The Economic Impact of Genetically Modified Organisms in Small Developing Countries

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ABSTRACT

The expected benefits from herbicide resistant transgenic rice in Uruguay are estimated with stochastic simulation techniques. Economic surplus methods that account for private profits are used to measure the magnitude and distribution of the benefits between producers and a multinational firm. Further, the adoption rate of transgenic rice is endogenous in the model and depends on the expected profitability of the technology. The results show that the potential benefits from the technology are relatively small because of the small production base. Multinational firms are, therefore, unlikely to develop locally adapted transgenic rice varieties without strategic partnerships with local institutions.

Keywords: economic impact, economic surplus, genetically modified organisms, stochastic simulation, developing countries

Introduction

The biotechnology science developed during the past decade has given rise to new agricultural technologies based on the manipulation of individual genes. The new products are usually known as Genetically Modified Organisms (GMOs) or transgenic organisms. High invention costs and the need for a high degree of specialization have concentrated their development within large multinational biotechnology companies, which are entitled to intellectual property rights (IPR) over the innovation to recover the research investments. While this conferred monopoly power acts as an incentive for the creation of the new technologies, it also affects the distribution of the benefits derived from adoption of GMOs.

Weak enforcement of IPR has until now resulted in the concentration of the adoption of GMOs in developed countries. Moreover, high fixed costs in developing biotechnology research capacity make it economically difficult for agricultural research systems in small developing countries, such as Uruguay, to develop locally adapted GMOs on their own. Relying on GMOs developed by multinational corporations, on the other hand, raises concerns that multinational monopolists may price GMOs to leave few benefits for country producers. In small developing countries, appropriate national strategies are needed to maximize the domestic benefits of GMOs, while leaving sufficient incentives for multinationals to partner in technology generation.

This paper presents an ex-ante evaluation of the size and distribution of the economic benefits from introducing a herbicide resistant genetically modified rice variety in Uruguay. Improved estimates of the potential benefits of GMOs will help inform agricultural research organizations in small countries like Uruguay to develop feasible policies to retain a greater share of the benefits from GMOs. A partial equilibrium framework is developed that accounts for the market power in transgenic seed of a multinational GMO owner. Economic surplus methods are used to measure the total benefits and their distribution between producers and the multinational firm. The benefits from transgenic varieties are estimated with stochastic simulation techniques that account for uncertainty in some key model parameters. Unlike most previous studies of technology impact, the adoption levels of GMOs are also directly linked to the per-unit cost reduction associated with the technology. The results indicate the total expected benefits from the introduction of the new variety are 10.4 million dollars. Benefits to Uruguay amount to 8.1 million dollars and the GMO owner receives 2.3 million dollars. By contrast, total benefits produced when a perfectly competitive market for the transgenic seed is simulated amount to 20.8 million dollars, all accruing to the country's rice producers.

Three important implications are drawn from the simulations. First, the total benefits generated by GMOs decrease with the seed markup charged by the monopolist. As the monopolist increases the level of the seed premium, producer profits are reduced and adoption rates decline. Producer benefits within the country are, therefore, reduced. Correspondingly, the profit maximizing seed mark-up for the multinational firm results in a lower than optimal level of technology adoption in the country. Second, a small market for varieties can significantly restrict attempts by the country to use license fees to recover, and redistribute back to producers and consumers, some of the profits captured by multinationals. Model estimates indicate that in a small country like Uruguay, the profits available to the multinational gene owner are small, leaving little room for redistribution of these profits before the multinational will choose not to sell the gene in the country. Third, given the limits on potential tax and tariff policies imposed on the country by small production base, agricultural research systems in small countries need to examine alternative cost and benefit sharing arrangements with multinational gene owners. Potential arrangements include shared licensing of genes introduced into locally adapted germplasm and regional licenses that spread multinational's fixed costs over a larger market area.

