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IMPACT OF BIOTECHNOLOGY IN EUROPE: THE FIRST FOUR YEARS OF *BT* MAIZE ADOPTION IN SPAIN

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Since 1995, genetically modified organisms have been introduced commercially into US agriculture. These innovations are developed and commercialised by a handful of vertically coordinated "life science" firms who have fundamentally altered the structure of the seed industry. Enforcement of intellectual property rights for biological innovations has been the major incentive for a concentration tendency in the upstream sector. Due to their monopoly power, these firms are capable of charging a "monopoly rent", extracting a part of the total social welfare. In the US, the first *ex post* welfare studies reveal that farmers and input suppliers are receiving the largest part of the benefits. However, up to now no parallel *ex ante* study has been published for the European Union. Hence, the EUWAB-project (European Union Welfare effects of Agricultural Biotechnology) aims at calculating the total benefits of selected agricultural biotechnology innovations in the EU and their distribution among member countries, producers, processors, consumers, input suppliers and government. This project (VIB/TA-OP/98-07) is financed by the VIB - Flanders Interuniversitary Institute for Biotechnology, in the framework of its Technology Assessment Programme. VIB is an autonomous biotech research institute, founded in 1995 by the Government of Flanders. It combines 9 university departments and 5 associated laboratories. More than 750 researchers and technicians are active within various areas of biotech research. VIB has three major objectives: to perform high quality research, to validate research results and technology and to stimulate a well-structured social dialogue on biotechnology. Address: VIB vzw, Rijvisschestraat 120, B-9052 Gent, Belgium, tel: +32 9 244 66 11, fax: +32 9 244 66 10, www.vib.be

Abstract

In the present paper we estimate the impact of a biotechnology innovation in Spanish agriculture. Transgenic *Bt* maize offers the potential to control corn borers, that cause economically important losses in Spanish maize cultivation, more efficiently. Since 1998, Syngenta commercializes the variety Compa CB, equivalent to an annual area of 25.000 ha, or an average adoption rate of 5,2% of Spain's total land allocation to maize. The profit increase engendered by this technological change during the four-year period 1998-2001 is estimated to be €8,4 million for Spanish agriculture and €2,8 million for Syngenta and the seed suppliers. The industry appears to be able to extract only one fourth of the total benefits. The lion share, i.e. three fourth, accrues to farmers.

Introduction

Since the Second World War, the industrialization of maize growing is essentially driven by technical and economical change. The first comprises a set of technological innovations in genetics, mechanics and chemistry. The commercialization of hybrid maize in the fifties, studied by Griliches (1957), can be considered the most important predecessor of biotechnology in the maize sector. Since the seventies, technical and economical constraints emerge, engendering a crisis, due to a slowing down of the productivity growth (Gaillard, 1988).

During the eighties, fixed costs increased, constituting roughly half of the production costs. This caused a sharp decline in maize profitability (Le Stum and Camaret, 1989), engendering a crowding out in the maize sector. This was due to the fact that the sector faced structural constraints (Gaillard, 1988), raising the demand for cost-reducing technological innovations. Biotechnology could be a tool to respond to this demand. In 1998, two transgenic maize varieties have been approved for commercialization in Spain. However, in 1999 the European Union (EU) issued a *de facto* moratorium on new approvals of transgenic crops. Hence, the only EU country where transgenic crops are grown is Spain. The purpose of this paper is to estimate the first impact of biotechnology in Europe through the case study of transgenic maize in Spanish agriculture. Secondly, we are interested in the heterogeneity and variability of the impact estimates in space and in time, its uncertainty and its sensitivity to our limited set of data and assumptions.

Economic Importance of Maize Growing in the World

Maize is world's most ubiquitous cereal (Table 1). It is cultivated from the equator to roughly 50° north or south latitude, from sea level to more than 3.000m altitude. No other cereal is used in as many different ways; nearly every part of the maize plant has economic value: the grain, the leaves, the stalks, the ears and sometimes the roots. Moreover, growing incomes in developing countries have stimulated demand for meat and poultry consumption and, as a result, derived demand for maize as animal feed (Pingali, 2001).

