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Potential Impact of Biotechnology in Eastern Europe: Transgenic Maize, Sugar Beet and Oilseed Rape in Hungary

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Abstract

In January 2005, the Hungarian farm ministry announced that it would not allow Monsanto's MON 810 maize to be planted or imported until tests had established whether transgenic crops contaminated other cultures. The present study is the first attempt to estimate the size and distribution of the *ex ante* welfare effects of transgenic crops in Hungary developing a partial equilibrium model following a counterfactual approach for the agricultural season 2003. Our model and data are conservative, such that the results have to be interpreted as lower estimates of the true impact. For uncertain parameters, we include subjective prior distributions. In 2003, maize, sugar beet and oilseed rape were planted on an area of respectively 1,150,000 ha, 53,000 ha and 71,000 ha in Hungary. Total benefits of *Bt* maize resistant to the European corn borer amount to an estimated 3 million euros, of which 76% accrues to the farmers and 24% to the seed industry. The adoption of *Bt* maize resistant to the Western corn rootworm translates into a total welfare increase of 16 million euros, of which farmers gain 65% and the industry 35%. The introduction of herbicide tolerant maize potentially generates 14 million euros, of which 73% is shared by the farmers and 27% is extracted by the industry. Herbicide tolerant sugar beet involves a welfare gain of 3 million euros, of which 50% flows to farmers and 50% to the seed industry. The adoption of herbicide tolerant oilseed rape could potentially engender a total benefit of 0.8 million euros, of which 61% is absorbed by Hungarian farmers and 39% is captured by the seed industry. We then conduct a stochastic sensitivity analysis through Monte Carlo simulation techniques to analyze the robustness and sensitivity of the model to the underlying parameter estimates and assumptions.

Introduction

During the eight-year period from 1996 to 2003, global area of transgenic crops increased more than 47 fold, i.e. from 1.7 million to 81.0 million hectares (James, 2004). The first United States (US) *ex post* welfare studies reveal that the benefits of these innovations are essentially shared among farmers and the seed industry (Falck-Zepeda *et al.*, 2000, Moschini *et al.*, 2000, Price *et al.*, 2003). On the level of the European Union (EU), the first *ex post* welfare study on transgenic maize adoption in Spain has now been published, reporting a total welfare gain of 15.5 million euros during the six-year period 1998-2003, of which Spanish farmers captured two thirds, the rest accruing to the seed industry (Demont and Tollens, 2004b). Some *ex ante* impact results on transgenic sugar beets are documented as well (Demont *et al.*, 2004a, Demont and Tollens, 2004a, Demont *et al.*, 2004b), reporting a global welfare increase of 1.2 billion euros during the five-year period 1996-2000, shared among EU producers (33%), the seed industry (16%) and the rest of the world (52%).

As of May 1st, 2004, 10 new Central and Eastern European Member States joined the EU. However, up to now no *ex ante* study has been published on the potential impact of transgenic crops in these new Member States (NMS). In January 2005, the Hungarian farm ministry announced that it would not allow Monsanto's MON 810 transgenic *Bt* maize to be planted or imported until tests had established whether transgenic crops contaminated other cultures (Agra Europe, 2005). This means foregoing important benefits for Hungarian maize farmers. Therefore, the present study is the first attempt to estimate the potential impact transgenic crops in Hungary, more specifically insect resistant *Bt* (*Bacillus thuringiensis*) maize, herbicide tolerant (HT) maize, HT sugar beet and HT oilseed rape.

Global Importance of Maize, Sugar Beet and Oilseed Rape

While maize is important in all continents, yields vary greatly, ranging from 1.6 t/ha in Africa to 10.5 t/ha in Belgium (FAO, 2004). The four largest EU-25 maize producers, together responsible for 72% of maize output, are France (29%), Italy (22%), Hungary (11%) and Spain (10%). Of the new Member States, Hungary (59%) is the dominant maize producer. Sugar stemming from sugar beet only accounts for 24% of global production, the rest is produced by sugar cane (F.O.Licht, 2004). Sugar beet is a typical European crop, grown in all European countries. The four largest EU producers, accounting for 33% of EU beet sugar, are France (13%), followed by Germany (11%) and Poland (5%). The latter represents 57% of the new Member States' sugar beet production, while 9% is produced in Hungary. Finally, the four largest EU producers of oilseed rape, accounting for 87% of production are Germany (33%), France (31%), the UK (16%) and Poland (7%). Hungary is responsible for 7% of the production.

Evolution of Maize Pests in Hungary

The major pests of maize in Hungary are the European corn borer (ECB) (*Ostrinia nubilalis* Hübner) and the Western corn rootworm (WCR) (*Diabrotica virgifera virgifera* LeConte). Over the last two decades, some changes were found within the phytophagous insect assemblage associated with maize in the Carpathian Basin. The new situation can be explained by climatic fluctuation and partly by land-use. The changes relate to (1) the voltinism[1] of the ECB, (2) the unexpected invasion of cotton bollworm and (3) the appearance of Western corn rootworm (Szabóky and Szentkirályi, 1995, Nagy *et al.*, 1999, Szentkiralyi, 2002, Kozár *et al.*, 2004, Camprag *et al.*, 2004). The year 2003 brought the biggest challenge maize growers have met so far. In addition to the drought, an important increase of insect populations caused severe injuries to plants. In spite of treatments, pests destroyed 20-50% of the potential yields (Vörös and Maros, 2004).

European Corn Borer

The European corn borer causes important crop damage in Southern and South-East Europe. In the Carpathian Basin major damage zones are in the southern part of the Basin (in the northern parts of Serbia), while severe damage is also caused less frequently in the southern part of the Trans-Tisza region (the Hungarian Maize Belt), on low-lying areas of the Great Hungarian Plain alongside the River Danube, and in parts of Transylvania (Romania). Less severe damage is also incurred in Central and Western Hungary.

Freshly hatched larvae start to feed on the youngest maize leaves from the middle of June. Older larvae may penetrate into the soft kernels on the ear, into the cob or into the cob shank, thus promoting the development of ear rot. Leaf feeding causes a certain reduction in assimilation, while stalk feeding leads to deterioration in the physiological status of the plant, depending on the extent of infestation. This in turn influences the yield. Penetration into the stalk also opens the way for fungal diseases (Szõke *et al.*, 2002).

The ECB is univoltine[2] in larger parts of Europe, except in the South where it has two real generations per year. In Hungary, since the late fifties, ECB flight patterns show a typical bimodal distribution with two separated peaks mainly in the warmer parts of

Hungary (Nagy and Szentkirályi, 1993, Keszthelyi and Lengyel, 2003). While second flight activity was previously only found in the central and southern parts of Hungary, from the eighties it has been registered in the whole area of the country, however, without causing any serious damage.