The Economic Surplus Model with Market Imperfection

Procedures and methods for analyzing the economic impact of agricultural technologies are well-established (see for example, Alston, Norton and Pardey, 1995). While different authors have followed different approaches, the measurement of the change in economic surplus generated after the adoption of the new technology is cited as one of the most accepted and often used methods. The method, however, is dependent on some strong assumptions with respect to the form of the supply functions and the nature of income effects and other parameters. On the other hand, most of the data required is generally available or can be easily generated.

Moschini and Lapan (1997) argue that the presence of Intellectual Property Rights (IPR) in agricultural innovations modifies the theoretical framework and assumptions of the conventional economic surplus approach. The reasoning is based on the fact that IPR confer limited monopoly power to firms producing the innovation. Since these innovations are in general embedded in the inputs, the common assumption of perfect competition in seed input market does not hold in this case. Rather, the firm producing the innovation sets its price to maximize private profit based on monopoly power. This monopoly profit needs to be accounted for when evaluating the welfare change after an agricultural innovation protected by IPR is adopted.

Since the economic surplus approach is usually focused on the commodity market, while the monopolist's profit is generated in the input market, the adjusted model proposed by Moschini and Lapan evaluates the total welfare change as the sum of the change in the

Marshallian Surplus in the agricultural market and the monopoly profit in the input market. The present study follows a similar approach to assess ex-ante the impact of herbicide resistant transgenic rice in Uruguay. Since rice is mainly grown for export, the empirical model applies the formulae in Alston, Norton and Pardey for a small open economy, adding the calculation of the monopolist's profit as the product of the seed premium and the adoption area. The model is as follows:

Change Total Surplus = Change Producer Surplus + Monopolist's Profit

Change in Producer Surplus = $P_w Q_0 K (1+ 0.5 K\varepsilon)$

Monopolist's Profit = $\mu * A_t$

P_w: world price

Q_0: pre-research quantity

K: technical change, shift of the supply curve as a proportion of the initial price

ε: supply elasticity

μ: seed markup

A_t: rate of adoption of the new technology

The coefficient for the technical change K can be calculated from the following formula:

$$K = \left(\frac{E(Y)}{\varepsilon} - \frac{E(C)}{1 + E(Y)} \right) p A_t (1 - d_t)$$

E (Y): expected increase in yield per hectare after the adoption of the new technology

E (C): proportionate change in variable input costs per hectare

ε: supply elasticity

p: probability of success of research in achieving the expected change in yield

d_t: depreciation factor for the new technology

Uncertainty in Parameter Estimates

The literature on economic surplus analysis applied to the evaluation of agricultural technologies has also been characterized by the use of deterministic values for uncertain variables. Sensitivity analysis is then used to create alternative scenarios for the economic impact of the technology. While the type of results generated is useful to estimate the direction of changes in economic surplus due to the innovation, they do not account for probability distributions of key parameters. Estimating the benefits derived from the introduction of Bt Cotton in the United States, Falck-Zepeda, Traxler and Nelson (2000) cite previous works to propose, "stochastic simulation should be used to replace sensitivity analysis in equilibrium displacement models". Further, ex-ante parameters embody more uncertainty than ex-post parameters since events have not happened yet. Probably the best example is the expected adoption area of a new agricultural technology, which is highly unknown in ex-ante evaluations but largely deterministic in ex-post studies. A certain degree of technological uncertainty is also present when farmers adopt a new technology for the first time. In the case of biotechnologies, however, this uncertainty seems to be higher because the genetically modified varieties are often viewed as having a higher degree of risk than more traditional varieties (Saha, Love and Schwart, 1994). As a result, the expected adoption rate, given an expected increase in yield, is likely lower for biotechnologies. Other sources of uncertainty are related to measurement error in market data and natural uncertainty arising from yield variability.

Parameter uncertainty is best represented through probability distributions rather than deterministic values. The equations of the model developed above indicate the type of data needed for the evaluation. The following variables are assigned probabilistic values: expected increase in yield per hectare, change in herbicide costs per hectare, level of seed premium, output price, maximum adoption rate, and price elasticity of supply.