Roughly, two distinct production systems can be distinguished. In Northern regions silage maize systems dominate. Being part of a cattle production system, the entire harvested plant is processed to animal feed. In Southern regions on the other hand, grain maize systems prevail. In these arable farming systems, grain production is optimized. Maize grain is commercialized and transformed to human food and animal feed. The occurrence of grain maize is correlated with the occurrence of corn borers, causing important production losses. In the Northern silage maize cropping systems, other diseases and pests prevail. This study concentrates on grain maize as a cereal, and corn borers as an important economic pest. In the remainder of the paper, the term 'maize' refers to 'grain maize'.

Table 1 shows that, while maize is an important crop in all continents, yields vary strongly, ranging from 1,7 ton/ha to the six-fold of 10,7 ton/ha. Through high yields, three continents, i.e. the US, South-America and Asia, produce three quarters of global maize production and the majority of maize export, which in its turn accounts for 12% of global maize production (Pingali, 2001). The three largest maize producers in the EU are France, Italy and Spain, responsible for 78% of EU maize production. Spain, EU's third largest maize producer, occupies an important place with 11% of total EU maize production.

The Corn Borer

The European Corn Borer (ECB) [*Ostrinia nubilalis* (Hübner)] and Mediterranean Corn Borer (MCB) or Corn Stalk Borer [*Sesamia nonagrioides* (Lefebvre)] are considered the most harmful insects in the most important maize producing countries. In North-America and Central-Europe, losses are primarily caused by the ECB. On a continental level, the number of ECB generations increases progressively from North to South (Mason *et al.*, 1996). In contrast to the US Corn Belt, where ECB occurs bivoltine, only one generation is observed in Central-Europe (Bohn *et al.*, 1999), while in Southern-Europe up to three generations are observed (Kergoat, 1999).

The MCB is considered one of the most severe maize pests around the Mediterranean Sea and Morocco. Like the ECB, the number of generations increases according to the latitude. Up to four MCB generations occur. Two generations prevail, but a single generation also occurs in some areas, like the Azores. In the Northeast of Spain, the South of Portugal, Sardinia and Greece, three generations dominate, while four generations can be observed in Morocco (Cordero *et al.*, 1998).

The degree of loss largely determines whether the adoption of a pest control strategy is economical. Bohn *et al.* (1999) estimate the average proportional production loss per corn borer and per plant at 6,05%. The insects cause severe physical damage to the plant. The borer penetrates the stalk and excavates large tunnels that result in important yield losses. This complicates the circulation of water and nutrients to the plant and the ear. Despite the fact that heavy rainfall and wind can also break maize stalks, insects are generally the main cause of losses. Important is the timing of corn borer attack. The plant is most vulnerable as soon as it developed six leaves until it reaches maturity. As soon as physical maturity is achieved, no important losses occur, apart from e.g. unfavorable weather conditions.

Crop Protection: Insecticides versus *Bt* Maize

Larvae from corn borers are difficult to control with chemical insecticides (e.g. organophosphates and synthetic pyrethroids) because they are vulnerable to sprays or residues for only a short time before they bore into and are protected by the cob, sheath-collar, or stalk (Jansens *et al.*, 1997). Insecticides could be useful when the larvae have just hatched or when they migrate to neighboring plants (Velasco *et al.*, 1999). Therefore, proper timing of insecticide application is crucial for success. Repeated applications of the chemical insecticides are often necessary. However, actual practices are rarely optimal, such that the use of insecticides is limited in Spain (Brookes, 2002).

Bacillus thuringiensis (*Bt*) is a naturally-occurring soil borne bacterium that is found worldwide. A unique feature of this bacterium is its production of crystal-like proteins that selectively kill specific groups of insects. These crystal proteins (Cry proteins) are insect stomach poisons that must be eaten to kill the insect. Once eaten, an insect's own digestive enzymes activate the toxic form of the protein. The Cry proteins bind to specific "receptors" on the intestinal lining and rupture the cells. Insects stop feeding within two hours of a first bite and, if enough toxin is eaten, die within two or three days (Ostlie *et al.*, 1997). *Bt* can be used to control ECB. The toxins are incorporated into sprays providing a natural crop protection tool for organic farming.

Plant geneticists create *Bt* maize by inserting a gene of the *Bacillus thuringiensis*, that causes the plant to produce the *Bt* toxin. Depending on the gene, the proteins Cry1Ab, Cry1Ac, Cry1B or Cry9C are produced. Labatte *et al.* (1996) demonstrate that *Bt* maize has a higher efficacy and shorter time response than insecticides, regardless of the infestation date. Therefore, *Bt* maize has the potential to improve ECB control dramatically, compared with current practices.