Western Corn Rootworm

The appearance of the Western corn rootworm in the southern region of the Carpathian Basin is the result of an accidental and 'successful' introduction of this north-American pest in Serbia in 1992. According to the rate of dispersal, it seems very likely that no climatic and/or ecological barriers exist for this species in the Carpathian Basin at present (Nagy *et al.*, 1999). The larvae hatch in the spring and feed on maize roots for several weeks. The damage to the roots can result in stunted growth of the maize plant, lodging, and eventual yield losses. Adults emerge from the soil in the summer and female adults can cause some yield loss through silk feeding (Tuska *et al.*, 2002), but most of the damage is caused by the root feeding of the larval stages (Wright *et al.*, 1999). Taking into account the value of maize production and potential yield loss, this invasive insect has to be considered one of the most important pests in Hungarian agriculture in the future (Hatala Zsellér and Széll, 2003).

Pest Control of Maize in Hungary

Chemical Control

In Hungary the degree of ECB infestation rarely reaches the level where chemical control is economic, so it is rarely carried out except in sweet maize and for seed production. A wide range of chemicals are used: phosporic acid esters, thiophosphoric acid derivatives, dithiophosphoric acid and carbamate derivatives, pyretroids, etc. ECB larvae from ECB are difficult to control with chemical insecticides 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 are effective when the larvae have just hatched or when they migrate to neighbouring plants (Velasco *et al.*, 1999). Therefore, proper timing of insecticide application is crucial for success and repeated applications are often necessary.

To control WCR, crop rotation away from maize one year is a highly effective non-chemical practice which has been historically adopted by farmers in the US (Payne *et al.*, 2003). As a way to reduce rootworm densities, it is more effective than insecticides. Traditionally, most insecticide use has been targeted at the larval stage. A variety of insecticide formulations and application methods are available. Liquid or granular insecticides may be applied at planting, i.e. seed or soil treatment, or at cultivation, i.e. at and after silking stage to reduce the number of WCR adults to prevent next year larval damage (Wright *et al.*, 1999).

Biotechnological Control

Using modern biotechnology, the genes coding for specific *Bacillus thuringiensis* (*Bt*) toxins were isolated in the 1980's and introduced into various crop plants to provide insect protection. Maize expressing a *Bacillus thuringiensis* protein for resistance against the European corn borer (*Bt* maize) was first registered in the USA in 1995. A second type of *Bt* maize expressing a *Bacillus thuringiensis* protein for resistance against the Western corn rootworm (Rice, 2004) was commercialized in the USA in

2003. The insertion of the *Bt* genes into the maize plant potentially improves a farmer's abilities to manage serious insect pests (Pilcher *et al.*, 2002). In addition, due to the protection of *Bt* varieties against physical insect damage, whether it comes from ECB, cotton bollworm or WCR, it has been widely reported that *Bt* varieties are associated with a lower incidence of secondary *Fusarium* contamination (Munkvold *et al.*, 1997, Munkvold *et al.*, 1999, Dowd, 2000, Wu *et al.*, 2004).

Weed Control of Maize, Sugar Beet and Oilseed Rape in Hungary

Conventional Control

In Hungary, effective weed control is more crucial to economic maize production than control of ECB. For sugar beet production, weed control is even more important (Pozsgai, 1984). Oilseed rape is a slow-growing crop. Consequently, it is also very sensitive to weed competition, especially during the early stages of development (Gianessi *et al.*, 2003a). To control weeds, conventionally a tank mix of soil active and leaf-active herbicides in pre- to early post-emergence of the crop is used.

Biotechnological Control

The post-emergence herbicides glyphosate and glufosinate-ammonium provide a broader spectrum of weed control than current herbicide programs, while at the same time reducing the number of active ingredients. Glyphosate was first introduced as a herbicide in 1971. The gene that confers tolerance to glyphosate was discovered in a naturally occurring soil bacterium. Glufosinate-ammonium was discovered in 1981. The gene that confers tolerance to glufosinate is also derived from a naturally occurring soil bacterium (Dewar *et al.*, 2000).

By inserting these herbicide tolerance (HT) genes into a plant's genome, two commercial transgenic HT systems resulted: the Roundup Ready® system, providing tolerance to glyphosate and the Liberty Link® system, tolerant to glufosinate-ammonium. These combinations of transgenic seed combined with a post-emergence herbicide offer farmers broad-spectrum weed control, flexibility in the timing of applications and reduce the need for complex compositions of spray solutions. Genetically engineered maize, sugar beet and oilseed rape varieties are obtained by insertion of these patented technologies into conventional local varieties: "NK603" RR maize (Monsanto, 2004), LL maize, RR sugar beet (Kniss *et al.*, 2004), and RR and LL oilseed rape (Fulton and Keyowski, 1999).

Model

As a general methodology we use a 'counterfactual approach' in which we hypothetically assume that in 2003 the analyzed transgenic crops were adopted by Hungarian farmers on the entire adoption potential of the new technologies. Due to the uncertain nature of these innovations, we will rely on conservative estimates and assumptions of model parameters and incorporate wide distributions to reflect the robustness of our model.

Bt Maize Resistant to European corn borer (ECB)

We estimate the impact of *Bt* maize analogously to Demont and Tollens (2004b). We assume that maize borer infestation decreases yield proportionally to the damage incurred despite pest control technology k. The technology k can be: absent ($k = o$), conventional through insecticides ($k = c$) or biotechnological through *Bt* maize ($k = g$). The observed yield y_k (t/ha) can be expressed as:

$$y_k = y_m\,[1 - (1 - a_k)\,s] \qquad (1)$$

with y_m (t/ha) the theoretical maximum yield attained under hypothetical absence of corn borers , a_k (%) the efficacy of technology k, measured by the proportion of larvae killed before affecting yield, and s (%) the theoretical average proportional loss caused by corn borers under absence of treatment in 2003.

In practice, ECB control is often limited to agricultural, mechanical methods, e.g. stalk-destroying, which should be finished until the beginning of the flight (Nagy, 1971). For the purposes of this modelling, we therefore assumed that farmers adopting *Bt* maize previously did not apply any insecticide treatment. This assumption implies that the benefits from adopting *Bt* maize are purely generated by a yield boost due to the intrinsic protection against ECB.

Following Demont and Tollens (2004b), we estimate the gain in total factor productivity (TFP) at the farm level by calculating the proportionate per-unit cost reduction DC (%) due to the conversion from no treatment ($k = o$) to *Bt* maize ($k = g$):

$$\Delta C = \frac{(w_k + c)/y_{jk} - (w_g + c)/y_g}{(w_k + c)/y_k} \qquad (2)$$

with c (euros/ha) all other costs that are independent of the choice of technology k, including the cost of conventional seed and w_k (euros/ha) the cost of technology k to combat corn borers. In case of no insecticide treatment ($k = o$), $w_k = a_o = 0$. The "technology fee" w_g (euros/ha) represents the price premium between *Bt* maize and conventional seed.

Bt Maize Resistant to Western corn rootworm

The real economic extent of the impact of the invasive WCR in Hungary is not yet known. According to Table 1, total infested area amounted to 9 million ha in 2003, of which 3 million is subject to economic adult activity[3]. Only 5,955 ha has been reported to reach the economic damage threshold of 3 on the Iowa scale (Hataláné Zsellér *et al.*, 2004c), representing 0.5% of the total maize area in Hungary. It is clear that the pest is still in its build-up phase. However, potentially the total area under continuous maize is at risk of economic damage level WCR infestation (MacLeod *et al.*, 2004), representing 40% of total maize area in Hungary (Magonette, 2004). Unfortunately, no field trials with MON 863 have been carried out in Hungary so far.