Another important issue is how to model the uncertainty over the 15-year period of the analysis. Two variables are assumed to be random events every year: price and expected increase in yield. Thus, they are modeled as having probabilistic distributions over the period and in each year they can take different values. Other variables, however, are assumed fixed once the first year event has occurred. It is rational to assume that per-unit cost reductions associated with the technology are fixed on average and, thus, farmers would expect to achieve the same cost reduction each year. The seed markup is also assumed fixed after the first contract has been established[1]. The value for the long-run elasticity of supply is determined on the first year and also remains constant over the rest of the period. The maximum expected adoption rate is determined by the first year's per-unit cost reduction value, and then calculated for the rest of the period based on a fixed adoption pattern.

Data

This section details the data used for the simulation and the probability distributions assumed for the specified random variables.

Expected Increase in Yield per Hectare

Crop yield is typically uncertain at the beginning of each cropping season. For new varieties, information about field trials performance can be used as a proxy for expected farm yields. However, there are no field trials of transgenic rice varieties in Uruguay. The expectations about the potential benefits of herbicide resistant transgenic rice come from reduced

[1] The seed markup only applies for the first ten years, the legal period for patent protection in Uruguay. After year 10, its value is zero.

herbicide costs rather than yield increases (Zorrilla, 2001). Nevertheless, Oard et al. (1996) suggest that a better weed control can potentially increase yield, all else equal. Hence, the expected increase in yield is assigned a triangular probability distribution with 0, 2.5 and 5 per cent as minimum, most likely and maximum possible values respectively.

Change in herbicide costs per hectare

The study simulates a reduction in variable herbicide costs due to the substitution of a GMO for the actual technology used to control the most relevant rice weed (*Echinochloa sp*.). The new alternative transgenic variety is assumed to be effective with a single application of the herbicide to which the variety is resistant, instead of the multiple applications needed in the traditional technology. This approach is similar to the Round-up Ready® technologies already on the market. Budget figures for rice in Uruguay show that the total cost of herbicides is 90 dollars per hectare, out of a total average cost for a five-year period of 1,100 dollars per hectare (Lavecchia, 2000; Asociación de Cultivadores de Arroz, 2001). Using Round-up Ready® technologies as a benchmark suggests that herbicide costs under the new technology may be set at 15 dollars per hectare, implying a net reduction of 75 dollars per hectare. The maximum herbicide costs under the new technology can be arbitrarily set at 60 dollars per hectare, assuming that higher values are beyond the threshold that would make farmers indifferent between the new and old varieties. The change in herbicide costs per hectare is therefore assigned a triangular distribution with 30, 75 and 90 dollars per hectare as minimum, most likely and maximum possible values.

Seed premium

The seed premium and the change in herbicide costs per hectare jointly determine the proportional change in variable input costs per hectare. The seed premium is the price that the owner of the gene charges above the competitive price of the seed in order to recover its research investments. The magnitude of the seed premium is associated with the degree of monopoly power in the seed market. It must be specifically accounted, since it affects the per-unit cost reduction that can ultimately be achieved with the new technology. Comparison with transgenic technologies available in the U.S for cotton and soybeans suggests that the seed premium, although extremely crop-specific, varies on average between 15 and 60 dollars per hectare (Hubbell, Marra and Carlson, 2000; Carpenter and Gianessi, 1999; Couvillion, Kari, Hudson and Allen, 2000). In a developing country, however, the monopolist may have lower profit margins or more elastic input demand. Therefore, the seed premium is assigned a triangular distribution with 10, 25 and 50 dollars per hectare as minimum, most likely and maximum possible values respectively. Since the seed premium that the monopolist is able to extract depends on the size of the expected reduction in herbicide costs per hectare, a positive correlation of 0.8 between both variables is also included in the model.

