-enhancing for the country experiencing the innovation (Bhagwati, 1968). Furthermore, explicit consideration of the relevant industry structure is necessary here. If the export industry is monopolistic, as seems likely when dealing with proprietary innovations, then the role for policy is much different than in the standard competitive paradigm, as articulated in the copious literature that has developed from Brander and Spencer's (1985) seminal article. While the early analysis of strategic trade policy towards exports focused on situations in which the links between markets were ignored, more recent papers have explored the implications of exports of intermediate products in vertically related markets [e.g., Spencer and Jones (1991, 1992)]. Unlike these papers, where imperfect competition prevails in both the intermediate and final product markets, the model that we develop here assumes imperfect competition for the industry supplying the innovations (because of IPRs), but postulates that the industry that purchases the innovated intermediate inputs (i.e., the farm sector) is competitive.

The methodological framework developed to analyze these questions is applied to the specific case of a recent success story in agricultural biotechnology innovation: Roundup Ready (RR) soybeans. RR soybeans, developed in the United States by Monsanto, are tolerant to a particular herbicide and allow farmers to cut costs by saving on less effective herbicides. Monsanto is marketing this innovation at a stiff price premium relative to traditional soybean varieties. Still, at current prices it appears that this innovation is superior to existing alternatives for a variety of farming conditions. Monsanto is actively attempting to market this innovation worldwide, and adoption rates have been climbing rapidly both in the United States and in South America (the other main soybean-growing region). Thus, the case of RR soybeans provides, in many respects, an ideal illustration of the central issues analyzed in this paper.

Roundup® and Roundup Ready® Soybeans

Roundup is the commercial name given by Monsanto to glyphosate, a herbicide discovered by Monsanto's Dr. John Franz in 1970. Glyphosate is an extraordinarily effective post-emergence herbicide that kills virtually all plants. Because of this non-selective feature, it was first marketed for weed control in roadside and in tree plantations. The spread of conservation tillage in the United States added a new dimension to the demand for Roundup, which can be used instead of plowing to remove weeds before seeding. It seems that Roundup also has favourable toxicological properties, breaking up quickly (once in the ground) into naturally occurring compounds.

Interest in agricultural use of Roundup has increased dramatically since the development of RR soybeans. Roundup works by inhibiting enolpyruvylshikimate-phosphate synthase (EPSPS), an enzyme crucial to the synthesis of some amino acids. Monsanto researchers found that a similar enzyme that occurs in a strain of agrobacterium (strain CP4) is not affected by Roundup. The gene responsible for this enzyme can be introduced into the genome of crops by at least two transformation methods (the gene gun was used for RR soybeans). The resulting transgenic plant then produces two versions of the enzyme, EPSPS and CP4-EPSPS. The latter allows the plant to carry on its metabolic functions even in the presence of Roundup herbicide. RR soybeans, so engineered, were first commercialized in the United States in 1996 and, together with Bt corn, have become the first highly successful transgenic field crop. RR soybeans allow over-the-top (post-emergence) applications of Roundup. This affords farmers a very effective weed control product that has a very broad spectrum of control. Furthermore, the RR technology gives farmers a wide window of intervention, making weed control less dependent on weather conditions. The RR technology is effective in all tillage systems, and leaves essentially no herbicide carryover that might interfere with crop rotation.

From a farmer's economic perspective, use of RR soybeans has the potential of cutting production costs, relative to standard varieties, because (at current prices) the RR technology involves lower herbicide expenses. Two other elements affect farmers' returns. First, the RR technology currently entails higher seed costs. In the United States, Monsanto's RR soybeans are marketed by a number of companies (under license). The marketing agreement for selling these seeds requires farmers to pay a sizable "technology fee," currently set at $ 6.50/bag (this amount represents about 40% of the price of standard soybean seed), and to agree to restrictive contractual terms (for instance, farmers can use the seed only for planting, cannot resell it, and cannot use harvested beans as seeds for next year's crop). Second, the RR technology may affect yield (as will be discussed later, it is not clear in what direction).

Modeling the Innovation

The model that we develop envisions a monopolist who markets the proprietary innovation (RR soybeans) to a large number of competitive farmers, both in the home country and abroad. There are a number of alternative ways of modeling the impact of an innovation on the agricultural production function. The one-factor-augmentation model used by Moschini and Lapan (1997) is perhaps the easiest one for the purpose of making the qualitative analysis on evaluating the size and distribution of welfare gains flowing from the innovation. But given our applied objectives here, a model that is closer to the actual working of the RR soybean innovation is desirable.

In any one country the total supply of soybeans is written as $Y_B = L \cdot y$, where Y_B is total production, L is land allocated to soybeans, and y denotes yield (production per hectare). Production per hectare depends on the use of seeds x and of all other inputs z. It is assumed that the per-hectare production function $f(z,x)$ requires a constant optimal density of seeds δ (amount of seed per unit of land), irrespective of the use of other inputs, for all likely levels of input and output prices. Hence, the variable profit function (per hectare), defined as:

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

is written in the additive form:

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

where p_B is the price of soybeans, r is the price vector of all inputs (excluding land and seed), and w is the price of soybean seed. These assumptions imply that the (optimal) yield function does not depend on the price of seed:

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

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

$$L = L(\pi)$$

Thus, total supply of soybeans is written as:

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

and total demand for soybean seed $x(p_B, r, w)$ is written as:

$$x(p_B, r, w) \equiv L(\tilde{\pi}(p_B, r) - \delta w) \cdot \delta$$

The new 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 subscripted 1 denotes the new technology, then:

$$\tilde{\pi}_1(p_B, r) > \tilde{\pi}(p_B, r)$$

The innovator-monopolist's problem is to select the price w_1 to charge for the new seed, given that the alternative (standard) seed is available at price w (we assume that the seed of standard soybean varieties is competitively supplied.) Let the subscript i ($i = 1, 2, \ldots, N$) denote countries, such that in each country the monopolist is facing a seed demand function $x_i(p_{B,i}, r_i, w_{1,i})$. If the innovative seed is produced at constant unit cost c, then the profit of the monopolist is written as:

$$\Pi^M = \sum_{i=1}^{N} x_i(p_{B,i}, r_i, w_{1,i})[w_{1,i} - c]$$

The objective of the monopolist is to maximize Π^M subject to a number of constraints. Specifically, the monopolist's choice of input prices is constrained by the presence of the alternative technology (i.e., traditional soybean varieties), such that the incentive compatibility constraint for the farmers' adoption decision requires:

$$\tilde{\pi}_{1,i}(p_{B,i}, r_i) - \delta w_{1,i} \geq \tilde{\pi}_i(p_{B,i}, r_i) - \delta w_i$$

By assumption, the demand for the innovative seed is proportional to the number of acres of land planted with this seed. Thus, the demand curve for seed must also incorporate equilibrium in the land market and in the final product (soybean) market. To illustrate how this demand curve is derived, consider what happens if the price of the seed $(w_{1,i})$ is set sufficiently low that the presence of the alternative technology is irrelevant and all soybean acreage is allocated to the new seed. Of course, such a low price is unlikely to be profit maximizing for the innovator-monopolist. But as the monopolist increases the price of seed, this lowers the rent earned on land, reduces land planted in soybeans, reduces output, and thus increases soybean prices.[1] As soybean prices increase, the land rents that could be earned using the older technology also increase. At a sufficiently high price for the innovative seed, the threat of the older technology constrains the monopolist's pricing decision (*i.e.*, the incentive compatibility constraint binds). Further increases in the price of the innovative seed lead to the diversion of land from the newer technology to the older technology (*i.e.*, adoption is incomplete). Thus, the demand curve for the innovative seed must incorporate the equilibrium conditions in other markets (e.g., the land and soybean markets), as well as the incentive compatibility constraint.