Adoption of *Bt* Maize

Transgenic maize has first been commercialized in the US and in Canada in 1996 and two years later in Argentina, South-Africa and some countries of the EU. Since then, its adoption increased up to 9,8 million ha in 2001 (Table 2). The majority, i.e. 5,9 million ha, are insect resistant (IR) *Bt* varieties. The other varieties are herbicide tolerant (HT) or stacked IR and HT varieties. Today, seven years after its introduction, the experiences of US farmers with *Bt* maize are well recorded (Pilcher *et al.*, 2002).

In 1998, Syngenta's *Bt* varieties Compa CB and Jordi CB have been approved for commercialization in Spain, but only the first has effectively been commercialized. In the spring of 2003, five additional varieties were approved, including Monsanto's MON810. Table 2 shows that from 1998 tot 2001 the Spanish *Bt* maize adoption stagnated at about 25.000ha because of a voluntary arrangement by Syngenta Seeds to limit seed availability until the EU wide moratorium on new GM approvals is lifted

(Brookes, 2002). Syngenta decided to limit the amount of seed available in 1999, 2000, 2001 and 2002 to the amount sold in 1998. Thus the take-up of the technology has been artificially constrained. In 2003 this constraint was lifted and the area planted this year has been about 32.000 ha.

Model

Due to the limited availability of data, the impact of *Bt* maize is estimated analogous to Ostlie *et al.* (1997), Marra *et al.* (1998) and Lemarié *et al.* (2001).[1] We assume that due to maize borer infestation the yield decreases, proportionally to the damage incurred despite pest control technology k. The technology k can be: none ($k = o$), conventional crop protection through insecticides ($k = c$) and biotechnological pest control *Bt* maize ($k = g$). The observed yield y_{jk} can be expressed as:

$$y_{jk} = y_{jm} \, [1 - (1 - a_k) \, s_j] \qquad (1)$$

with y_{jm} the theoretical maximum attained yield under hypothetical complete absence of corn borers in year j, a_k the efficacy of technology k, measured by the proportion of larvae killed before affecting yield, and s_j the theoretical average proportional loss caused by corn borers in year j under absence of treatment. The profit of the farmer using technology k in year j is:

$$p_{jk} = p_j \, y_{jk} - w_k - c_j = p_j \, y_{jm} \, [1 - (1 - a_k) \, s_j] - w_k - c_j \qquad (2)$$

with w_k the cost of technology k to combat corn borers and c_j all other costs that are independent of the choice of technology k, including the cost of conventional seed. In the case of an insecticide treatment ($k = c$) w_k comprises the cost of the product and

[1] Hyde *et al.* (1999) use a more complex model, requiring data that are not available for our study.

the spraying application. For biotechnological crop protection ($k = g$), w_k represents the technology fee. In case of no treatment ($k = o$), $w_k = 0$.

Since 2001 the adoption of *Bt* maize stagnated at an average of 5,2% (Table 2), while the adoption of insecticides reached 13 to 22% during 1999-2001 (*cfr. infra*). Brookes (2002) observed some *Bt* maize adopters who did not previously use insecticides. Since no data is available on the share of this category of adopters, we reasonably assume that the actual *Bt* maize adopters were insecticide users before adoption. This will provide us a conservative impact estimate. Change in profit due to the conversion from insecticides ($k = c$) to *Bt* maize ($k = g$) in year j, can be expressed as:

$$Dp_j = p_{jg} - p_{jc} = p_j \, y_{jm} \, s_j \, (a_g - a_c) + (w_c - w_g) \qquad (3)$$