We opt for an extremely simple yet transparent model. The only certainty we have is the reported area L_d (ha) where damage exceeded the economic threshold of 3 on the Iowa scale (Table 1). We therefore assume that only the area of continuous maize L_c (ha), which is only a fraction of total maize area L (ha), is potentially at risk for economic WCR damage. Further, we assume that farmers are rational and that the area under economic damage is treated with chemicals to control WCR. Finally, in the best case scenario we assume that only in the area L_d damage is high enough to justify WCR-resistant maize adoption, leading to an adoption rate of $r_g = L_d/L$. In the worst case scenario we assume that WCR has spread and reached economic levels on the total area under continuous maize L_c, justifying an adoption rate of $r_g = L_c/L$. The yield of transgenic WCR-resistant maize y_g (t/ha) can be expressed as a function of the yield y_c (t/ha) under conventional WCR control and the average yield benefit *ß* (%) of WCR-resistant maize relative to control with chemicals:

$$y_g = y_c\,(1 + ß) \qquad (3)$$

The gain in total factor productivity (TFP) resulting from the conversion from chemical treatment ($k = c$) to WCR-resistant maize ($k = g$) can now be estimated through equation 2.

Herbicide Tolerant Maize, Sugar Beet and Oilseed Rape

We assess the economic impact of HT crops by considering that the innovator will base its pricing decisions on actual herbicide costs in Hungary. Different authors stress the importance of taking into account farmer heterogeneity in assessing the impact of the recent biotechnology innovations in agriculture (Fulton and Keyowski, 1999, Desquilbet *et al.*, 2001, Bullock and Nitsi, 2001, Fulton and Giannakas, 2004). Although numerous factors determine farmer heterogeneity, such as soil characteristics, managerial capabilities, education, market access, weeding programs, etc., due to data limitations we base our analysis on the most important factor in the adoption of HT crops, i.e. actual herbicide use and costs. Herbicide costs are typically distributed following a lognormal curve, as can be seen in the study of Desquilbet *et al.* (2001). This curve is consistent with the nonnegativity of herbicide costs and their right-skewed nature. Following this assumption, the density function *f* of herbicide costs w_c (euros/ha) can be expressed as (Figure 1):

$$f(w_c) = \begin{cases} \dfrac{1}{w_c s\sqrt{2p}}\, e^{-\frac{(\ln(w_c)-m)^2}{2s^2}} & (w_c > 0) \\ 0 & (w_c \le 0) \end{cases} \qquad (4)$$

with mean $e^{m+\frac{s^2}{2}}$, variance $e^{2m+s^2}(e^{s^2}-1)$ and median e^m.

In this paper, we will assume ‘competitive pricing’, i.e. the innovator will price the new technology such that the recommended replacement program based on HT seed and the associated herbicide, i.e. glyphosate, will reflect the average herbicide expenditure $\overline{w}_c$ (euros/ha) in conventional weeding (Figure 1):

$$w_g + g\overline{g} = \overline{w}_c = \int_0^\infty w_c\, f(w_c)\,dw_c \Leftrightarrow w_g = \int_0^\infty w_c\, f(w_c)\,dw_c - g\overline{g} \qquad (5)$$

with w_g (euros/ha) the price premium of the transgenic seed, g (euros/l) the average glyphosate price and $\overline{g}$ (l/ha) the recommended glyphosate rate of the replacement program.

Theoretically, given this price premium w_g, only farmers facing higher herbicide expenditures at the right tail of the lognormal distribution (Figure 1), i.e. $w_c > w_g + g\overline{g}$, are willing to adopt the transgenic seed. In doing so, they make an additional profit $p(w_c, w_g, \overline{g})$ (euros/ha) equal to:

$$p(w_c, w_g, \overline{g}) = w_c - w_g - g\overline{g} \qquad (6)$$

The adoption rate $r_g(w_g, \overline{g})$ can then be predicted as:

$$r_g(w_g, \overline{g}) = \int_{g\overline{g}+w_g}^{\infty} f(w_c)\,dw_c = 1 - F(g\overline{g} + w_g) \qquad (7)$$

with $F(w_c)$ the cumulative distribution function of $f(w_c)$. If we define $f_a(w_c)$ as the adopters' density function of herbicide costs, it follows that:

$$f_a(w_c) = \begin{cases} \dfrac{f(w_c)}{r_g(w_g,\bar{g})} & (w_c > g\bar{g} + w_g) \\ 0 & (w_c \le g\bar{g} + w_g) \end{cases} \qquad (8)$$

The average benefits $\bar{p}(w_g, \bar{g})$ (euros/ha) of all adopting farmers then amounts to:

$$\bar{p}(w_g,\bar{g}) = \int_{g\bar{g}+w_g}^{\infty} p(w_c, w_g, \bar{g}) f_a(w_c) dw_c \qquad (9)$$

It is important to note that the assumption of competitive pricing endogenizes the price premium in such a way into the model that $\bar{p}$ is only a function of the mean and standard deviation of the herbicide costs' distribution, i.e. independent of $\bar{g}$ and g. The yield boost *ß* (%) generated by the HT system and essentially caused by the lower toxicity of the weeding operation on the crops, is incorporated using equation 3. Following equation 2, the per-unit cost reduction ΔC (%) due to the conversion from the conventional ($k = c$) to the HT system ($k = g$) is estimated as:

$$\Delta C = \frac{(\bar{w}_c + c)/y_c - [\bar{w}_c + c - \bar{p}(w_g,\bar{g})]/y_g}{(\bar{w}_c + c)/y_c} \qquad (10)$$

Aggregation to the National Level

Next, we model the innovation as a technology spill-in into Hungary, mainly from the US which started to adopt transgenic crops first. The low presence of Hungary in global maize, sugar beet and oilseed rape production in 2003 suggests modelling Hungary as a small open economy, i.e. not able to influence world prices significantly through the adoption of the new technology. This argument suggests modelling demand in Hungary as infinitely elastic and modelling the change in producer surplus ΔPS (euros) as (Alston *et al.*, 1995, p. 227):

$$\Delta PS = p\, Q\, K\, (1 + 0.5\, K\, e) \qquad (11)$$

with e the supply elasticity and Q (t) total production in 2003. The proportionate vertical supply-shift K (%) is calculated as:

$$K = r_g\, \Delta C \qquad (12)$$

with r_g (%) the adoption rate of the transgenic crop. The gross profit Π (euros) captured by the seed industry[4] is:

$$\Pi = w_g\, L\, r_g \qquad (13)$$

with L (ha) the total amount of land allocated to the crop. It is important to stress that this represents a gross profit, i.e. not taking into account any marketing and distribution expenditures associated with the commercialization of transgenic seed. Finally, total welfare increase W_{tot} (euros) in Hungary in 2003 is:

$$W_{tot} = W + \Pi \qquad (14)$$

Data

Due to its nature, an *ex ante* assessment of the economic impact of transgenic crops requires data which is not available. We use data mining, subjective estimates and information from economic theory. The data mainly comes from Hungarian literature and farm level survey data collected by the Hungarian Research and Information

Institute for Agricultural Economics (AKII, 2004), represented in Table 5, Table 6 and Table 7. [5]

We model data uncertainty through stochastic simulation techniques. For uncertain parameters we introduce prior subjective stochastic distributions, based on literature review and subjective estimates, and through Monte Carlo simulation techniques we generate posterior distributions for the outcomes in our model. The parameter estimates and subjective distributions are collected in Table 4.