Given this demand for seed, the monopolist chooses the profit-maximizing price. If, at the unconstrained monopoly solution, the incentive compatibility constraint does not bind, the innovation is drastic; otherwise, the innovation is nondrastic and the presence of the alternative technology constrains the monopolist's optimal pricing decision, as explained in Moschini and Lapan (1997).[2] Note that the innovation can affect soybean supply, and hence soybean price, through two distinct avenues: by changing the amount of land allocated to soybean production and by changing average yield per acre. Because yields per acre will in general differ between the old and new technologies, changes in the adoption rate (for any given amount of land allocated to soybeans) will change equilibrium soybean prices, and hence the price the monopolist can charge for RR seed.[3] Let equilibrium prices of soybeans be denoted by $p_{B,i} = p_{B,i}(w_1;.)$, where $w_1 \equiv \left[w_{1,1}, w_{1,2}, \ldots, w_{1,N}\right]$ is the vector of N innovated input prices (one for each of the producing countries). Then the monopolist's problem can be rewritten as:

1 The demand for other inputs, besides land, changes as the seed price increases, and these input prices also could change. To simplify, we assume these prices are given and focus on the endogeneity of land and soybean prices.

2 The notions of drastic and nondrastic innovations were introduced by Arrow (1962).

3 In the present model, therefore, it is possible to have a "supply response" due to the innovation even when the latter is a nondrastic innovation, unlike what applies to the model used by Moschini and Lapan (1997).

$$\max_{w_1} \left\{ \sum_{i=1}^{N} x_i\big(p_{B,i}(w_1), r_i, w_{1,i}\big)\big[w_{1,i} - c\big] \right\}$$

$$s.t. \quad \tilde{\pi}_{1,i}\big(p_{B,i}(w_1), r_i\big) - \delta w_{1,i} \geq \tilde{\pi}_i\big(p_{B,i}(w_1), r_i\big) - \delta w_i \quad , \quad \forall i$$

In what follows we will not characterize the optimality conditions for this problem. We will instead rely on observed pricing behavior by the monopolist to carry out our welfare calculations.

We should note at this point that in this model the innovator-monopolist could choose to price the innovation such that adoption is complete. In reality, it is common to observe that a superior innovation is not adopted immediately, and that new and obsolete technologies may coexist at any given point in time. This is known as the process of "diffusion" in the literature on technology adoption (Karshenas and Stoneman, 1995). Heterogeneity among users, uncertainty, and information considerations are among the explanations that have been offered to explain the time path of adoption. In noncompetitive settings, licensing and strategic interactions among agents also can affect the diffusion of innovations (Reinganum, 1989). Whereas in most models of diffusion the adoption of a superior technology eventually will be complete, in the model that we have outlined above it is actually possible that incomplete adoption of a superior innovation may attain, in equilibrium, because of the optimizing choice of the innovator-monopolist [for reasons similar to those articulated in Lapan and Moschini (1999)]. In the application that follows we will not attempt to model explicitly the diffusion process, but we will simply carry out our analysis for alternative exogenously given adoption rates.

The Model: Regional and Parametric Specification

To analyze the welfare effects of the trading and adoption of RR soybeans, we need to choose an appropriate spatial model, as well as to select parametric specification for the functional relationships that are postulated.

Regional Specification

To arrive at a suitable regional specification for our model, a preliminary look at the geographical distribution of production and trade for soybeans and soybean products (the so-called "soybean complex") is in order. Table 1 reports data of soybean production and utilization for the most recent available year, 1997-98. It is apparent that soybeans are grown mostly in the Americas, which account for over 80% of world soybean production. The main competition for the United States comes from South America, where soybean production is concentrated in essentially two countries: Brazil and Argentina. The United States is the single largest producer and the single largest exporter of soybeans, while the European Union is the single largest importer. The dominance of the United States on the world market is perhaps overstated in Table 1; a more accurate picture is obtained by accounting for the closely integrated soybean oil and meal markets.

There are two basic uses for soybeans. There is demand for soybean whole seed to produce food products, stock feed, and seeds (the "direct use" column in Table 1). But the most important use of soybean is crushing, which results in the production of soybean oil and soybean meal in roughly fixed proportions. Table 2 reports data on production and utilization of soybean oil and soybean meal in 1997-98. It is interesting to note that South America produces almost as much oil and meal as the United States, and accounts for a much larger share of the corresponding export markets. The European Union is the largest importer of soybean meal, but it is actually a net exporter of soybean oil. China is the largest importer of soybean oil, but the market for this product is geographically more dispersed than that of soybeans and soybean meal.

Based on the evidence contained in Tables 1 and 2, we believe that we can adequately capture the essence of production and trade in the soybean complex with a three-region model. The regions that we identify are: United States (US) ($i = U$), South America (SA) ($i = S$), and Rest of the World (ROW) ($i = R$).

Parametric Specification

In addition to fitting the general innovation framework discussed earlier, the chosen parametric specifications need to be flexible enough to account for the main features of the problem but simple enough to allow ease of calibration and solution. To begin with the parametric specification of supply, in each country (and, for the time being, dropping the subscript i for notational simplicity), profit per hectare is written as:

$$\pi = A + \frac{G}{1+\eta} p_B^{1+\eta} - \delta w \qquad \text{standard technology}$$

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

where: η = elasticity of yield with respect to soybean price; A, G = parameters subsuming all other input prices (the vector r), 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 (reflecting technology fee). It is useful to note that this formulation allows the new technology to affect yield (through the parameter β); profit per hectare is affected through this parameter and, separately, through the parameter α. Note that the yield functions are $y = Gp_B^{\eta}$ for the standard technology and $y = (1+\beta)Gp_B^{\eta}$ for the RR technology.

For a given adoption rate $\rho \in [0,1]$, average profit per hectare is:

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

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, which depend on output price and adoption rates, that is:

$$L = \lambda \overline{\pi}^{\theta}$$

where: θ = elasticity of land supply with respect to soybean profit per hectare; and, λ = scale parameter. Hence, the aggregate supply of soybeans is written as:

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

As illustrated earlier, the demand for soybeans is a derived demand that depends mostly on the demand for soybean meal and soybean oil. Following most existing oilseed models, we explicitly account for the structure of the soybean complex by specifying separate demand functions for the three "final" uses identified earlier. If p_O and p_M denote the price of oil and the price of meal, respectively, then the final demand functions for oil and meal are written as $D_O(p_O)$ and $D_M(p_M)$. Additionally, the demand for soybean whole seed (to produce food products, stock feed, and seeds) is written as $D_B(p_B)$. These three demand functions are specified in constant elasticity form as:

$$D_{B,i}(p_{B,i}) = \kappa_{B,i} p_{B,i}^{-\varepsilon_{B,i}}$$

$$D_{O,i}(p_{O,i}) = \kappa_{O,i} p_{O,i}^{-\varepsilon_{O,i}}$$

$$D_{M,i}(p_{M,i}) = \kappa_{M,i} p_{M,i}^{-\varepsilon_{M,i}}$$

where $\varepsilon_{j,i}$ is the (constant) demand elasticity for product j in region i.