The first term of this formula refers to the difference in efficacy, while the second term relates to the cost difference between both technologies. Total change in profit W_j in year j in Spain is calculated as:

$$W_j = Dp_j \, L_j \, ?_j \qquad (4)$$

with total maize area L_j and adoption rate $?_j$ in year j. The present value W in 2002 of the aggregated profits since 1998 can be calculated as:

$$W = \sum_{j=1998}^{2001} \Delta\Pi_j (1+i)^{2002-j} \qquad (5)$$

with interest rate i. The gross profit Π_j captured by Syngenta in year j is (Moschini and Lapan, 1997):

$$\Pi_j = w_g \, L_j \, ?_j \qquad (6)$$

The present value Π in 2002 of the aggregated gross profits since 1998 is:

$$\Pi = \sum_{j=1998}^{2001} \Pi_j (1+i)^{2002-j} \qquad (7)$$

Finally, the present value in 2002 of the total welfare increase W_{tot} in Spain is:

$$W_{tot} = W + \Pi \qquad (8)$$

Data

An important constraint for our impact assessment is the scarcity and low precision of data. Therefore, we use stochastic simulation techniques, analogous to Davis en Espinoza (1998), through the software @Risk of Palisade Corporation (2000). We introduce prior stochastic distributions for uncertain parameters and through Monte Carlo simulation techniques we generate posterior distributions for the outcomes in our model.

Irrigation

The Spanish climate necessitates irrigation. 91,8% of total maize area is irrigated (MAPA, 2002), symbolized by the parameter *irr*. Only in the North, maize can be grown without irrigation. Irrigated land is cultivated more intensively, plant density is higher and investment per unit of land and yields are higher.

Insecticide Use and Cost

During 1999-2001, only 59.000 to 98.000ha, i.e. 13 to 22% of total maize area was sprayed with insecticides against ECB and MCB (Brookes, 2002). We model the uncertainty around insecticide adoption $?_c$ through a triangular distribution with a minimum of 13%, a most likely value of 18% and a maximum of 22%:

$$?_c \sim \text{Triangular}(13\%; 18\%; 22\%) \qquad (9)$$

This is lower than in France, where one third of the maize area is sprayed (Lemarié *et al.*, 2001), but higher than in the extensive US Corn Belt, where insecticide is only used in 5% of the area (Gianessi and Carpenter, 1999).

Estimates for the insecticide cost are reported by Brookes (2002). The application cost per hectare a_{irr} in irrigated maize can be modeled as:

$$a_{irr} \sim \text{Triangular}(€18; €21; €24) \qquad (10)$$

For aerial spraying, the application cost per hectare is modeled as:

$$a_{air} \sim \text{Triangular}(€36; €39; €42) \qquad (11)$$

The average application cost per hectare a is an average of the application costs of both spraying techniques, weighted according to the occurrence of irrigation:

$$a = a_{irr}\, irr + a_{air}\,(1 - irr) \qquad (12)$$

The insecticide cost per hectare v for corn borer control is modeled as:

$$v \sim \text{Triangular}(€24; €54; €84) \qquad (13)$$

Total insecticide cost per hectare w_c is:

$$w_c = a + v \qquad (14)$$

Technology Fee

To estimate the technology fee, the difference is calculated between the seed cost of the most sold *Bt* variety, i.e. Compa CB, and the average seed cost of equivalent conventional varieties of the Ciclo 700 type: Aristis, Eurodis, Juanta, PR32R42, Kelada, Proxima, Missouri, Sele, Trebbia en Tietar. We find a technology fee of €35 per hectare, i.e. 20,6% of the seed cost. Since the Spanish government limits the commercialization of *Bt* maize seed, this price is artificial since it did not originate from a free market. Nevertheless, an *ex ante* study estimated a profit maximizing technology fee of €36 per hectare for France (Lemarié *et al.*, 2001), very close to the official price of *Bt* maize seed in Spain. Brookes (2002) finds a lower technology fee of €29-31 for Spain. This price is a recommended price and many farmers receive the technology at lower prices through cooperatives. The AGPME (Asociación General de Productores de Maíz de España) confirms that local cooperatives sell their seed to members at lower prices, i.e. €18-19 per hectare, than the prices recommended by the seed industry.[2] At least 70% of the Spanish maize seed market would apply these lower prices. These data allow us to model the technology fee w_g as:

$$w_g \sim \text{Triangular}(€18; €18{,}5; €35) \qquad (15)$$

Theoretical Loss due to Corn Borers

The most important yield factor is the annual loss due to corn borers. This loss varies considerably from year to year. Therefore, we estimate an average stochastic distribution for this parameter and we use the same distribution for each of the four analyzed years. We can reasonably assume the distributions to be mutually independent, since Hurley *et al.* (2001) found time trends of ECB losses to be statistically[3] insignificant. According to the authors, gamma as well as lognormal distributions are used to model insect damage. They prefer a lognormal distribution since it provides a better statistical fitting. Parallel to their findings, we define the theoretical average proportional loss s_j by corn borers in year j in absence of pest control as:

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[2] As a comparison, the technology fee of *Bt* maize in the US is estimated at €26 per hectare in 1997, €21,5 per hectare in 1998 and 1999 and €16-17 per hectare in 2001 (Gianessi *et al.*, 2002), while Benbrook (2001) estimates this fee to be higher, i.e. €24,5 per hectare during the same period.

