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The Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) and other Benefits and Costs of Introducing Transgenic Maize in the EU-15

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Summary

The decision to release a new transgenic crop variety for planting in the European Union is a decision under irreversibility and uncertainty. We use a real option model to assess the ex-ante incremental benefits and costs of the decision to release *Bt* maize and HT-maize in the EU-15 member states. The analysis uses Eurostat data for modeling the benefits and costs of non-transgenic maize using partial equilibrium models. The farm level benefits and costs of *Bt* maize and HT maize are derived from field trials conducted within the EU-funded ECOGEN project in combination with secondary data sources. Adoption curves, hurdle rates, and maximum incremental social tolerable irreversible costs (MISTICs) are calculated at country level for selected EU-15 member states. In general, the results show

that the MISTICs on a per capita level are very small confirming previous results calculated in values for the year 1995. The MISTICs per farm are much larger. This indicates a problem for decision makers.

Introduction

Despite several concerns, transgenic crops have been introduced and rapidly adopted in the United States and other countries (James, 2004). Several studies confirm that on average the gross margin per area from transgenic crops is at least as high as, and sometimes higher than, that of non-transgenic crops. However, there seems to be a regional difference in the distribution of benefits, which are correlated with regional factors like pest infestation levels and climatic conditions. Empirical studies also indicate that the amount of pesticides may decrease, but only in specific regions and in specific years. (Carpenter and Gianessi, 1999; Fernandez-Cornejo et al., 1999; Fulton and Keyowski, 1999; Scatasta et al., 2006a). Wesseler (2005) provides a detailed background on the environmental effects of transgenic crops.

Rapid adoption of transgenic crops by farmers has been explained by the greater benefits farmers gain from planting transgenic crops. Variable production costs are reduced, due to reduced pest management and labour. Gross revenues increase due to an increase in yield from improved plant spacing. Additional benefits arise from improved risk management and insurance against pests and a reduction in equipment costs in no-tillage production systems (Kalaitzandonakes, 1999). All these are reversible benefits at the farm level (i.e., the effects would stop as soon as the transgenic crop is no longer planted and do not carry over into subsequent years). Decision makers are particularly concerned about the irreversible costs of planting transgenic crops (i.e. effects that would still be evident even after the crop is no longer planted). Gene flow and non-target effects can be considered as irreversible costs as they have to be paid for in addition to the costs that can be recovered if the planting of the transgenic crop stops (Kendall et al., 1997; Krimsky and Wrubel, 1996; Kuiper et al., 2000; Nillesen et al., 2006a; Peterson et al., 2006). The decrease in pesticide use by planting transgenic crops and *Bt* crops (i.e. crops expressing an insecticidal protein from *Bacillus thuringiensis*) in particular not only reduces farmers' expenses but also provides additional benefits, since the application of pesticides may have negative impacts on the environment and human health (Antle and Pingali, 1994; Waibel and Fleischer, 1998; Fleischer, 1998). Most of these external costs of pesticide application are irreversible.

One could perhaps think of reversing some of the irreversible effects such as on biodiversity or pest resistance, however, even if that were possible it would not be costless and Demont et al. (2005) show an irreversibility effect could still exist.

The possibility of irreversible costs with the introduction of transgenic crops into the European Union (EU) was one of the major arguments for some of the EU member states to block new approvals of genetically modified organisms (GMOs) until the European Commission proposed additional legislation governing their introduction (Commission of the European Communities, 1999). The decision became to be known as the *quasi moratorium* on GMOs.

The irreversible effects of transgenic crops, and the uncertainty about their future costs and benefits, will impact when and if they will be released. Both irreversible costs and uncertainty and their impact on optimal investment have been widely analysed (e.g. McDonald and Siegel, 1986; Dixit and Pindyck, 1994; Trigeorgis, 1996). Recently, the approach has been applied, among other things, to the adoption of soil conservation measures (Winter-Nelson and Amegbetto, 1998), marketing (Richards and Green, 2003), wilderness preservation (Conrad, 2000), agricultural labour migration (Richards and

Patterson, 1998), the introduction of herbicide-tolerant sugar beets in the EU (Demont et al. 2004) and the analysis of government reforms (Leitzel and Weisman, 1999). In the case of transgenic crops there are the additional irreversible government policy costs of the implementation of biosafety regulations and changes in patent laws. As they may be of importance, we will concentrate in this paper on the crop related irreversibilities.