Bt Maize Resistant to European Corn Borer

The annual loss s due to ECB in Hungary varies considerably from year to year. Therefore, analogous to Demont and Tollens (2004b), we build a bio-economic stochastic distribution for this parameter. In Table 2 we combine different data sources from literature to estimate the parameters of the lognormal distribution. Since only 10 annual averages are available, we use the overall median instead of the overall average for the mean of the lognormal distribution. The median is more robust for outliers than the average in the case of such a small skewed sample. Using the standard deviation for the lognormal distribution, we assume s ~ Lognormal(5.4; 4.3). Finally, since no negative losses or losses greater than 100% can be incurred, we truncate the lognormal distribution to the interval [0,1].

The monopolistic innovator's pricing behaviour is limited by the low yield benefit of chemical treatments and, secondly, by the large heterogeneity of ECB damage within the region of Hungary in a given year. The seed supplier has to set its price low enough to provide adoption incentives to a sufficiently large segment of farmers. Therefore, we assume a price premium following a triangular distribution with a minimum, average and maximum of respectively 0 euros/ha, 6 euros/ha[6] and 13 euros/ha or 0%, 10% (Czepó, 2004) and 20% of the seed cost and a maximum adoption potential of 10%.

Bt Maize Resistant to Western Corn Rootworm

Since WCR is still in its build-up phase, we conservatively assume that the average root rating of the adoption area amounts to 4, one root rating above the economic threshold of 3 (Hataláné Zsellér *et al.*, 2004a). Since no field trials with MON 863 have been carried out in Hungary yet, we base our yield assumptions of MON 863 on US findings. Mitchell (2002c) reports yield benefits of MON 863 relative to chemical control for different root ratings (Table 3). The right-skewed nature of the data suggests modelling $ß$ through a lognormal distribution. We shape the distribution to the lower and upper percentiles and adjust the median until the estimated mean equals 4.2%. This results in a standard deviation of 7.3%.

Tóth (2004a) reports chemical treatment costs for WCR control in maize of 28-32 euros/ha for seed treatment (pelleting), 44-71 euros/ha for soil treatment and 28-56 euros/ha for plant treatment. In column 8 of Table 5, we report the insecticide costs of only those farmers who use insecticides, i.e. 18% of the total sample of 827 farms. Seed treatment costs are included in the seed costs. This information allows us to conservatively model insecticide costs through a triangular distribution with a minimum of 28 euros/ha, an average of 50 euros/ha and a maximum of 71 euros/ha, i.e. on average 79% of the seed cost. We assume that the price premium w_g will follow this pattern and define a triangular distribution for it, characterized by a minimum of 0%, a most likely value of 40% of the seed cost, i.e. 25 euros/ha[7] or half of the average chemical treatment cost, and a maximum of 79%, i.e. 50 euros/ha or the average chemical treatment cost. By subtracting this cost from the total production costs (column 11 in Table 5), we obtain an estimate of 'all other costs' c. We assume that the adoption of WCR-resistant maize is between the reported share of the area under economic damage, i.e. L_d/L, and the share of the total area under continuous maize, i.e. L_c/L. To allow all possible scenarios between the two extremes to occur with an equal probability, we model r_g through a uniform distribution (Table 4).

Herbicide Tolerant Maize, Sugar Beet and Oilseed Rape

We calibrate the lognormal distributions of the herbicide cost of the three crops on the survey data from the AKII (2004) using the average and the standard deviation of the observed herbicide costs (Table 5, Table 6 and Table 7). The average glyphosate price g was around 6 euros/l in 2003 (Czepó, 2004). The recommended glyphosate rates $\bar{g}$ are 5 l/ha for HT maize, 6 l/ha for HT sugar beet and 2.5 l/ha for HT oilseed rape.

In literature, there is quite some discussion about the yield effects of HT crops. Recent research on North Carolina's farmers did not reveal any statistically significant yield differences at the 95% level between HT maize, cotton and soybeans and their conventional counterparts (Marra *et al.*, 2004f, p. 43). Likewise, European field trials showed no increase in any HT crop (Schütte, 2003). Based on these findings, we conservatively assume a normal distribution for the yield boost of HT crops with a mean of 0% and a standard deviation of 2.5%. This allows this parameter to vary in a 95% confidence interval between a yield drag of 5% and a yield boost of 5% (Table 4).

Aggregation to the National Level

We use the producer price estimates from the survey carried out by the AKII (2004). The average and standard deviation from the sample (Table 5, Table 6 and Table 7) allows us to introduce price uncertainty into the analysis through normal distributions (Table 4). National produced quantities Q, allocation of land L and yields y_k of the different crops are derived from the FAOSTAT dataset (FAO, 2004).

Elasticities are taken from an updated version of the European Simulation Model (ESIM), where they have been simulated through behavioural equations instead of econometrics. To derive supply elasticities for the analyzed crops, we simply sum the area supply and yield elasticities. To reflect the high uncertainty surrounding the calculation of supply elasticities, mentioned above, we introduce triangular distributions for these parameters, based on the strict positivity of elasticities from theory and a maximum of twice the base value (Table 4).

Results

Descriptive Statistics

As mentioned, our model results have to be interpreted as conservative estimates. To obtain an idea of the variability of the impact estimates and the sensitivity of the model to our parameter estimates and assumptions, we generate 100,000 iterations in @Risk (Palisade Corporation, 2002a) to obtain posterior distributions for the outcomes of the model. In Table 8, Table 9, Table 11, Table 12 and Table 13 for each biotechnology innovation, the mean and 95% confidence interval limits of the farmer's surplus, industry's rent and total welfare gain are tabulated. In the last column, the average distribution of the benefits is represented.

In the case of *Bt* maize resistant to ECB, a total welfare gain of 3 million euros is estimated for the agricultural season 2003, of which 2 million euros accrues to farmers and 0.7 million euros to the seed industry (Table 8). Some authors have observed a negative correlation between farm heterogeneity regarding the utility of a new technology and monopolistic pricing behaviour (Oehmke and Wolf, 2002). In Hungary, due to the low average importance of ECB and the high heterogeneity of ECB attacks, the innovator probably will not be able to extract a large share of the benefits through a high price premium. Therefore, we assumed a conservative price premium of 10% of the seed cost. As a result, three quarters is absorbed by Hungarian agriculture and only one quarter by the seed industry. In 8% of the cases, farmer benefits were negative. These losses can be considered as *ex ante* risk premiums paid by the farmers in order to protect their production from high ECB attacks.