Adoption rate

Adoption rates are highly uncertain in ex-ante analyses and have a large influence on the magnitude of the change in total surplus. The difficulty in assigning an ex-ante value arises because many factors affect both the path of adoption of a technology over time and the maximum adoption rate achieved. Based on historic information for adoption of rice varieties in Uruguay, the adoption path over the 15-year period of the analysis is calculated assuming a logistic initial phase of increase, a constant maximum between years 5 and 10, and a linear decline after year 10 with zero per cent adoption in year 16 (Zorrilla, 2001).

Unlike previous studies, the analysis assumes that the maximum adoption rate is endogenous to the model and depends on the profitability of the technology, which is represented by the estimated per-unit cost reduction. The latter is also a random variable depending, among others, on the expected increase in yield per hectare, the elasticity of supply, the change in herbicide costs per hectare and the seed markup.

The maximum adoption rate is assigned a triangular distribution whose values are conditional on the per-unit cost reduction that the model previously calculates. Initial calibrations with the available data show that the maximum per-unit cost reduction of the model is below 15 per cent[2]. The interval between 0 and 15 per cent was then arbitrarily divided into six equal ranges of 2.5 points. Following the Stanford Research Institute Risk Assessment Protocol for expert elicitation described in Morgan and Henrion (1990), the minimum, most likely and maximum possible values for the maximum adoption rate under each range of per-unit cost reduction was elicited from the head of the Rice Research Program of the National Agriculture Research Institute (INIA) of Uruguay. The elicited values are shown in table 1. Then, applying conditional functions embedded in the spreadsheet software used to run the model, the simulation selects the corresponding distribution of maximum adoption rates according to the per-unit cost reduction achieved, and this value is used to calculate the 15-year time path of adoption.

[2] The maximum per-unit cost reduction was initially calculated for calibration purposes applying the values of the variables that give the maximum expected per-unit cost reduction that can be achieved.

Table 1. Range of per-unit cost reductions and maximum expected adoption rates for each range (Source: elicited from Zorrilla, 2001).

Range for Per-Unit Cost Reduction (%)	**Expected Maximum Adoption Rate (% - Triangular Distribution Values)**		
	Lowest	*Most Likely*	*Highest*
0 – 2.5	0	2	5
2.5 - 5	0	3	5
5 – 7.5	3	7	20
7.5 - 10	5	15	30
10 – 12.5	20	40	60
12.5 - 15	30	60	70

Price

Based on time-series data for prices received by Uruguayan rice farmers during the period 1981 – 1999, the price is assigned a normal distribution with mean 182.3 dollars per ton and standard deviation of 35.1 dollars per ton (Asociación de Cultivadores de Arroz, 2001).

Price Elasticity of Supply

No estimates for Uruguay were found regarding the price elasticity of supply for rice, but Moschini and Lapan show that the results are sensitive to the level of the price elasticity. Based on literature review, it is assigned a triangular distribution with minimum possible value of 0.3, most likely value of 1.0, and maximum possible value of 1.5.

Deterministic variables

All the other model parameters are assigned deterministic values. Total average rice costs, as explained before, are 1,100 dollars per hectare. Since the technology is assumed released, probability of success of the research is 100 per cent. The depreciation rate of the technology is assumed to be 10 per cent per year beginning in year 10 and represents, for instance, the increased resistance to herbicides that weeds acquire. Exogenous output growth is assumed to be 1 per cent per year. Base quantities for year 1 are 889,200 tons, calculated using average cropping area in Uruguay for the period 1991-2000 and average yield for the period 1995 – 1999, net of domestic consumption (Asociación de Cultivadores de Arroz, 2001). A discount rate of 5 per cent is applied. The simulation was run using *@Risk 3.5 for Excel*, setting the convergence criteria to 1 per cent and selecting Latin Hypercube sampling.

Results

The results for the change in producers' surplus, monopolist's profit and total surplus are presented in table 2 for the mean, and 5 per cent and 95 per cent confidence intervals[3].

Table 2. Simulation results: change in producers' surplus, monopolist's profit and total surplus (in U.S. dollars).