Trade and Market Equilibrium

Trade takes place at all levels of the soybean complex (i.e., for beans, oil, and meal). In addition, there also is (potentially) trade in the new technology embedded in the RR soybean seeds. Competitive equilibrium with three regions in the soybean complex will result in at most two trade flows for each product. Assuming that the United States and South America will be net exporters for all three products at all price levels of interest,[4] the equilibrium conditions can be written in terms of US prices. We further assume that unit transportation costs between regions are constant.[5]

---

4 This condition, of course, will be checked at the counterfactual equilibria computed below.

5 Here we do not attempt to model commercial policies with any detail. We may note, however, that soybeans and soybean meal are essentially duty-free for most relevant importers (such as the European

Suppose that crushing one unit of soybeans produces γ_O units of oil and γ_M units of meal; and that unit crushing costs in region i are constant and equal to m_i (the so-called crushing margin). Then, for given regional supply quantities $Y_{B,i}$ of soybeans, and given changes in stocks $\Delta S_{j,i}$ for product j in region i, the spatial market equilibrium conditions are written as:

$$\frac{1}{\gamma_O}\left\{\sum_{i=U,S,R}\left[D_{O,i}(p_{O,i})+\Delta S_{O,i}\right]\right\}+\sum_{i=U,S,R}D_{B,i}(p_{B,i})=\sum_{i=U,S,R}\left[Y_{B,i}-\Delta S_{B,i}\right]$$

$$\frac{1}{\gamma_O}\left\{\sum_{i=U,S,R}\left[D_{O,i}(p_{O,i})+\Delta S_{O,i}\right]\right\}=\frac{1}{\gamma_M}\left\{\sum_{i=U,S,R}\left[D_{M,i}(p_{M,i})+\Delta S_{M,i}\right]\right\}$$

$$p_{B,U}+m_U=\gamma_O p_{O,U}+\gamma_M p_{M,U}$$

$$p_{B,S}=p_{B,U}+t_{B,S}$$

$$p_{M,S}=p_{M,U}+t_{M,S}$$

$$p_{O,S}=p_{O,U}+t_{O,S}$$

$$p_{B,R}=p_{B,U}+t_{B,R}$$

$$p_{M,R}=p_{M,U}+t_{M,R}$$

$$p_{O,R}=p_{O,U}+t_{O,R}$$

where $t_{j,i}$ are the price differentials for product j in region i (relative to the United States) that reflect (constant) transportation costs (as well as, possibly, equivalent specific tariffs of existing commercial policies).

Union and Japan), whereas soybean oil is subject to import duties by most importers (Meilke and Swidinsky, 1998). For the purpose of our model, the effect of possible import policies is assumed to be captured by the specified price differentials.

Calibration

To evaluate the welfare effects of the adoption of RR soybean, both in the United States and abroad, the parameters of the model are calibrated such that, at the assumed value of some parameters discussed below, the model predicts the prices and quantities of soybean and soybean products for the year 1997-98. Quantity data are reported in Tables 1 and 2, and were discussed earlier. Table 3 reports available prices in the soybean complex. The base prices for the model are the US farm price for soybeans ($ 230/MT in 1997-98) and the Decatur (US) price for soybean meal and soybean oil (respectively $ 193/MT and $ 571/MT in 1997-98). Comparison of f.o.b. prices in Table 3 suggests that US producers enjoy a slight cost advantage in shipping soybeans and soybean products to the relevant import markets. Based on the price differentials reported in Table 3 [corroborated by recent freight rates data (Williams, 1998)], we estimate the following price differentials, which are held constant through the analysis: $t_{B,S} = -10$, $t_{M,S} = -10$, $t_{O,S} = -10$, $t_{B,R} = 30$, $t_{M,R} = 30$, and $t_{O,R} = 60$. The higher price differential for soybean oil for the ROW reflects higher import duties, which are common for many oil-importing countries (Meilke and Swidinsky, 1998). The technical coefficients γ_O and γ_M are set to the average world values as implied by Table 1 ($\gamma_O = 0.1808$ and $\gamma_M = 0.7942$), and the base value for the crush margin is then estimated to be $m_U = 26.52$. These parameters will determine the vertical and spatial configuration of prices, given US prices for soybeans and soybean products.

A critical set of parameters to be selected concerns the modeling of the innovation at the production level. Consider first the effects of RR adoption on per-hectare costs and profit. There is widespread agreement that the RR technology, at current input prices, decreases production costs for farmers. A benchmark is provided by Table 4, which reports estimated soybean production costs for 1999 for typical Iowa farm conditions. The cost budget for the standard technology is estimated by Iowa State University Extension (Duffy and Vontalge, 1999). The cost budget for the RR technology represents our estimate based on parameters provided by agronomists, as well as current market price conditions. From

Table 4 it is apparent that RR soybeans provide better returns per unit of land, even after accounting for higher seed prices. The actual cost reduction critically depends on whether one or two over-the-top Roundup treatments are carried out, ranging from about \$15 to \$28/hectare.[6] It turns out that this estimated cost reduction range is essentially the same as that reported in Carlson, Marra, and Hubbell (1997). Based on that, we conservatively assume an average cost saving of \$20/hectare and thus put $\Delta\pi = 20$.[7] From Table 4, and other production cost budgets for no tillage systems, we also estimate the average per-hectare seed cost for standard soybean varieties for the United States at $\delta w = 45$. The current "technology fee" reported in Table 4 implies that the markup premium on RR soybean seeds is $\mu = 0.43$.[8] Based on these assumptions (and on other parameters discussed below) we can calibrate the parameter α by using the difference in per-hectare profit between RR and standard technology, which for our specification implies:

$$\alpha = \Delta\pi - \beta \frac{Gp_B^{1+\eta}}{1+\eta} + \delta w \mu$$

A somewhat more difficult task is to calibrate the production parameters of the model for the other regions, especially where RR soybeans are not yet grown. Beginning with the seed price markup, it is widely accepted that IPR protection is weaker elsewhere in the world than in the United States. For example, whereas the sale of RR soybean seed to US farmers involves explicit and restrictive contracts, no such contracts are written for Argentine farmers. In fact, farmers cannot be legally forbidden to use harvested seeds for next year's own planting in Argentina. Similar considerations will likely apply to

6 That is, from \$6.08 to \$11.54/acre.

7 Based on calculations provided by others, and informal communication with people in the industry, this perhaps is a conservative estimate of the average herbicide cost saving afforded by the RR technology (e.g., Rankin, 1999).

8 In addition to the technology fee of \$6.50 per 50 lb bag set by Monsanto, there seems to be an additional price premium for RR seeds in the current planting season (perhaps \$1/bag). But that effect is ignored here.

other major foreign producing regions, such as Brazil and China. Thus it is unreasonable to expect the innovator-monopolist to be able to apply the same markup pricing in these regions. Based on such considerations, we set the markup coefficient for South America at one-half the US value (i.e., $\mu = 0.22$). Given that China accounts for one-half of the ROW production, and that IPR protection is likely more problematic for this country than for South America, for the ROW we set the markup coefficient at one-fourth the US value (i.e., $\mu = 0.11$). We also note, based on Argentine data (Margenes Agropectuarios, 1998), that farm prices for soybean seed tend to be somewhat lower overseas.[9] Based on such considerations, for both South America and the ROW we set $\delta w = 40$.

Cost savings are also somewhat more difficult to estimate outside the United States, where growing conditions can differ substantially. Groves (1999) reports cost reductions in Argentina as high as $25-30/hectare (presumably net of increased seed costs). A relevant consideration is that the cost savings of the RR technology are linked to herbicide use, and herbicide prices appear to be lower outside the United States, among other things because of weaker IPR protection.[10] Based on such considerations we estimate the cost saving provided by RR technology to be the same for both South America and ROW as for the United States, and put $\Delta\pi = 20$ for these regions as well. Given the assumed μ and $\Delta\pi$ values, the parameter α is calibrated as discussed earlier.

As for the effect of RR technology on yield, current experimental evidence seems to suggest that currently RR soybeans are somewhat less productive than standard soybean varieties (e.g., ISU Extension, 1998; Oplinger et al., 1998). But such experimental evidence should be carefully use in our context for at least two reasons. First, the yield drag of RR soybean is likely due to the particular way that the herbice

9 Perhaps because of the particular marketing system used, whereby farmers buy first-generation seed from licensed growers rather than buying the original seed from the seed company.