WCR, although still in its build-up stage, is a more homogenous pest than ECB. This is reflected in the price premium of WCR-resistant maize which we assumed four times higher than in the case of ECB-resistant maize. Despite this higher price premium, two thirds is absorbed by the agricultural sector (Table 9). Total benefits amount to 16 million euros, of which farmers gain 11 million euros and the industry 6 million euros. Given our parameter estimates and model assumptions, only in 0.01% of the cases negative farmer benefits are recorded. But even in the case of net financial losses, farmers could consider the investment in WCR-resistant seed as a risk premium in order to protect themselves from WCR attacks. Moreover, we did not account for the so-called nonpecuniary benefits. Alston *et al.* (2002) were the first to estimate these benefits through *ex ante* willingness-to-pay (WTP) surveys in the US. They estimated an average nonpecuniary benefit for adopters of the technology of 16 euros/ha, consisting in handling and labour time savings, human safety, environmental safety, consistent control (reduced yield risk), equipment cost savings and better standability. The interviews we had with Hungarian farmers reveal a WTP for these nonpecuniary attributes of about 59-99 euros/ha, i.e. much higher than the estimate in the US and mostly higher than the price premiums we calculated for the different crops (Table 10).

Regarding HT crops, we used heterogeneity in herbicide use to estimate the competitive price premium, farmer benefits and adoption rate of the transgenic variety. The results are presented in (Table 10). The competitive price premium of 8 euros/ha[8] for HT maize is modest due to low average herbicide costs (Table 5), but comparable to the low price premium of 6 euros/ha we assumed for *Bt* maize resistant to ECB. In the case of sugar beet, the crop is such a bad competitor against weeds that herbicide expenditures are very high to achieve economic production (Table 5). The HT system represents a drastic innovation in this case, allowing the innovator to charge a high price premium (Table 10), i.e. 81 euros/ha[9] or 63% of the seed price, and extracting half of the total benefits (Table 12). The estimated price premium of HT oilseed rape is about 12 euros/ha[10] or 34% of the seed price. The predicted adoption rates of 40%, 38% and 35% for respectively HT maize, sugar beet and oilseed rape are modest and reflect the expected adoption rates of early adopters. For oilseed rape it is in line with Monsanto's seed market share of 40% in oilseed rape seed breeding (Kiss and Bói, 2001, Nagy, 2004).

In the case of HT maize, a total welfare gain of 14 million euros is estimated, of which 10 million euros flows to farmers and 4 million euros to the seed industry. These impact estimates and benefit sharing, i.e. three quarters versus one quarter, are very comparable with the case of ECB-resistant maize. However, in 4% of the iterations, farmers suffer losses, mainly due to the possibility of a yield drag. Even in these cases, it is possible that farmers find it profitable to adopt the HT technology, because of non-pecuniary benefits not included in our analysis. To date, only one complete study exists attempting to estimate the non-pecuniary benefits of HT crops by distinguishing between convenience factors (management time savings, equipment savings, etc.), conservation tillage benefits (cost savings, time savings, environmental benefits, etc.), less adverse effects from herbicide drift on livestock production, human safety benefits and environmental benefits (Marra *et al.*, 2004d).

The total benefits of adopting HT sugar beets are about 3 million euros, equally distributed among farmers and the industry. Negative farmer benefits only occur in 0.2% of the cases. The total welfare increase of HT oilseed rape is much smaller, i.e. 0.8 million euros, due to the low importance of this crop in Hungary. Of these benefits, 0.5 million euros accrues to farmers and 0.3 million euros to the industry. The benefit sharing, i.e. two thirds versus one third, is in line with the case of WCR-resistant maize. Only in 0.5% of the cases, farmers lose due the possibility of a yield drag. Finally, Table 14 shows that the average farmers' surplus per adopted hectare of transgenic crops ranges from 19-81 euros/ha.

Sensitivity Analysis

In Table 15 and Table 16 we report the results of a stochastic sensitivity analysis by running a linear regression analysis on the 100,000 simulated iterations. The coefficients listed are statistically significant[11] normalized regression coefficients associated with each input. A regression value of 0 indicates that there is no significant relationship between the input and the output, while a regression value of 1 or -1 indicates a 1 or -1 standard deviation change in the output for a 1 standard deviation change in the input. The coefficient of determination R^2 listed at the bottom of the column is simply a measurement of the percentage of variation that is explained by the linear relationship (Palisade Corporation, 2002b).

In all cases, R^2 is satisfactory high, signifying that the linear relationship sufficiently explains the variation in the iterations. In the case of *Bt* maize resistant against ECB, most of the variation is explained by the wide distribution we assumed for ECB damage (Table 15). Logically, the technology fee is negatively correlated, but only plays a role in the distribution of the benefits, not in the total welfare gain. Due to the linear model we assumed in equation 13, the correlation between price premium and industry's profit is 100%. Producer price plays a non-negligible role, as well as the efficacy of the new technology. Given our assumed subjective distributions and model parameters, supply elasticity does not seem to drive the model results.

In the case of WCR-resistant maize, essentially the same sensitivities are observed. The assumed wide uniform distribution of potential adoption is now mainly driving the results, followed by the yield benefit. Again, the assumed cost of the new technology negatively influences farmers' benefits but has a much smaller effect on total welfare gain. The cost of the conventional technology also plays an important role. Industry's profit is now driven by both the adoption rate and the price premium. Again, supply elasticity hardly seems to influence the results.

Since we completely exploited heterogeneity in conventional weeding to estimate price premiums, benefits and adoption of HT crops, re-introducing this variability into the analysis has but a limited sense. Instead, we only introduce variability for the yield boost, supply elasticity and producer prices (Table 4), reflected in Table 11, Table 12 and Table 13. The sensitivity analysis essentially produces the same normalized regression coefficients for all three crops, i.e. between 0.999 and 1.000 for the yield boost, between 0.007 and 0.017 for the supply elasticity and 0.000 for the producer prices. The yield boost assumption clearly drives the results. As mentioned before, literature does not provide strong arguments for the presence of a yield boost due to the planting of HT crops. The 2.5% and 97.5% quantiles in Table 11, Table 12 and Table 13 illustrate the effect of a yield boost of respectively -5% and 5%. In the case of maize, a yield drag of less than 5% would cancel out all benefits from the new technology. For sugar beet and oilseed rape, it would reduce the benefits to respectively one third and one quarter. Assuming a yield boost of 5% on the other hand would roughly double the benefits of HT crops.

Environmental Effects

It is important to note that our *ex ante* welfare calculation only contains private reversible effects. In reality, technologies also engender non-private effects, the so-called externalities. The number of biosafety related publications concerning transgenic organisms has increased within the decade 1990–2004 to 4,896 citations according to one of the most comprehensive databases, published online by the ICGEB (2002). The Hungarian Biosafety Homepage published online by the Agricultural Biotechnology Center (2004) contains a complete database of Genetically Modified Organisms (GMOs) emitted in Hungary as well as some biosafety related documents and links.