	Mean	***5%***	***95%***
Producers' Surplus	$ 8,118,819	$ 269,386	$ 20,315,440
Monopolist's Profit	$ 2,335,690	$ 117,534	$ 5,979,041
Total Surplus	$ 10,454,510	$ 386,920	$ 26,294,481
Producers' %	77.66 %	69.62 %	77.26 %
Monopolist's %	22.34 %	30.38 %	22.74%

On average, the expected change in economic surplus for rice producers is 8.1 million dollars for the entire period (15 years). Monopolist's profit amounts to 2.3 million, and total

[3]The results refer to the Net Present Value (NPV) of benefits over a 15-year period.

surplus change to 10.4 million dollars. These figures represent a distribution of benefits between producers and monopolist of 78 per cent and 22 per cent respectively. Since it is assumed that the monopolist extracts the profit out of the country, from Uruguayan's point of view 78 per cent of the total surplus generated by the technology remains locally and 22 per cent is transferred out.

It is interesting to compare the total surplus generated under imperfect markets (the monopolist's power) with what would have happened had the input market for the seed variety been perfectly competitive. Economic theory suggests that the presence of the monopolist, represented in the model by the seed markup, decreases the total surplus generated. The model was run setting the seed markup to zero to simulate a perfectly competitive market for the transgenic seed, and results are shown in table 3.

Table 3. Simulation results under perfectly competitive market for the transgenic seed change in producers' surplus and total surplus (in U.S. dollars).

	Mean	***5%***	***95%***
Producers' Surplus	$ 20,868,460	$ 4,158,791	$ 61,180,660
Total Surplus	$ 20,868,460	$ 4,158,791	$ 61,180,660

Previous literature indicates that the change in the absolute size of the results comparing perfect and imperfect markets is not as great as the change in distribution (Alston, Sexton and Zhang, 1997). The present results, however, show that the absolute size may change considerably. The difference arises from the use of an endogenous adoption rate. Assuming perfectly competitive markets, the total surplus increases from 10.4 million to 20.8 million dollars. Since the gene owner is not represented any more, the increase in producers' surplus is even greater, from 8.1 million to 20.8 million dollars

Next, the correlation coefficients are generated to identify the variables that most affect the total surplus change (table 4). The variables with the highest correlation with the change in total surplus are the expected increase in yield (0.47), the change in herbicide costs per hectare (0.39), and the adoption rate (0.34). It is significant that the expected increase in yield has the highest correlation, since it clearly makes it an important variable for the technology to be successful. This fact has strong implications on the appropriate strategies that should be followed to increase the expected benefits from a new transgenic variety. Particularly for small markets, it seems that gene owners would do better by introducing the technology into locally adapted varieties than by creating a new variety with lower yield.

Table 4. Correlation coefficients of uncertain parameters with total surplus and monopolist's profit.

	Total Surplus	***Monopolist's Profit***
Expected yield increase	0.469	0.486
Change in herbicide costs	0.39	0.51
Adoption Rate	0.336	0.309
Seed Premium	0.174	0.384
Supply elasticity	- 0.414	- 0.321

The positive correlations with the change in herbicide costs per hectare and with the adoption rate are expected. The correlation with the supply elasticity is -0.41. This arises, in part, because an increase in the supply elasticity directly reduces the per-unit cost reduction. Varying the mean of the distribution for the supply elasticity has a large impact on the magnitude of the results. For a mean of 0.5, the expected producer surplus is 12.4 million dollars, the expected monopolist profit is 3.1 million dollars, and the expected total surplus is 15.5 million dollars. When the mean of the supply elasticity is set at 1.3, the results are 7.2 million dollars for the producer surplus, 2.1 million dollars for the monopolist's profit and 9.3 million dollars for the total surplus. Since the reason to treat the elasticity as stochastic was the lack of proper data, the accuracy of future work and predictions can be improved with better estimates for this variable. The positive sign of the correlation between the seed markup and the total surplus (0.17) is explained by the assumed positive correlation with the reduction in herbicide costs per hectare. The model allows for higher seed markup levels when reductions in herbicide costs per hectare are larger. Larger cost reductions produce positive changes in total surplus, which in turn imply that the markup can be set at a higher level.