[3] with a degree of significance of 5%

$$s_j \sim \text{Lognormal}(m\,;\,s) \qquad (16)$$

Data on average annual losses caused by corn borers in Spain are very scarce. We rely on Alcalde (1999) and Fernandez-Anero *et al.* (1999), who report estimates for these losses s_j during the four-year period 1995-1998 (first row in Table 3). The loss has been estimated by comparing the yield of *Bt* varieties with that of isogenic varieties, that have exactly the same genetic composition with the exception of the *Bt* gene. This is the most accurate methodology to estimate the yield boost of transgenic insect resistant varieties (Demont and Tollens, 2001). Since we only dispose of a small sample of four data points, according to Hurley (2002), we use the median (9%) as most likely value m for the lognormal distribution. The median is more robust for outliers (26% in 1997) than the average (13%) in the case of such a small skewed sample. We use the standard deviation (9%) as an estimate for s.

By dividing the annual loss s_j by the average loss of 6% per corn borer per plant (Bohn *et al.*, 1999), we obtain estimates of the population sizes, measured in the average number of borers per n (second row in Table 3). In absence of pest control, in Spain on average two corn borers per maize plant can be found. Calculating the coefficient of variation (CV) (last column) allows us to compare the parameters of the stochastic distribution of Spain with data from the US. The Spanish situation is most comparable with the average of 11% and standard deviation of 9% observed in Cumming County (Hurley *et al.*, 2001). According to Hurley (2002), our estimated parameters are realistic, despite the small sample size. The average is high, justifying the use of the median as most likely value. The coefficient of variation is in the range of values (0,75 – 1) found in the US. The occurrence of one severe loss every four to eight years has also been observed in the US (Rice and Ostlie, 1997). Finally, since no negative losses or losses greater than 100% can be incurred, we truncate the lognormal distribution and limit it to the interval [0,1].

Efficacy of Both Technologies

Estimates of the efficacy of insecticides to control corn borers vary considerably. An average value for the insecticides used in Spain as a benchmark is 80% (Bergua, 2002). Nevertheless, in literature other estimates can be found. Lemarié *et al.* (2001) reports an efficacy of only 75% in France. Labatte *et al.* (1996) observes an efficacy of 72% in case of a suboptimal application timing. On the other hand, Hyde *et al.* (2000) report efficacies of 90% for recently developed insecticides. Therefore, we model the efficacy of an insecticide spraying as:

$$a_c \sim \text{Triangular}(72\%; 80\%; 90\%) \qquad (17)$$

Low values allow capturing the impact of the potential development of ECB resistance against insecticides while high values capture the potential emergence of technological innovations in conventional spraying techniques. We assumed a wide variation of efficacy, since timing plays a crucial role. Timing is rarely optimal and this is one of the reasons why insecticide use is limited in Spanish maize growing (Brookes, 2002).

Regarding the efficacy of *Bt* maize in Spain, no data is available. The farmers reported no yield loss from using it (Brookes, 2002). We conservatively use the value of 95% (Lemarié *et al.*, 2001). Uncertainty about the efficacy of *Bt* maize in Spain a_g is modeled by assuming:

$$a_g \sim \text{Triangular}(90\%; 95\%; 100\%) \qquad (18)$$

Low values capture the potential development of ECB resistance against the *Bt* toxin. Labatte *et al.* (1996) observed the extreme value of 100%.

The efficacy of the absence of a treatment is zero, i.e. $a_o = 0$. Total average efficacy a_k of the observed mix of technologies, used to estimate the theoretical maximum yield y_{jm} in equation 1, is weighted as follows:

$$a_k = a_c ?_c + a_g ? + a_o (1 - ?_c - ?) = a_c ?_c + a_g ? \qquad (19)$$

Other Parameters

Adoption rates (James, 1997, 1998, 2000, 2001a, 2001b), yields, area harvested (Eurostat, 2002) and prices (Eurostat, various issues) are modeled as deterministic parameters, i.e. without stochastic distribution. Prices have been deflated using the GDP deflator (World Bank, 2002). For the interest rate *i* we use a risk adjusted rate of return of 10,5% derived from the capital asset pricing model (CAPM).