A growing body of scientific literature about the non-private effects of *Bt* maize is available, reviewed by James (2003). The major concerns include (1) effects on non-target organisms, (2) gene flow, (3) the impact of Cry1Ab proteins in soil and surface water, (4) the evolution of pest resistance, (5) the development of antibiotic resistance and (5) food and feed safety aspects of *Bt* maize. However, also positive externalities are reported, such as (1) lower contamination of aquifers with insecticides, (2) lower farmers' exposure to insecticides and (3) lower levels of the mycotoxin fumonisin in *Bt* maize.

HT systems also potentially entail irreversible environmental externalities. First of all, glyphosate, the herbicide that substitutes for the conventional herbicide mixes, has been widely studied for its environmental and human health impacts, extensively documented in Sullivan and Sullivan's (1997) latest compendium of 763 references and abstracts, of which the earlier edition had been criticised by Zammuto (1994). The second concern relates to gene flow from HT crops to closely related weeds, the so-called 'weediness'. Ammann (2000) provides a critical review of the literature on these issues for HT sugar beet and HT oilseed rape.

However, herbicides also cause systematic losses of seed banks and difficulties in reversing it and consequently play a prevailing role in damaging biodiversity. If HT crops result in less herbicide applications, the introduction provides additional benefits. In the US Heartland, only in one of two years, a significant reduction in the number of herbicide treatments has been observed due to the adoption of HT maize, but no significant difference has been found in the total volume of active ingredients (Fernandez-Cornejo *et al.*, 2003). In Europe, a reduction of application frequencies is only expected for HT sugar beet (Schütte, 2003).

Discussion and Conclusions

We find conservative total welfare gains ranging from 0.8 million euros to 16 million euros on average, depending on the importance of the crop and the size of the innovation. Farmers' share of the benefits varies from one half to three quarters and this mainly depends on the heterogeneity of expenditures of the conventional technology and the size of the innovation. At one extreme, *Bt* maize is a marginal innovation with limited potential for rent creation by the seed industry. At the other extreme, HT sugar beet is a drastic innovation allowing the innovator to capture a sizable part of the benefits.

Four elements limit the monopolistic seed industry's ability to charge a high price premium and extract a large part of the benefits. The first is farmer heterogeneity (Weaver and Kim, 2002, Oehmke and Wolf, 2002). *Bt* maize resistant to ECB, for example, has to be sufficiently cheap to provide sufficient adoption incentives to a highly heterogeneous group of farmers with respect to the damage they suffer from ECB attacks. The second is uncertainty and irreversibility (Weaver and Wesseler, 2004). The farmer faces *ex ante* uncertainty regarding future ECB damage, input and output prices, agricultural and biotechnology policy regulations in the EU and the potential for irreversible environmental costs. The existence of irreversible benefits on the other hand will strengthen the seed industry's pricing power. The third is competition from the chemical industry leading to 'restricted monopoly pricing' (Weaver and Kim, 2002) and incomplete adoption (Lapan and Moschini, 2000). An exception would be the case of commercial maize in Hungary where hardly any insecticides are used. As a result, the seed industry will face limited competition from the pesticide sector. The fourth is competition within the biotechnology industry which has led to technology price declines in all countries where transgenic crops have been introduced (Gianessi *et al.*, 2002d).

This benefit sharing is consistent with the majority of biotechnology impact distribution studies in literature. Demont and Tollens (2004b) found that, due to the adoption of *Bt* maize in Spain in 1998-2003, farmers gained two thirds (65%) of the total benefits, while one third (35%) accrued to the seed industry. Price *et al.* (2003) review eight published studies and add four own-calculated estimates. Adding Qaim (2003) and Demont and Tollens (2004b), we have a sample of 14 impact distribution estimates of transgenic crops. Our meta-analysis of these estimates suggest that on average, farmers and consumers extract 61% of total domestic benefits, or with a 95% confidence interval between 52% and 70%, the rest accruing to the seed industry.

In our analysis we model Hungary as a small producer facing an infinite elastic demand. As a result, no price declines are generated by our model impeding Hungarian consumers to capture any gains from the new technology. The innovation is essentially a technology spill-in, mainly from the US. The only way Hungarian consumers can benefit from the innovation is through declining world prices due to the large scale adoption of transgenic crops in large exporting economies, such as the US (e.g. for maize), Canada (e.g. for oilseed rape) and the EU as a whole (e.g. for sugar beet) (Demont and Tollens, 2004a).

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Table 1 : Spread of the Western Corn Rootworm in Hungary, 1998-2003

	1998	1999	2000	2001	2002	2003
Area infested (10^3 ha)	3,000	4,000	5,000	7,000	7,800	9,300
Area with economic adult activity (10^3 ha)	.	.	0.2	1,000	2,000	3,000
Area facing economic larval damage (ha)	.	.	3,130	3,058	5,381	5,995

(Kiss and Edwards, 2001, Ripka and Princzinger, 2001a, Ripka and Princzinger, 2001b, Princzinger *et al.*, 2002, Hataláné Zsellér *et al.*, 2004b, Kiss *et al.*, 2005)

Table 2 : Data Mining on European Corn Borer Losses in Hungary

	1961	1971	1975	1976	1977	1978	1979	1990	1998	2001
ECB damage	4.8%[a]	4.2%[a]		11.0%[a]		10.7%[d]	3.1%[e]	17.5%[f]	5.7%[g]	5.6%[h]
ECB damage	2.8%[a]			1.7%[c]						5.0%[h]
ECB damage	7.7%[a]		6.5%[b]	6.0%[b]	1.9%[b]	3.2%[b]	2.6%[b]			4.1%[i]
Annual average	5.1%	4.2%	6.5%	6.2%	1.9%	7.0%	2.8%	17.5%	5.7%	4.9%
Average	6.2%	Median				5.4%				
StDev	4.3%	Coefficient of variation (CV)				69.4%				

[a] Hertelendy (1976)
[b] Pálfy (1983)
[c] Hertelendy (1978)
[d] Mile and Ilovai (1979)
[e] Gyurkó (1980)
[f] Szõke (2002)
[g] Keszthelyi *et al.* (2000)
[h] Keszthelyi and Najat (2002)
[i] Keszthelyi *et al.* (2002)

Table 3 : Estimated Average Yield Benefit for US Maize Hybrids Containing Event MON 863 Relative to Control with a Soil Insecticide

-------------- Root Ratings --------------				Average		
Untreated	Soil Insecticide	MON 863	Change	Yield Benefit	2.5% percentile	97.5% percentile
1	1.00	1.00	0.00	0.0%	0.0%	0.0%
2	1.36	1.25	0.11	1.4%	0.0%	5.2%
3	1.72	1.49	0.23	2.8%	0.1%	10.2%
4	**2.08**	**1.74**	**0.34**	**4.2%**	**0.1%**	**15.1%**
5	2.44	1.98	0.45	5.7%	0.2%	19.9%
6	2.80	2.23	0.57	7.1%	0.2%	24.5%

(Mitchell, 2002a)