The correlations between the different parameters and the monopolist's profit are also indicated on table 4. As expected, the correlation of monopolist's profits with the seed markup is positive and higher (0.38) than the correlation between total surplus and the seed markup. This is due to the direct relationship between the profits and the level of seed premium charged. The high correlation with the reduction in herbicide costs per hectare (0.51) is due, as before, to the correlation assumed between change in herbicide costs and seed markup. The high correlation with the expected yield increase (0.49) reconfirms the importance of the variable in determining the magnitude of the benefits from GMOs. The positive impact on the expected profits comes through the influence on the final adoption rate achieved, which for the monopolist's has a positive correlation of 0.31. As for the total surplus, the supply elasticity is negatively correlated with profits (-0.32).

The sensitivity of the results to the level of the seed markup was examined by changing the mean of the distribution for the latter. The sensitivity analysis show that when the mean of the seed markup is changed to 35 dollars per hectare from the original level of 25, producers' surplus is reduced 7.85 million dollars, monopolist's profit remains constant at 2.32 million dollars and total surplus is reduced to 10.17 million dollars. When the mean of the seed markup is changed to 15 dollars per hectare, producers' surplus increases to 9.94 million dollars, monopolist's profit is reduced to 2.17 million dollars and total surplus increases to 12.11 million dollars[4]. Thus, as expected, the total surplus generated decreases with the markup, while between $25 and $35 markups monopolists fail to increase their profits. It should be also noted that the assumption about the functional form of the maximum adoption rate with respect to the per-unit cost reduction of the new technology (see table 1) can be used to generate more drastic results. For example, the seed markup can be increased to a level such that one of the thresholds of adoption is reached, adoption rates decline sharply and total benefits are reduced more than proportionally with a markup.

Conclusions

According to the simulation results, the expected total change in economic surplus generated by the introduction of a transgenic rice variety in Uruguay is 10.4 million dollars. Out of the total, 8.1 million dollars (78%) correspond to producers' and national surplus and 2.3 million dollars (22%) are extracted out of the country as multinational firm profit. If the

[4] The results refer to the mean of producers, monopolist and total surplus.

transgenic variety were released in a perfectly competitive seed market, the expected producers' and total surplus is 20.8 million dollars, with no profits for the owner of the innovation.

The total benefits to society generated by GMOs decrease with the seed markup charged by the monopolist. As the monopolist increases the level of the seed premium, producer profits are reduced and adoption rates decline. Producer benefits within the country are reduced. Thus, the profit maximizing seed mark-up for the multinational results in a lower than optimal level of technology adoption in the country and lower levels of total benefits. Still, monopolist profits are necessary to spur the large research investments needed to develop genetically modified varieties. The results for both producers and the monopolist provide an indication of the total size of returns to potential investments in a transgenic rice variety. The results suggest that, given the size of the market, it seems unlikely that a private company would find it profitable to invest in the creation of a specifically adapted transgenic variety for Uruguay. Moreover, the small market size and the associated relatively small pool of total benefits significantly restrict the ability of the country to use license fees to recover and redistribute back to producers and consumers some of the profits captured by multinationals. Traxler (1999) shows, however, that when conditions like proper law enforcement and availability of locally adapted varieties (among others) are met, GMO companies are willing to enter small markets. Strategic alliances between multinational companies and national institutions producing locally adapted varieties may increase the attractiveness of investments. The conclusion is further supported by the high correlation found between the surplus generated and the expected yield increase of the new variety, suggesting that the yield gains associated with local adaptability play a major role in increasing the magnitude of the expected benefits of a genetically modified variety.

Given the limits on potential tax and tariff policies imposed on the country by small market size, agricultural research systems in small countries also need to examine alternative cost and benefit sharing arrangements with multinational gene owners. Potential arrangements include shared licensing of genes introduced into locally adapted germplasm, and regional licenses and collaborative networks that spread national research systems and multinational's fixed costs over a larger market.

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