10 For example, most international patents for Roundup have expired, and generic glyphosate products compete with Monsanto's Roundup elsewhere in the world, whereas Monsanto retains a compound patent in the United States through the year 2000.

resistence trait is introduced into commercial varieties. Because this trait is essentially additive, there does not seem to be any reason why the agronomic potential of soybean varieties should suffer, at least in the intermediate run (when the trait has made its way into the best commercial varieties). Second, such experimental tests are in any case measuring an agronomic potential that is not necessarily relevant here. Because RR soybeans allow a better weed control technology, the RR technology may actually increase yields in many typical farming situations. Indeed, Monsanto claims that RR varieties outperformed standard varieties in the United States in 1997 and 1998 (Monsanto, 1999a), and estimates the ceteris paribus yield effect of superior weed control due to Roundup at 2 bushels/acre (Monsanto, 1999b) (a gain of roughly 5 percent). Our baseline calibration takes the conservative assumption of no yield effect and sets $\beta = 0$ in all regions. We will explore the implication of yield effects at the sensitivity analysis stage.

Assumptions on the elasticity of acreage supply and on demand elasticities for soybean and soybean products are based on comparable parameters in existing soybean and oilseed models (Table 5). The picture that emerges from this cursory literature review suggests a consensus on inelastic supply of soybeans, and even more inelastic demands. But apart from that, there is really no consistent indication that emerges from Table 5 as to regional or vertical (i.e., across products) differences in elasticities. Given that, we set all demand elasticities for all products considered here to 0.4 (in absolute value). As for supply elasticities, we believe that the range represented in Table 5 underestimates producers' ability to switch between crops as profitability changes, especially in South America. Thus, we let the elasticity of land supply with respect to soybean prices, defined as $\psi = (\partial L/\partial p_B)(p_B/L)$, be 0.8 in the United States, 1.0 in South America, and 0.6 in the ROW. Given that, the parameter θ is calibrated as $\theta = \psi\pi/(p_B y)$. Finally, because it seems widely accepted that the response of (optimal) yields to changes in prices is limited, we set $\eta = 0.05$ in all regions.

Given the assumed parameters just discussed, the remaining coefficients A, G, λ, κ_B, κ_O, and κ_M were calibrated so as to retrieve acreage, quantity, yield, and price data for 1997-98 as reported in Tables 1-3.[11] For the purpose of this calibration step, the adoption rate used was the actual one observed in the year 1997-98, as reported by James (1998) (i.e., $\rho = 0.13$ for the United States, $\rho = 0.2$ for South America, and $\rho = 0$ for the ROW [12]). Table 6 summarizes the base values of the key parameters used to compute equilibria and welfare measures under various scenarios.

Results

The model detailed above was used to evaluate the welfare effects in the soybean complex arising from the adoption of RR soybeans. First of all, for all counterfactual simulations we set $\Delta S_{j,i} = 0$ for all products and all regions (i.e., we assume that stock decisions are not affected by RR adoption). Next, we established the benchmark by solving the model with $\rho = 0$ everywhere.[13] All counterfactual scenarios then were evaluated relative to this benchmark. We computed the change of producer surplus in each region, as well as the change in consumer surplus in each market in each region using standard procedures (Just, Hueth, and Schmitz, 1982).[14] Specifically, let $\overline{p}_{j,i}$ represent the equilibrium price for product j in region i in the benchmark scenario, and $\hat{p}_{j,i}$ represent the equilibrium price for product j in region i in a particular adoption scenario. The corresponding change in consumer surplus is computed as:

$$\Delta CS_{j,i} = \int_{\hat{p}_{j,i}}^{\overline{p}_{j,i}} D_{j,i}(v)dv .$$

11 To calibrate the parameter A we need an estimate of the profit per hectare in the base year. Based on data reported in Table 4, as well as similar data for Argentina (Margenes Agropectuarios, 1998), we estimated the "land rent" in the base year to be 40% of the per-hectare revenue. In any event, this calibrated parameter is essentially an inconsequential scaling constant.

12 The latter is probably strictly not correct because China reportedly is planting some RR soybeans (James, 1998), although data on the extent of adoption are lacking.

13 All computations were carried out by using user-written programs coded in GAUSS.

14 Because we have assumed constant unit crushing costs, there is no rent in this model that accrues to processors.

where v is a dummy variable of integration. Similarly, if $L_i(\pi_i)$ denotes the optimal allocation of land to soybeans in region i, the variation in producer surplus (relative to the benchmark where the unit profit is $\overline{\pi}_i$, say) due to the innovation (which leads to a unit profit $\hat{\pi}_i$) is:

$$\Delta PS_i = \int_{\overline{\pi}_i}^{\hat{\pi}_i} L_i(v)dv$$

The monopolist's profit is computed simply as:

$$\Pi^M = \sum_{i=U,S,R} \hat{\rho}_i \hat{L}_i \mu_i \delta w_i$$

where $\hat{L}_i$ is the total amount of land allocated to soybean production in country i when the adoption rate is $\hat{\rho}_i$ and the equilibrium soybean price is $\hat{p}_{B,i}$. Finally, the total welfare change for the United States is defined as $\Delta W_U = \sum_j \Delta CS_{j,U} + \Delta PS_U + \Pi^M$, whereas for the other two regions it is computed as $\Delta W_i = \sum_j \Delta CS_{j,i} + \Delta PS_i \; (i = S, R)$.

Table 7 reports the results of our main simulations. First we look at the case in which the adoption rate is $\rho = 0.55$ for the United States, $\rho = 0.32$ for South America, and $\rho = 0$ in the ROW. This is, roughly, the scenario that is unfolding for the next crop year (1999-2000), during which RR adoption in the United States is forecasted to be well above 50%, RR adoption in Argentina is expected to be 100% (Groves, 1999), and Brazil might start producing RR soybeans following a recent regulatory approval. Under these conditions it emerges that the welfare change for consumers (relative to the benchmark) is positive everywhere, whereas the welfare change for producers is positive in the United States and South America but negative in the ROW. The innovator-monopolist's profits are sizeable and account for 60% of the welfare gains accruing to the home country, which itself captures the lion's share of the worldwide benefits. For the scenario that is unfolding in the crop year 1999-2000, the worldwide efficiency gain is estimated at about $804 million, 45% of which is captured by the innovator-monopolist.

One of the questions that we posed earlier concerns the implications of the international spillover of the new technology from the home country to other regions that compete in the production of the final product(s). In principle such a spillover could have adverse effects for the home country's overall welfare because it erodes the competitive position of the producers of the final good (which is also exported). It turns out that the welfare of the United States (as a country) is slightly improved as RR technology is exported. This conclusion can be evinced from Table 7 by comparing the scenario $\{\rho_U = 1, \rho_S = 0, \rho_R = 0\}$ with the scenarios $\{\rho_U = 1, \rho_S = 1, \rho_R = 0\}$ and $\{\rho_U = 1, \rho_S = 1, \rho_R = 1\}$. The home benefits come in the form of larger profit for the innovator-monopolist and increased consumer surplus due to decline in prices. But the home country's export of the new technology is particularly taxing for domestic soybean producers, whose welfare is adversely affected by the export of the innovation. In particular, moving from the scenario where only the United States adopts $\{\rho_U = 1, \rho_S = 0, \rho_R = 0\}$ to that of worldwide adoption $\{\rho_U = 1, \rho_S = 1, \rho_R = 1\}$, US producers lose two thirds of their welfare gains. Under the scenario of worldwide adoption $\{\rho_U = 1, \rho_S = 1, \rho_R = 1\}$ the innovator-monopolist profit constitutes 69 % of the US welfare gains. Conditional upon full adoption in the United States, foreign adoption of RR technology benefits the farmers of the country adopting the new technology and the innovator (as well as consumers everywhere). The last two columns of Table 7 report the equilibrium soybean production and equilibrium soybean complex prices in the United States under the various scenarios considered here (prices in other regions are determined by the spatial equilibrium conditions). These results give an idea of the market changes that underlie the welfare measurement just discussed. For example, worldwide complete adoption of RR soybean is estimated to bring about, ceteris paribus, a 0.6% increase in soybean production and a 2.6% decrease in the price of soybeans.