Table 4 : Estimates and Subjective Prior Distributions of Model Parameters

Parameter	Symbol	Distribution	Unit	Sources
***Bt* maize resistant to ECB**				
ECB damage	s	Lognorm(5.4; 4.3)	%	Table 2
ECB *Bt* maize efficacy	a_g	Triang(95; 97.5; 100)	%	(Labatte *et al.*, 1996)
Bt maize price premium (% of seed cost)	w_g	Triang(0; 10; 20)	%	assumption (Czepó, 2004)
Bt maize price premium	w_g	Triang(0; 6; 13)	euros/ha	assumption
Bt maize adoption rate	r_g	10	%	assumption
***Bt* maize resistant to WCR**				
Area under continuous maize	L_c	460,000	ha	(Magonette, 2004)
Area under economic WCR damage, Iowa scale > 3	L_d	5,995	ha	(Hataláné Zsellér *et al.*, 2004d)
Yield benefit of WCR-resistant maize relative to chemical control	$ß$	Lognorm(4.2; 7.3)	%	Table 3 (Mitchell, 2002b)
WCR cost of chemical control	w_c	Triang(28; 50; 71)	euros/ha	(AKII, 2004, Tóth, 2004b)
Bt maize price premium (% of seed cost)	w_g	Triang(0; 40; 79)	%	assumption
Bt maize price premium	w_g	Triang(0; 25; 50)	euros/ha	assumption
Bt maize adoption rate	r_g	Uniform(0.5; 40)	%	assumption
Herbicide tolerant crops				
Maize herbicide cost	w_c	Lognorm(40; 21)	euros/ha	Table 5 (AKII, 2004)
Sugar beet herbicide cost	w_c	Lognorm(120; 79)	euros/ha	Table 6 (AKII, 2004)
Oilseed rape herbicide cost	w_c	Lognorm(29; 27)	euros/ha	Table 7 (AKII, 2004)
Average glyphosate price	g	6	euros/l	(Czepó, 2004)
HT maize recommended glyphosate rate	$\bar{g}$	5	l/ha	(Czepó, 2004)
HT sugar beet recommended glyphosate rate	$\bar{g}$	6	l/ha	(Czepó, 2004)
HT oilseed rape recommended glyphosate rate	$\bar{g}$	2.5	l/ha	(Czepó, 2004)
HT maize yield boost	$ß$	Normal(0; 2.5)	%	(Marra *et al.*, 2004c)
HT sugar beet yield boost	$ß$	Normal(0; 2.5)	%	(Kniss *et al.*, 2004, Marra *et al.*, 2004e)
HT oilseed rape yield boost	$ß$	Normal(0; 2.5)	%	(Fulton and Keyowski, 1999, Marra *et al.*, 2004a)
Aggregation to the national level				
Maize producer price	p	Normal(126; 16)	euros/t	(AKII, 2004)
Sugar beet producer price	p	Normal(33; 5)	euros/t	(AKII, 2004)
Oilseed rape producer price	p	Normal(208; 16)	euros/t	(AKII, 2004)
Maize supply elasticity	e	Triang(0; 0.9; 1.8)	-	(Banse *et al.*, 2004)
Sugar beet supply elasticity	e	Triang(0; 0.7; 1.4)	-	(Banse *et al.*, 2004)
Oilseed rape supply elasticity	e	Triang(0; 1.3; 2.5)	-	(Banse *et al.*, 2004)

Table 5 : Survey Data of Maize Cultivation in Hungarian Farms

Maize	Area sown (ha)	Yield (t/ha)	Seed cost (euros/ha)	Pecticide cost (euros/ha)	Herbicide cost (euros/ha)	Insecticide cost[a] (euros/ha)	Insecticide cost[b] (euros/ha)	Labour-pesticide (euros/ha)	Machinery costs (euros/ha)	Total cost (euros/ha)	Producer price (euros/t)
Weighted average	19	3.7	63	44	40	2	21	4	145	442	126
Standard error	60	1.2	17	22	21	7	12	8	62	115	16
Minimum	0	1.0	2	0	0	0	0	0	10	205	61
Maximum	2160	7.9	162	167	167	67	67	75	386	746	158
Sample size	827	827	827	827	827	827	145	827	827	827	827

[a] This cost has been averaged over all 827 farmers, including 682 farmers that do not use any insecticides.

[b] This cost has been averaged over only the group of 145 farmers that use some insecticides.

(AKII, 2004)

Table 6 : Survey Data of Sugar Beet Cultivation in Hungarian Farms

Sugar Beet	Area sown (ha)	Yield (t/ha)	Seed cost (euros/ha)	Pecticide cost (euros/ha)	Herbicide cost (euros/ha)	Labour-pesticide (euros/ha)	Machinery costs (euros/ha)	Total cost (euros/ha)	Producer price (euros/t)
Weighted average	28	36.6	129	192	120	8	40	1,044	33
Standard error	45	9.2	34	86	79	17	31	246	5
Minimum	3	15.9	40	0	0	0	5	616	20
Maximum	305	68.0	252	349	333	71	312	1,573	51
Sample size	51	51	51	51	51	51	51	51	51

(AKII, 2004)

Table 7 : Survey Data of Oilseed Rape Cultivation in Hungarian Farms

Oilseed Rape	Area sown (ha)	Yield (t/ha)	Seed cost (euros/ha)	Pecticide cost (euros/ha)	Herbicide cost (euros/ha)	Labour-pesticide (euros/ha)	Machinery costs (euros/ha)	Total cost (euros/ha)	Producer price (euros/t)
Weighted average	42	1.6	37	52	29	6	132	402	208
Standard error	73	0.6	22	35	27	8	36	88	16
Minimum	1	0.7	3	0	0	0	39	222	170
Maximum	625	2.9	107	142	99	32	278	671	257
Sample size	65	65	65	65	65	65	65	65	65

(AKII, 2004)

Table 8 : Descriptive Statistics of the Impact of *Bt* Maize Resistant against ECB in Hungary in 2003

	2.5% quantile	Mean	97.5% quantile	Average share
Farmers' surplus (euros)	-364,202	2,240,911	8,807,194	76%
Industry's rent (euros)	160,884	719,593	1,278,264	24%
Total welfare gain (euros)	510,229	2,960,505	9,497,539	100%

Table 9 : Descriptive Statistics of the Impact of *Bt* Maize Resistant against WCR in Hungary in 2003

	2.5% quantile	Mean	97.5% quantile	Average share
Farmers' surplus (euros)	565,773	10,666,550	34,563,060	65%
Industry's rent (euros)	300,518	5,771,842	16,479,330	35%
Total welfare gain (euros)	1,101,732	16,438,390	43,336,200	100%

Table 10 : Predicted Price Premiums and Adoption Rates of HT Crops in Hungary in 2003

	Maize	Sugar beet	Oilseed rape
Price premium (euros/ha)	8	81	12
Price premium (% of seed cost)	13%	63%	34%
Adoption rate (%)	40%	38%	35%

Table 11 : Descriptive Statistics of the Impact of HT Maize in Hungary in 2003

	2.5% quantile	Mean	97.5% quantile	Average share
Farmers' surplus (euros)	-1,192,280	10,083,380	20,702,820	73%
Industry's rent (euros)	3,718,113	3,718,113	3,718,113	27%
Total welfare gain (euros)	2,525,833	13,801,490	24,420,940	100%