Results

Average Impact Results

In Table 4 the average values are presented, generated by the model. In the sixth column the four-year average (1998-2001) is reported. Annually, Spanish *Bt* maize adopters gain €1,7 million or €73 per hectare, taking into account an average loss by corn borers of 9% (Fernández-Anero *et al.*, 1999, Alcalde, 1999). The aggregated benefit accumulated during the four-year period and actualized to 2002 amounts to €8,4 million (last column). During the same period, Syngenta extracts an annual gross profit of €0,5 million or an aggregated profit of €2,8 million from the new technology.[4] Average total annual welfare change is €2,2 million and accumulates to €11,2 million after four years of adoption. Farmers gain three fourth (75,3%) of the total benefits, while only one fourth (24,7%) accrues to the gene developer and the seed companies. This benefit sharing is consistent with the majority of biotechnology impact studies in literature. It is also consistent with the typical pricing strategy 3/4:1/4 applied by gene developers (Boeken, 2002).

Uncertainty

To obtain detailed information regarding the uncertainty associated with our impact results, we generate a *posterior* distribution for the latter, given the assumed *prior* distributions of the uncertain parameters. Using @Risk we generate 100.000 iterations configured by a Latin Hypercube simulation. The obtained distribution provides information about the potential impact and its probability associated with the introduction of *Bt* maize in Spain since 1998 (Table 5). The total profit for Spanish maize growers is between €4,9 million and €14,5 million, with a probability of 95% (Figure 1). Due to lower uncertainty regarding technology fees, we obtain a narrower distribution for Syngenta's gross profit, i.e. between €2,1 million and €3,8 million with a probability of 95%. Thus, with a probability of 95%, agriculture captures between 60% and 85% of total profit and the biotechnology industry between 15% and 40%. According to the model, the probability of agriculture capturing less than half of the benefits is only 0,1%. Less than the widely cited share of three fourth only occurs with a probability of 46%.

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[4] This gain is distributed among Syngenta and the seed companies that pay a technology license to Syngenta. Since we do not have any information about this contract, we can not calculate the share captured by the seed companies. In this study, the term 'Syngenta' also comprises the seed companies.

Sensitivity Analysis

Since the model is fed by some uncertain parameters, defined by subjective distributions, it is important to assess the influence of our assumptions on the model results. Therefore, we analyze the data generated by the iterations in @Risk. Through a regression analysis, the influence of each individual parameter on the calculated impact estimates is assessed. Table 6 reports the regression results. The estimates of the profits for Spanish agriculture (first column) can be explained for 86% by the linear regression model. The cost of the conventional technology turns out to be the most important factor (coefficient of 0,528), due to the assumed large distribution. We expect insecticide prices to fall as a reaction on adoption of *Bt* maize. As a result, this price decline will have an important influence on the benefits of *Bt* maize. In the second place comes the theoretical loss by corn borers, followed by the efficacy of the conventional technology, which is negatively correlated with the impact results. Any technological innovation increasing insecticide efficacy will compete with *Bt* maize, reducing the relative difference between both technologies. Logically, the technology fee is negatively correlated with the farmers' benefits of *Bt* maïs, but only comes at the fourth place.

Due to the static character of the model through equation 6, the benefits for Syngenta are simply a function of the technology fee. The question is how this price will evolve as soon as the market for *Bt* maize seed is liberalized. On the one hand, demand for transgenic seed will increase, boost prices and erode the benefits of the new technology. On the other hand, the entrance of more companies, e.g. Monsanto, Pioneer and Limagrain, to the market for transgenic maize seed in 2003 erodes prices. Probably, the number of gene developers will remain limited, due to the continuous process of consolidation observed in the sector (Traill and Duffield, 2002). Remarkably is the fact that total benefits (column 3) are not affected by the technology fee, only benefit sharing (columns 4 and 5). The license between the biotechnology industry and the farmer and the cost of the conventional technology essentially drive the welfare distribution of the new technology.