Another interesting question concerns the impact of intellectual property rights, as modeled here, on the ex-post distribution of welfare gains attributable to the innovation. To address this question, in Table 8 we report the estimated welfare effects for the main scenarios under consideration assuming that

(a) the new technology is competitively supplied (i.e., putting $\mu_i = 0$, $\forall i$), or (b) there is equal international IPR protection (implemented here with equal seed price markups $\mu_i = 0.43$, $\forall i$). First, by comparing the overall welfare gains from the innovation in Tables 7 and 8 we can establish a measure of the efficiency loss due to the exercise of market power by the innovators. It is apparent that such a welfare loss is extremely small. For example, in the scenario of worldwide complete adoption, the efficiency gains under competitive provision of the innovation are only 0.2% larger than those attained by the assumed markup pricing. This result is a reflection of the inelastic demand and supply functions that characterize the soybean complex, as well as the fact that, conditional on land allocated to soybeans, the demand for seed is completely inelastic. Also, the observed markup pricing which is used in the above comparison is not necessarily the optimal monopolistic solution. More interesting, perhaps, is the distribution of the welfare changes. In particular, it is clear that the United States would be adversely affected by the international spillover of the new technology were the latter to be competitively supplied. Comparing the scenario $\{\rho_U = 1, \rho_S = 0, \rho_R = 0\}$ with the scenarios $\{\rho_U = 1, \rho_S = 1, \rho_R = 0\}$ and $\{\rho_U = 1, \rho_S = 1, \rho_R = 1\}$ it emerges that US producers would gain considerably if the RR technology were (freely) available only within the United States, but a good share of these gain would be lost as this technology also is made available to their foreign competitors. More importantly, the gains that accrue to domestic consumers as the RR technology is adopted abroad do not offset the parallel producer losses, and the home country as a whole would be made worse off by overseas adoption of the new technology, were the latter to be competitively supplied. This US welfare loss from foreign adoption of the superior technology is due to the deteriorating terms of trade (export prices) for the United States.

The second part of Table 8 looks at the welfare effects under the assumption that the RR seed price markup is the same everywhere (and reflecting the current level of the technology fee as applied in the United States). Here, export of the new technology would be beneficial to the United States. Not surprisingly, strengthened IPRs help the welfare of the innovating country. If a new technology such as

RR soybeans is to be made available to competing countries, the market power due to IPRs allows the innovating country to extract some of the efficiency gains that are generated by the new technology. Again, however, producers in the home country are adversely affected by the technological spillover. But strengthening international IPRs also has benefits for US producers (they lose less if foreign producers are required to pay the same markup on improved seeds).

To investigate the robustness of the results discussed this far, we provide some sensitivity analysis in Table 9. Because we have already briefly discussed the effects of altering the price markup in Table 8, here we concentrate attention on the following key parameters: demand elasticity, acreage supply elasticity, and per-hectare profitability increase due to RR technology (the yield response parameter will be considered later). For ease of interpretation here we limit the attention to the scenario of worldwide complete adoption. For comparison purposes we report the welfare effects associated with the base values of all parameters at the top of Table 9. For each of the three sets of parameters we illustrate the welfare results associated with a *ceteris paribus* increase and decrease of the parameter values.

Doubling the value of demand elasticities would increase the computed welfare of producers and decrease the gain to consumers (relative to the base-values scenario). Opposite effects would hold if the demand elasticities are halved. Doubling supply elasticities has an effect on welfare computations that is opposite to that of doubling demand elasticities: in such a parametric situation one would find smaller gain for soybean producers, and (slightly) larger gains for consumers. The sensitivity of the results to the assumed supply shift is considered next. In the model this effect works through the parameter α, but for clarity here we report it in terms of the estimated per-hectare profit increase $\Delta\pi$ (at given prices), from which the parameter α is calibrated. As can be seen, increasing this parameter from 20 to 30 would increase the gains to producers and (to a lesser extent) to consumers. Opposite effects would hold if the per-hectare profit increase $\Delta\pi$ were lowered to 10. The profit to the innovator-monopolist, on the other hand, is extremely robust to all these alternative parametric assumptions.

The remaining sensitivity analysis that we wish to investigate is with respect to the parameter β, which controls the yield response to the adoption of the RR technology. As discussed earlier, there are no compelling agronomic reasons to expect that the yield potential of RR soybeans should be affected one way or another. But realized yields, which embody the economic decision of farmers, are a different matter altogether. Because the RR technology seems to offer a superior weed control mechanism, it is quite possible that RR adoption would results in yield increase because of diminished weed competition. It turns out that the value of the β parameter is crucial to many of the results outlined earlier. Thus, rather than confining the effects of this parameter to the narrow bounds of Table 9, we report in Table 10 the more complete analysis of Table 7, but with the assumption $\beta = 0.05$ [i.e., a 5% yield gain due to RR technology, as claimed by Monsanto (1999b)] replacing the assumption $\beta = 0$.[15]

It is apparent that this yield parameter is crucial in determining the benefits to producers. The scenario of $\beta = 0.05$ generates large welfare losses for producers for almost every scenario. In particular, US producers are negatively affected by the adoption of the new technology (the exception is when adoption only takes place in the United States). These massive welfare losses for the producers are due to the price decline that is associated with the supply shift due to the yield effect. It is worth noting that the market adjustments required to bring about these welfare effects are not out of the ordinary, as can be gathered from the last two columns of Table 10. For example, worldwide complete adoption of RR soybean for the case of $\beta = 0.05$ is estimated to bring about, *ceteris paribus*, a 2.1% increase in soybean production and a 6.1% decrease in the price of soybeans. On the other hand, the assumption of a 5% yield increase considered here would result in increased welfare gains for consumers, which essentially offset the welfare losses to producers. Overall, therefore, the welfare gains attributable to RR technology

15 We should make it explicit that the *ceteris paribus* condition here means that the parameter $\Delta\pi$ is held constant, whereas the parameter α is re-calibrated with the new value of β. This explains why, for example, the overall world welfare gains associated with $\beta = 0$ are larger than those for the case of $\beta = 0.05$.

adoption are not affected by alternative assumptions about yield response, but the distribution of these welfare gains between consumers and producers, and across regions, is quite sensitive to yield response assumptions. What is also robust, once again, are the returns to the innovator-monopolist. This is because adoption rates and price markup are held constant in all scenarios, so that monopoly profit only changes as land allocated to soybean is varied. Comparing the scenario $\{\rho_U = 1, \rho_S = 0, \rho_R = 0\}$ with the scenarios $\{\rho_U = 1, \rho_S = 1, \rho_R = 0\}$ and $\{\rho_U = 1, \rho_S = 1, \rho_R = 1\}$, it emerges that the negative impact on US welfare of exporting the RR technology are amplified in the presence of a positive yield response. As before, US producers are particularly hurt by the export of the US technology, and total US welfare actually falls as the innovation is adopted elsewhere in the world.