Table 12 : Descriptive Statistics of the Impact of HT Sugar Beet in Hungary in 2003

	2.5% quantile	Mean	97.5% quantile	Average share
Farmers' surplus (euros)	532,952	1,638,328	2,675,734	50%
Industry's rent (euros)	1,646,186	1,646,186	1,646,186	50%
Total welfare gain (euros)	2,179,139	3,284,515	4,321,921	100%

Table 13 : Descriptive Statistics of the Impact of HT Oilseed Rape in Hungary in 2003

	2.5% quantile	Mean	97.5% quantile	Average share
Farmers' surplus (euros)	115,709	479,262	821,899	61%
Industry's rent (euros)	306,186	306,186	306,186	39%
Total welfare gain (euros)	421,894	785,448	1,128,084	100%

Table 14 : Average Farmers' Surplus per Adopted Hectare

	ECB-resistant maize	WCR-resistant maize	HT maize	HT sugar beet	HT oilseed rape
Area (ha)	1,150,000	1,150,000	1,150,000	53,000	71,000
Average adoption rate (%)	10%	20%	40%	38%	35%
Farmers' surplus (euros)	2,240,911	10,666,550	10,083,380	1,638,328	479,262
Farmers' surplus (euros/ha)	19	46	22	81	20

Table 15 : Sensitivity Analysis of the Impact of *Bt* Maize Resistant against ECB in Hungary in 2003

	Farmers' surplus	Industry's rent	Total welfare gain
Theoretical damage	0.979	0.000	0.986
Price premium *Bt* maize	-0.125	1.000	-0.008
Maize producer price	0.112	0.000	0.113
Efficacy *Bt* maize	0.011	0.000	0.012
Maize supply elasticity	0.000	0.000	0.000
R^2	98.5%	100.0%	98.4%

Table 16 : Sensitivity Analysis of the Impact of *Bt* Maize Resistant against WCR in Hungary in 2003

	Farmers' surplus	Industry's rent	Total welfare gain
Adoption *Bt* maize	0.633	0.734	0.795
Yield benefit of MON 863	0.570	0.000	0.465
Price premium *Bt* maize	-0.302	0.591	-0.024
Chemical treatment cost	0.239	0.000	0.196
Maize supply elasticity	0.006	0.000	0.005
Maize producer price	0.000	0.000	0.000
R^2	81.6%	89.0%	88.5%

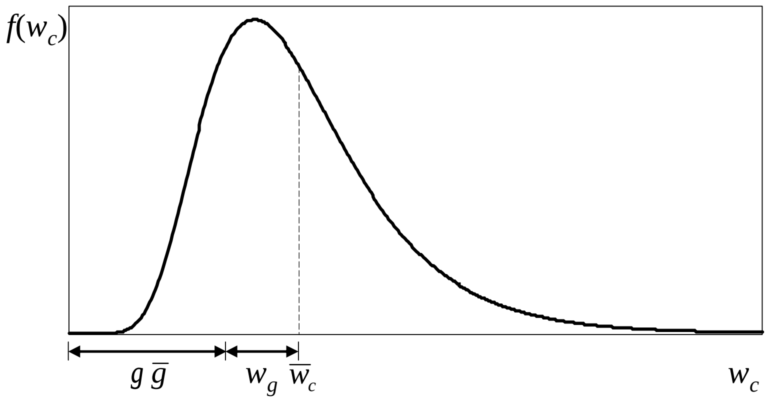

Figure 1 : Theoretical Distribution of Herbicide Costs and Pricing Decision of the Innovator

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[1] The voltinism expresses the annual number of generations produced by a species.

[2] Univoltine species annually produce one single generation.

[3] This represents the area with a population level such that economic larval damage will occur if maize is planted. Adults lay their eggs in the soil of maize fields during the summer and larvae hatching from overwintering adults will damage the maize root system. If the full economic adult activity area is rotated, no economic larval damage will be suffered. If no rotation is applied, theoretically the whole economic adult activity area will be economic larval damage area.

[4] The 'seed industry' includes the gene developers, e.g. Monsanto, and the seed suppliers, e.g. Pioneer in Hungary.

[5] The data are calculated as a weighted average of the individual groups of sample farms. For weighting purposes, the AKII used the data of the General Agricultural Census of year 2000. The weight shows how many farms in the similar group of the population a farm in the sample represents. This way the data does not only characterize the farms in the sample group but also the statistical population they represent (Kovács and Keszthelyi, 2003).

[6] This is much lower than in areas with a higher ECB pressure. As a comparison, the technology fee of *Bt* maize in the US is estimated at 26 €/ha in 1997, 22 €/ha in 1998 and 1999 and 16-17 €/ha in 2001 (Gianessi *et al.*, 2002a), while Benbrook (2001) reports a higher fee, i.e. 25 €/ha during the same period. The price premium of *Bt* maize in France was projected in *ex ante* at 36 €/ha (Lemarié *et al.*, 2001). Brookes (2002) reports a technology fee of 29-31 €/ha in Spain. This price is recommended by the seed industry but many farmers pay lower prices through local cooperatives, i.e. 18-19 €/ha, capturing 70% of the Spanish maize seed market. Up to 2003, *Bt* maize seed was only supplied by one company, i.e. Syngenta. In 2003 five new varieties were registered and four new companies have entered the market, i.e. Pioneer, Monsanto, Nickerson and Limagrain. With this additional competition in mind it is likely that technology fees will fall. This has happened in all other countries where transgenic crops have been introduced (Gianessi *et al.*, 2002c). Therefore, our conservative seed price premium assumption might be representative for the future introduction of *Bt* maize in Hungary.

[7] Alston *et al.* (2002) found a comparable competitive seed price premium of 27 €/ha.

[8] Marra *et al.* (2004b) did not find any significant difference in seed costs between HT and conventional maize for North Carolina farmers. Back in 2001 there was relatively little adoption of HT

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maize and as a result Monsanto was lowering the price to that of conventional corn. There was a significantly higher seed cost for cotton and for soybeans relative to their conventional counterparts (Marra, 2004).

[9] Since nowhere in the world HT sugar beet has been commercialized, the seed price premium has not been established yet. Our estimate is in line with the premium of 77 €/ha estimated in *ex ante* for France (Lemarié *et al.*, 2001) and is situated between the high estimated price premiums in the US, i.e. 133 €/ha (Burgener *et al.*, 2000), 157 €/ha (Rice *et al.*, 2001), 128 €/ha (Gianessi *et al.*, 2002b) and 164 €/ha (Kniss *et al.*, 2004), and the lower price premiums assumed for the EU, i.e. 32-48 €/ha (May, 2003) and 38 €/ha (Gianessi *et al.*, 2003b).

[10] This is lower than the price premium of 47 €/ha reported for HT canola in Canada in 1999 (Fulton and Keyowski, 1999) and projected 49 €/ha for HT oilseed rape in France (Desquilbet *et al.*, 2001).

[11] The degree of significance is 5%.