Finally, since the supply of transgenic seed is artificially limited to a small fraction of the Spanish maize area and an even smaller fraction of total Spanish maize supply, we assume that the supply shift of the technology is too small to affect national maize prices. As a result, in our model we ignore the benefits accruing to Spanish consumers. In the long run, as soon as the moratorium is lifted and important adoption can take place, potentially up to 36% according to Brookes (2002), benefits will flow from farmers to distributors and finally to consumers.

Conclusion

Maize is the most spread cereal on earth and has a wide range of yields. Spain provides one tenth of EU's maize production. Two types of corn borers cause severe losses in this sector. This opens up perspectives for transgenic *Bt* maize, providing a tool to control these insects more efficiently. Up to 2002, Syngenta voluntarily limited transgenic maize seed supply to an equivalent of 25.000 ha of the variety Compa CB. As a result, adoption rates stagnated to an average of 5,2% of Spanish maize area.

If we conservatively assume that this minority of *Bt* maize adopters were insecticide users before adoption, we can express their profit change in an efficacy change and a cost change due to the new technology. As a result, during the four-year period 1998-

2001 Spanish maize growers capture €8,4 million while Syngenta and the seed suppliers gain €2,8 million. Three fourth of the benefits accrues to agriculture, while only one fourth is extracted by the industry. This result is primarily sensitive to our assumptions about insecticide costs and losses by corn borers.

Up to now, the Spanish situation was artificial in a sense, since Syngenta voluntarily limited its seed supply. The question remains to which extent the observed technology fee was artificial too. The price of the seed was similar to the price in the US and with additional competition in 2003 and into the future, it is likely that prices will fall. This is what has happened in all other countries where transgenic crops have been introduced (Gianessi *et al.*, 2002). The biotechnology industry will probably not be able to extract the lion share of the benefits. American literature shows that farmers are generally the main beneficiaries of agricultural biotechnology innovations. In the long run, these benefits flow from farmers to downstream sectors, distribution and finally the consumer.

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Table 1 : Importance of Grain Maize Growing in the World, Average 1998-2001

	Area (ha)	%	Yield (t/ha)	Production (t)	%	% EU
Africa	25.707.058	19%	1,7	42.510.580	7%	
Asia	42.945.503	31%	3,8	162.707.525	27%	
Canada	1.124.925	1%	7,4	8.277.800	1%	
EU-15	4.285.425	3%	8,9	38.315.470	6%	100%
Austria	182.784	0%	9,2	1.672.631	0%	4%
Belgium-Lux.	34.797	0%	10,7	373.846	0%	1%
France	1.799.446	1%	8,8	15.776.935	3%	41%
Germany	367.395	0%	8,8	3.252.600	1%	8%
Greece	208.435	0%	8,9	1.865.340	0%	5%
Italy	1.061.200	1%	9,4	9.943.290	2%	26%
Netherlands	17.450	0%	8,7	148.675	0%	0%
Portugal	167.494	0%	6,0	1.001.204	0%	3%
Spain	446.425	0%	9,6	4.280.950	1%	11%
Zouth-America	17.052.722	12%	3,3	56.300.081	9%	
US	28.765.728	21%	8,5	245.192.464	40%	
Other	18.521.844	13%	2,8	52.572.590	9%	
World	138.403.204	100%	4,4	605.876.510	100%	

FAO (2002)

Table 2 : Adoption of Transgenic and *Bt* maize in the World and in the EU

Area (ha)	1996	1997	1998	1999	2000	2001
World						
Transgenic maize	300.000	3.200.000	8.300.000	11.100.000	10.300.000	9.800.000
Bt maize	300.000	3.000.000	6.700.000	7.500.000	6.800.000	5.900.000
EU						
Bt maize Spain	0	0	19.000	20.000	27.665	25.000
Share (%)	0	0	4,1%	5,0%	6,5%	5,0%
Bt maize France	0	0	2.000	0	0	0
Share (%)	0	0	0,1%	0%	0%	0%

James (1997, 1998, 2000, 2001a, 2001b)

Table 3 : Data Mining of the Average Theoretical Loss by Corn Borers

	1995	1996	1997	1998	Average	Median	Stdev	CV (%)
s Spain	0,09[a]	0,06[a]	0,26[a]	0,09[b]	0,13	0,09	0,09	0,74
n Spain	1,49	1,01	4,36	1,49	2,09	1,49	1,53	0,74
n Cumming County	.	.	.	.	1,84[c]	.	1,49	0,81[c]
s Cumming County	.	.	.	.	0,11	.	0,09	0,81
Loss per borer	.	.	.	.	0,06[d]	.	.	.