In conclusion, the sensitivity analysis illustrated in Tables 9 and 10 suggests that most of the qualitative results discussed here are fairly robust to alternative assumptions concerning some key parameters. The one exception is the conclusion that RR adoption always benefits producers. Specifically, that conclusion is reversed if, *ceteris paribus*, one were to assume that RR technology does in fact lead to increased soybean yields realized by farmers. Because this parameter is crucial to some of the qualitative conclusions that we obtain here, additional evidence on this score would be desirable.

Caveats and Conclusions

The results that we have discussed above are obviously subject to a number of qualifications. On the one hand, the model is highly aggregated (the world is represented by only three regions and there is no heterogeneity allowed within a given region), and the parameterization of the model is very parsimonious. On the other hand, even within this specialized model, there are a number of critical parameters whose calibration is difficult, given available information. Hence, the analysis of this paper can only hope to provide approximate answers to the problems of interest. The reader is well advised to concentrate attention on the direction of change and on the order of magnitude of the welfare effects that are estimated, rather than putting too much stock in the actual numerical results. Sensitivity analysis can help somewhat in assessing the confidence one can put in our results, and the reader with strong different priors on some key parameters may find that section useful.

Conditional on the validity of the parametric specification and calibration chosen, our welfare analysis is still incomplete for several reasons. First, our model does not explicitly account for the possible adjustment in other prices in the demand and supply functions. Thus, our measurements are strictly "partial equilibrium" ones. Second, the computation of the monopolist's profit does not account for an additional source of profit for the innovator: the sale of Roundup herbicide. Without more information on the herbicide market, it is difficult to account in a satisfactory way for this effect. But we suspect that in the intermediate run this omission may not be too relevant, because competition from generic glyphosate products may constrain Monsanto's ability to capture rents in the herbicide market. Finally, we do not attempt to quantify the alleged environmental benefits that accrue because adoption of RR soybean induces a substitution of herbicide use towards glyphosate and away from more environmentally damaging ones.

Turning now to our main findings, the base scenario suggests that the overall efficiency gains due to RR adoption are quite sizeable. Not surprisingly for an innovation that is patented, a good share of these efficiency gains are captured by the innovator. But consumers also benefit (because of reduced prices for soybean and soybean products). At the observed pricing of the RR innovation, the welfare of producers in the adopting regions is positively affected. But US producers are hurt by the export of the new technology per se, because such international innovation spillover hampers their competitive position. The sensitivity analysis carried out highlights that some of our conclusions are critically dependent on the assumption that the innovation does not affect soybean yields. When such an assumption is replaced by the alternative that RR adoption does increase farmers' yields, we find that farmers are negatively affected by the innovation. In such a scenario, competitive farmers really have no choice but to adopt the cost-reducing innovation. At given prices this new technology induces a larger allocation of land to soybean production and an increased supply of soybeans. The supply shift tends to depress prices in the soybean complex, and the drop in prices here is amplified by inelastic demands for soybeans and soybean products. In equilibrium, farmers employ a superior technology but face lower soybean prices and, given the parameters of our model, land allocated to soybean production is reduced and producers' welfare also is reduced. The results of this yield increase scenario may also give a clue on the possible qualitative welfare effects to be expected by other biotechnology innovations aimed at increasing pest and stress resistance, for which an yield increase effect is widely documented (as with Bt corn, for example). Such proprietary yield increasing innovations are likely to be damaging to the welfare position of farmers, although they are equally likely to result in large efficiency gains for society at large.

Related issues concern the role of IPRs and the worldwide marketing of the innovation on the welfare of US producers and of the United States at large. Conditional upon international spillover of the technology taking place, as one may expect for a superior innovation such as RR soybeans, it is fortunate for the United States that this innovation is marketed by a private firm who, through pricing of a proprietary technology, can capture some of the efficiency gains due to RR technology. But these effects are limited by the extent of IPR protection. Weak IPRs overseas mean that the innovating firm cannot recover as much return from that market segment. In fact, insofar as the discoverer is endowed with substantially more market power at home than abroad, the ensuing pricing of the innovation ends up discriminating against domestic soybean producers (relative to foreign soybean producers).

References

Alston, J.M., G.W. Norton, and P.G. Pardey, Science under Scarcity - Principles and Practice of Agricultural Research Evaluation and Priority Setting, Ithaca, NY, Cornell University Press, 1995.

Arrow, K.J., "Economic Welfare and the Allocation of Resources for Inventions," in R.R. Nelson, ed., The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton University Press, 1962.

Besen, S.M., and L.J. Raskind, "An Introduction to the Law and Economics of Intellectual Property," Journal of Economic Perspective, 5(Winter 1991):3-27.

Bhagwati, J. N., "Immiserizing Growth: A Geometrical Note", Review of Economic Studies, 25 (1958):201-205.

Bhagwati, J. N., "Distortions and Immiserizing Growth: A Generalization", Review of Economic Studies, 35(1968):481-485.

Brander, J. A., and B. J. Spencer, "Export subsidies and market share rivalry", Journal of International Economics, 18(1985):83-100.

Carlson, G., M. Marra, and B. Hubbell, "Transgenic Technology for Crop Protection: The New "Super Seeds," Choices, (1997), 3rd quarter, 31-36.

Coe, D.T., and E. Helpman, "International R&D Spillovers," European Economic Review 39(May 1995):859-887.

Duffy, M. and A. Vontalge, "Estimated Costs of Crop Production in Iowa 1999," Iowa State University Extension, Fm-1712, January 1999. (http://www.extension.iastate.edu/Pages/pubs/fm3.htm)

Eaton, J. and S. Kortum, "International Technology Diffusion: Theory and Measurement," International Economics Review, 40 (August 1999), 537-570.

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee, Agricultural Research and Development - Public and Private Investments under Alternative Markets and Institutions. USDA, ERS Agricultural Economic Report No. 735, May 1996.

Groves, G.C., "Argentina 1999 Oilseeds and Products Annual," USDA, Foreign Agricultural Service, GAIN Report # AR9029, April 1999.

Huffman, W.E. and R.E. Evenson, Science for Agriculture - A Long-Term Perspective, Ames, IA, Iowa State University Press, 1993.

ISU Extension, 1998 Iowa Crop Performance Test – Soybeans, Iowa State University Extension, AG 18, November 1998).

James, C., Global Review of Commercialized Transgenic Crops: 1998, ISAAA Brief No. 8-1998, Ithaca, NY, 1998.

Just, R.E., D.L. Hueth and A. Schmitz, Applied Welfare Economics and Public Policy, Englewood Cliffs, NJ, Prentice-Hall, 1982.

Karshenas, M. and P. Stoneman, "Technological Diffusion," in P. Stoneman, ed., Handbook of the Economics of Innovation and Technological Change, Oxford, Blackwell, 1995.

Lapan, H. and Moschini, G. "Incomplete Adoption of a Superior Innovation," Staff Paper, Department of Economics, Iowa State University, 1999.

Maredia, M.K., R. Ward, and D, Byerlee, "Econometric Estimation of a Global Spillover Matrix for Wheat Varietal Technology," Agricultural Economics 14(1996):159-173.

Margenes Agropectuarios, Les Numeros del Campo, Ano 14, Diciembre 1998.

Meilke, K.D. and M. Jay, Zero-for-Zero and the Canadian Oilseed Complex, Report prepared for Agriculture and Agri-Food Canada, Ottawa, February 1997.

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

Meyers, W.H., S. Devadoss, and M. Helmar, The World Soybean Trade Model: Specification, Estimation, and Validation, Technical Report 91-TR 23, CARD, Ames, Iowa, September 1991.

Monsanto, "Roundup Ready Soybeans Out Yield National Average," Press release, S. Louis, MO, Jan. 22, 1999a. http://www.monsanto.com/ag/_asp/monsanto.asp

Monsanto, "Roundup Ready Soybeans Website -- Yield Data," 1999b. http://www.monsanto.com/ag/_asp/monsanto.asp

Moschini, G. and H. Lapan, "Intellectual Property Rights and the Welfare Effects of Agricultural R&D," American Journal of Agricultural Economics, 79(November 1997):1229-1242.