[a] Alcalde (1999) [b] Fernández-Anero *et al.* (1999) [c] Hurley *et al.* (2001) [d] Bohn *et al.* (1999)

Table 4 : Economic Impact of *Bt* maize on Spanish Agriculture and Syngenta

Year	1998	1999	2000	2001	Average	Aggr.
Adoption (%)	4,1%	5,0%	6,5%	5,0%	5,2%	5,2%
Agriculture (€/ha)	74	73	72	72	73	376
Agriculture (€)	1.388.143	1.438.900	1.997.386	1.807.447	1.657.969	8.447.083
Syngenta (€)	448.662	469.517	658.241	600.243	544.166	2.769.395
Total Impact (€)	1.836.805	1.908.417	2.655.627	2.407.690	2.202.135	11.216.478
Agriculture (%)	75,6%	75,4%	75,2%	75,1%	75,3%	75,3%
Syngenta (%)	24,4%	24,6%	24,8%	24,9%	24,7%	24,7%

Table 5 : Descriptive Statistics of the *Posterior* Distribution of the Aggregated Impact of *Bt* Maize on Spanish Agriculture and Syngenta

	Minimum	2,5% Quantile	Mean	97,5% Quantile	Maximum
Agriculture (€)	1.912.122	4.862.516	8.447.083	14.545.810	57.149.820
Syngenta (€)	2.092.240	2.145.134	2.769.395	3.759.179	4.060.972
Total Impact (€)	5.877.234	7.750.803	11.216.478	17.290.610	60.088.580
Agriculture (%)	32,5%	60,2%	75,3%	85,4%	96,2%
Syngenta (%)	3,8%	14,6%	24,7%	39,8%	67,5%

Table 6 : Regression Results of the Sensitivity Analysis

Parameter	Agriculture	Syngenta	Total	Agriculture (%)	Syngenta (%)
Insecticide Cost v	0,528	0,000	0,536	0,514	-0,514
Theoretical Loss s_{2000}	0,383	0,000	0,389	0,254	-0,254
Theoretical Loss s_{1998}	0,349	0,000	0,354	0,235	-0,235
Theoretical Loss s_{1999}	0,315	0,000	0,319	0,220	-0,220
Theoretical Loss s_{2001}	0,314	0,000	0,319	0,217	-0,217
Efficacy Insecticides a_c	-0,253	0,000	-0,257	-0,211	0,211
Technology Fee w_g	-0,171	1,000	0,000	-0,644	0,644
Efficacy *Bt* maize a_g	0,138	0,000	0,140	0,117	-0,117
Irrigated App. Cost a_{irr}	0,051	0,000	0,051	0,048	-0,048
Adoption of Insecticides ?$_c$	-0,004	0,000	-0,004	-0,002	0,002
Aerial Application Cost a_{air}	0,004	0,000	0,004	0,004	-0,004
R^2	0,859	1,000	0,855	0,950	0,950

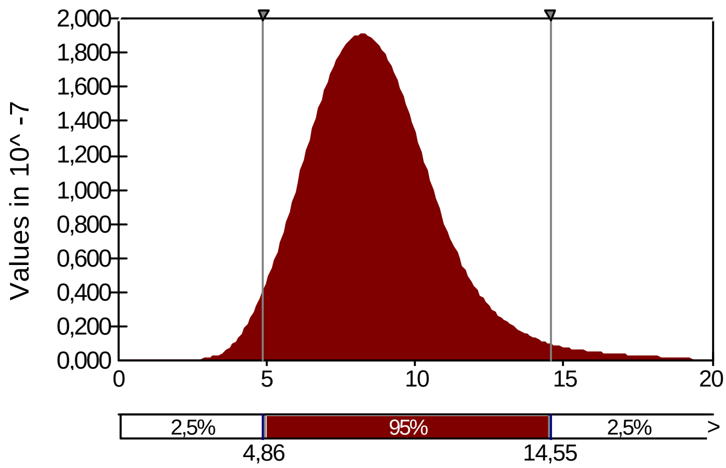

Figure 1 : *Posterior* Distribution of the Aggregated Impact of *Bt* Maize on Spanish Agriculture (Values in Million Euros)

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