Oil World, Oil World Annual 1998, ISTA Mielke GmbH, Hamburg, Germany, 1998.

Oplinger, E.S., et al., Wisconsin Soybean Variety Test Results, A3654, Department of Agronomy and Plant Pathology, University of Wisconsin-Madison, 1998. http://www.uwex.edu/ces/soybean/research/98soyvar/98soyvar.pdf

Park, W.G., "International R&D Spillovers and OECD Economic Growth," Economic Inquiry 33 (October 1995):571-591.

Rankin, M., "Making the Roundup Ready Decision," University of Wisconsin – Extension, January 1999. http://www.uwex.edu/ces/crops/RRsoybn.htm

Rausser, G.C., S. Scotchmer, and L. Simon, "Intellectual Property and Market Structure in Agriculture," Working Paper 880, Department of Agricultural and resource Economics, University of California-Berkeley, 1999.

Reinganum, J.F., "The Timing of Innovation: Research, Development, and Diffusion," in R. Schmalensee and R.D. Willig, editors, Handbook of Industrial Organization, volume I, Amsterdam, North-Holland, 1989.

Roningen, V.O., and P. M. Dixit, "Economic Implications of Agricultural Policy Reforms in Industrial Market Economies," USDA, ERS, Staff Report No. AGES 89-36, August 1989.

Spencer, B. J., and R. W. Jones, "Vertical Foreclosure and International Trade Policy", Review of Economic Studies 58(1991):153-70.

Spencer, B. J., and R. W. Jones, "Trade and Protection in Vertically Related Markets," Journal of International Economics 32(1992):31-55.

USDA, Oilseeds: World Markets and Trade, Foreign Agricultural Service, Circular Series FOP 05-99, May 1999.

Williams, F., "Ocean Freight Rates for International Grain Shipments," Quarterly Report, USDA, Agricultural Marketing Service, 1998.

Table 1. Soybean Production and Utilization, 1997-98

	Area	Yield	Prod'n	Net exports	Δ in Stocks	Direct use	Crush
World	69.3	2.26	156.6	NA	1.9	22.1	132.4
United States	28.0	2.62	73.2	23.6	1.8	4.3	43.5
South America	22.0	2.50	55.0	12.2	0.1	2.9	39.8
Argentina	7.1	2.70	19.2	1.8	0.0	0.8	16.6
Brazil	13.0	2.42	31.5	8.0	0.1	1.9	21.5
Paraguay	1.2	2.49	3.0	2.4	-0.0	0.1	0.5
Rest of the World	19.3	1.47	28.4	-35.8	0	14.9	49.1
European Union	0.5	3.44	1.6	-16.1	-0.0	1.4	16.3
China	8.4	1.76	14.7	-2.8	0.0	6.8	10.7
Japan	0.1	1.75	0.1	-4.9	0.0	1.3	3.7
Mexico	0.1	1.47	0.2	-3.2	-0.0	0.1	3.3

Source: USDA, Foreign Agricultural Service.

Note: Area is in millions of hectares, yield is in metric tons per hectare, and all total quantities are in millions of metric tons.

Table 2. Soybean Oil and Meal, Production and Utilization, 1997-98 [millions of metric tons (MT)]

Soybean Oil

	Production	Net export	Δ in Stocks	Consumption
World	23.94	NA	0.09	23.85
United States	8.23	1.40	-0.06	6.89
South America	7.19	3.44	0.08	3.67
Argentina	2.87	2.70	-0.07	0.1
Brazil	4.00	1.21	-0.00	2.79
Rest of the World	8.52	-4.84	0.07	13.29
European Union	2.94	1.09	0.00	1.85
China	1.78	-1.63	0.13	3.28
Mid East/N Africa	0.26	-1.58	0.00	1.84

Soybean Meal

	Production	Net export	Δ in Stocks	Consumption
World	105.15	NA	0.14	105.01
United States	34.63	8.41	0.00	26.22
South America	31.82	22.53	0.49	8.8
Argentina	13.53	12.90	0.01	0.62
Brazil	16.94	10.65	0.29	6
Rest of the World	38.70	-30.94	-0.35	69.99
European Union	12.74	-12.02	-0.02	24.78
China	8.58	-4.19	0.00	12.77
Mid East/N Africa	1.11	-3.67	-0.03	4.81

Source: USDA, Foreign Agricultural Service.

Table 3. Prices in the Soybean Complex (US $/MT)

	93-94 [a]	94-95 [a]	95-96 [a]	96-97 [a]	97-98 [a]	Avg
SOYBEANS						
US farm price [b]	233	205	263	274	230	241
US Gulf, f.o.b. [b]	248	226	288	293	247	260
Argentina f.o.b. [b]	231	214	277	288	231	248
Brazil f.o.b. [b]	235	217	284	285	240	252
Rotterdam c.i.f. [b]	259	248	304	307	258	275
SOYBEAN MEAL						
US (Decatur), 44% [b,d]	199	167	248	286	193	219
Brazil, 44-45%, f.o.b. [b,d]	182	172	256	289	201	220
Argentina (pell.) f.o.b. [b]	174	151	233	257	174	198
Rotterdam c.i.f. (Argentine 44-45%) [c,d]	202	184	256	278	197	223
Rotterdam c.i.f. (Brazil 48%) [c,d]	211	194	266	293	212	235
SOYBEAN OIL						
US (Decatur) [c]	596	605	550	504	571	565
US Gulf, f.o.b. [c]	...	643	569	527	622	590
Brazil, f.o.b. [c]	546	629	540	518	618	570
Argentine, f.o.b. [c]	545	625	540	517	617	569
Rotterdam, f.o.b. [c]	580	642	575	536	633	593

Notes: (a) Fiscal years (October to September).
(b) Source: USDA.
(c) Source: Oil World.
(d) Percentage refers to protein content.

Table 4. Production Costs for Soybeans in Iowa, 1999 ($/acre, conventional tillage, soybeans following corn [a])

	Standard [b]		Roundup Ready [c]	
	Fixed	Variable	Fixed	Variable
Pre-harvest machinery	14.03	5.70	14.03	5.70
Seed [d]		18.00		18.00
Technology fee [e]				7.80
Herbicide		30.00		10.18 [f] [15.33] [g]
Fertilizer and other intermediate inputs		36.95		36.95
Interest		5.44		4.72 [f] [5.03] [g]
Harvest machinery	13.57	5.95	13.57	5.95
Labor	15.75		15.75	
Land	125.00		125.00	
Total	168.35	102.04	168.35	90.50 [f] [95.96] [g]
RR cost reduction				11.54 [f] [6.08] [g]

Notes: (a) Based on yield of 45 bu/acre.

(b) Source: Duffy and Vontalge (1999).

(c) Source: Our adaptation of ISU extension budgets.

(d) 1.2 bags/acre.

(e) $ 6.50/bag.

(f) Based on one over-the-top Roundup treatment (32 oz/acre of Roundup Ultra and 3 lbs/acre of ammonium sulphate) (note: here we do not adjust labor and pre-harvest machinery costs to reflect the saving of one herbicide pass).

(g) Based on two over-the-top Roundup treatments (48 oz/acre of Roundup Ultra and 5 lbs/acre of ammonium sulphate).

Table 5. Elasticities Commonly Used for the Soybean Complex

	Supply (Area) elasticity	Oil Demand elasticity	Meal Demand Elasticity
United States	0.22 [a] 0.60 [b] 0.30 [c]	-0.08 [a] -0.37 [b] -0.10 [c] -0.30 [d]	-0.11 [a] -0.31 [b] -0.12 [c] -0.12 [d]
Argentina	0.25 [d]	-0.30 [d]	-1.31 [d]
Brazil	0.44 [a] 0.55 [d]	-0.06 [a] -0.10 [b] -0.30 [d]	-0.05 [a] -0.25 [d]
Canada	0.35 [b] 0.31 [c]	-0.40 [b] -0.10 [c] -0.35 [d]	-0.40 [b] -0.36 [c] -0.37 [d]
China	0.28 [d]	-0.20 [d]	-0.25 [d]
European Union / European Community	0.22 [a] 0.40 [b] 0.84 [c]	-0.04 [a] -0.40 [b] -0.10 [c] -0.50 [d]	-0.07 [a] -0.37 [b] -0.25 [c] -0.25 [d]
Japan	0.65 [b] 0.07 [c]	-0.04 [a] -0.47 [b] -0.10 [c] -0.20 [d]	-0.06 [a] -0.35 [b] -0.20 [c] -0.20 [d]

Sources: (a) FAPRI model, Meyers, Devadoss and Helmar (1991);
(b) SWOPSIM model, Roningen and Dixit (1989);
(c) AGLINK model, from Meilke and Jay (1997);
(d) AG CANADA model, Meilke and Swidinsky (1998)

Table 6. Base Values of Key Parameters

	United States	South America	ROW
Supply (Area) elasticity (ψ)	0.8	1.0	0.6
RR unit profit increase $(\Delta\pi)$ \$/hectare	20	20	20
Price elasticity of yield (η)	0.05	0.05	0.05
RR yield change coefficient (β)	0	0	0
Bean demand elasticity $(-\varepsilon_B)$	-0.4	-0.4	-0.4
Oil Demand elasticity $(-\varepsilon_O)$	-0.4	-0.4	-0.4
Meal Demand Elasticity $(-\varepsilon_M)$	-0.4	-0.4	-0.4
Unit seed cost \$/hectare (δw)	45	40	40
RR seed price markup (μ)	0.43	0.22	0.11
Price differential for beans (t_B)	--	-10	30
Price differential for oil (t_O)	--	-10	60
Price differential for meal (t_M)	--	-10	30

Table 7. Estimated Welfare Effects of RR Technology in the Soybean Complex (millions of US $)

Region	ρ	ΔCS beans	ΔCS oil	ΔCS meal	ΔCS total	ΔPS	Π^M	ΔW total	Soybean supply	US Prices
US	0	0	0	0	0	0	0	0	72.4	$p_B = 228$
SA	0	0	0	0	0	0		0	54.1	$p_O = 565$
ROW	0	0	0	0	0	0		0	28.1	$p_M = 192$
US	0.55	9	31	42	81	156	358	596	73.0	$p_B = 226$
SA	0.32	6	17	14	36	27		64	54.2	$p_O = 560$
ROW	0	31	60	111	201	-58		144	27.9	$p_M = 191$
US	1	10	35	47	91	391	546	1028	73.8	$p_B = 226$
SA	0	7	19	16	41	-124		-83	53.5	$p_O = 560$
ROW	0	35	67	124	226	-65		161	27.9	$p_M = 190$
US	1	21	71	96	187	213	735	1136	73.1	$p_B = 223$
SA	1	14	38	32	84	178		262	54.9	$p_O = 555$
ROW	0	71	137	255	463	-132		331	27.7	$p_M = 188$
US	1	25	87	117	230	135	819	1183	72.8	$p_B = 222$
SA	1	17	47	39	103	120		223	54.6	$p_O = 552$
ROW	1	87	168	312	568	224		791	28.5	$p_M = 188$

Table 8. **Welfare Effects of RR Technology in the Soybean Complex under Alternative Market Structures for the Provision of the Innovation (millions of US $)**

Competition: $\{\mu_U = 0, \mu_S = 0, \mu_R = 0\}$

Region	ρ	ΔCS beans	ΔCS oil	ΔCS meal	ΔCS total	ΔPS	Π^M	ΔW total
US	1	19	67	90	177	782	0	958
SA	0	13	36	30	79	-239		-160
ROW	0	67	130	240	437	-125		312
US	1	35	121	162	317	519	0	836
SA	1	23	64	54	142	194		335
ROW	0	120	232	431	783	-222		561
US	1	40	141	188	369	422	0	791
SA	1	27	75	63	165	121		287
ROW	1	140	271	502	913	210		1123

Equal Seed Price Markup: $\{\mu_U = 0.43, \mu_S = 0.43, \mu_R = 0.43\}$

Region	ρ	ΔCS beans	ΔCS oil	ΔCS meal	ΔCS total	ΔPS	Π^M	ΔW total
US	1	10	35	47	91	391	546	1028
SA	0	-7	19	16	41	-124		-83
ROW	0	35	67	124	226	-65		161
US	1	16	56	75	147	286	918	1352
SA	1	11	30	25	66	-50		116
ROW	0	56	108	201	365	-104		260
US	1	18	62	83	163	258	1248	1668
SA	1	12	33	28	73	28		101
ROW	1	62	119	222	403	23		426

Table 9. Sensitivity Analysis: Selected Parameter Values
Welfare Effects (millions of US $, case of complete worldwide adoption)

Parameters	Region	ΔCS	ΔPS	Π^M	ΔW
Base values	US	230	135	819	1183
	SA	103	120		223
	ROW	568	224		791
Demand elasticities: Base values $\times 1/2$	US	266	67	815	1148
	SA	119	69		188
	ROW	658	197		855
Demand elasticities: Base values $\times 2$	US	180	228	823	1232
	SA	81	190		271
	ROW	445	260		705
Supply elasticities: Base values $\times 1/2$	US	175	236	819	1230
	SA	78	196		275
	ROW	433	262		695
Supply elasticities: Base values $\times 2$	US	272	56	818	1146
	SA	122	61		183
	ROW	674	194		868
Unit profit increase (cost reduction): $\Delta\pi = 10$	US	115	67	815	997
	SA	52	59		111
	ROW	284	111		395
Unit profit increase (cost reduction): $\Delta\pi = 30$	US	344	206	822	1371
	SA	154	183		336
	ROW	849	338		1188

Table 10. Sensitivity Analysis: Yield Increase Scenario ($\beta = 0.05$)
Estimated Welfare Effects of RR Technology in the Soybean Complex
(millions of US $)

Region	ρ	ΔCS beans	ΔCS oil	ΔCS meal	ΔCS total	ΔPS	Π^M	ΔW total	Soybean supply	US Prices
US	0	0	0	0	0	0	0	0	72.3	$p_B = 229$
SA	0	0	0	0	0	0		0	53.9	$p_O = 567$
ROW	0	0	0	0	0	0		0	28.2	$p_M = 193$
US	0.55	23	81	108	212	-93	355	474	73.9	$p_B = 224$
SA	0.32	16	43	36	95	-154		-59	54.0	$p_O = 556$
ROW	0	80	155	288	524	-150		374	27.8	$p_M = 189$
US	1	28	98	132	258	59	540	858	76.0	$p_B = 223$
SA	0	19	52	44	116	-346		-230	52.1	$p_O = 553$
ROW	0	98	189	351	638	-182		456	27.7	$p_M = 189$
US	1	51	177	237	464	-328	718	853	74.5	$p_B = 218$
SA	1	34	94	79	208	-224		-16	55.3	$p_O = 542$
ROW	0	176	340	631	1147	-324		823	27.3	$p_M = 184$
US	1	62	214	287	564	-512	795	846	73.7	$p_B = 215$
SA	1	42	114	97	252	-360		-108	54.6	$p_O = 537$
ROW	1	214	413	766	1393	-33		1359	29.4	$p_M = 182$