The objective of this paper is to present economic benefits and costs for pest resistant (*Bt*) maize and herbicide tolerant (HT) maize and to identify, *ex-ante,* potential social welfare impacts of adoption of *Bt* maize and HT maize for grain maize production in the 15 member states of the EU (EU-15). A model will be presented that shows how those concerns can be considered explicitly by using the concept of *Maximum Incremental Social Tolerable Irreversible Costs* (MISTICs).

Materials and Methods

Methodological approach to assess the benefits and costs of transgenic crops

Consider a decision maker or a decision-making body similar to an EU agency, such as the European Food Safety Authority (EFSA) or the United States Environmental Protection Agency (US-EPA), that has the authority to decide whether or not a particular transgenic crop, e.g. a toxin-producing crop like *Bt* maize, should be released for commercial planting. The agency can approve an application for release or postpone the decision and wait to up-date the information about possible benefits and costs of the technology. The objective of the agency is to maximize the welfare of producers and consumers in the economy while ignoring positive and negative transboundary effects.

Within this setting the welfare effect of releasing a specific transgenic crop can be described as the discounted sum from T till infinity of the social incremental reversible net benefits, *W*, minus the difference between incremental irreversible costs, *I*, and incremental irreversible benefits, *R,* of the technology.

As the agency has the possibility to postpone the decision on whether or not to release the transgenic crop, the agency has to maximize the value resulting from this decision, *F(W)*, to maximize the welfare. This objective can be described as maximizing the expected value from releasing the transgenic crop:

$$\max F\left(W\right) = \max E\left[\left(W_T - \left(I_T - R_T\right)\right)e^{-\rho T}\right] \tag{1}$$

where E is the expectation operator, T the point in time when the transgenic crop is released into the environment and ρ the discount rate. $T=0$ implies an immediate release and $T>0$ postponing the release.

The welfare effect at farm level is the difference between the sums of gross margins from transgenic crops minus the total sum of gross margins from the alternative non-transgenic crop (termed the conventional crop for the rest of the paper) minus private incremental irreversible investment costs plus incremental irreversible benefits (Weaver and Wesseler, 2005). The welfare benefits of *Bt* grain maize and HT grain maize can be modelled for EU-15 member states by using a small open economy model. Potential welfare losses (deadweight losses) of EU agricultural policy will not be considered, as the EU policy is seen as the efficient outcome of different pressure groups lobbying for policies. The private incremental reversible net-benefit in a given year is then the difference in gross margin on a hectare basis between the transgenic and the conventional crop times the area planted with the transgenic crop. As we do not consider changes in administration costs and spill-over effects, the private incremental reversible benefits are equal to the social incremental reversible benefits of introducing the *Bt* maize and HT maize, respectively.

The area allocated over time to planting transgenic crops can be expected to increase following a logistic adoption pattern (Demont et al, 2004). Consequently, the annual social incremental reversible benefits increase over time as well. For comparison of future and present social incremental reversible benefits, future social incremental reversible benefits will be discounted. The total social incremental reversible benefit of introducing *Bt* maize or HT maize is the sum of the annual incremental reversible benefits per hectare times the area allocated to the crop, in this case grain maize, times the adoption rate over an infinite period of time:

$$W_T = \int_T^{\infty} W_{\max}(t)\theta(t)e^{-\mu t}dt \qquad (2)$$

where the subscript *max* indicates values at complete adoption and *t* represents time, θ, the rate of adoption of the new technology and μ the risk-adjusted discount rate.

Similarly, the social incremental irreversible benefits of introducing transgenic grain maize are $R_T = \int_T^{\infty} R_{\max}(t)\theta(t)e^{-\mu t}dt$.

Under the assumption that the social incremental reversible benefits follow a continuous time continuous state process (Wesseler, 2003) *Bt* maize and HT maize should be released at the point in time, where the current social incremental reversible benefits W_T are greater than the difference between the social incremental irreversible costs (I_T) and the social incremental irreversible benefits (R_T) weighted by the size of the uncertainty and flexibility associated to the adoption of a new technology (or hurdle rate). The hurdle rate is commonly expressed in the form $\beta/(\beta-1)$, where $\beta > 1$ captures the combined flexibility, irreversibility and uncertainty effect (Demont et al., 2004). A hurdle rate of, e.g., 1.7 implies the incremental benefit of the new technology has to be at least 1.7 times the net irreversible costs to be considered more beneficial than the best alternative technology available.

As long as the social incremental reversible benefits, W_T, are less than the social incremental net-irreversible costs, $(I_T\text{-}R_T)$, weighted by the hurdle rate, $W_T < \beta/(\beta-1)(I_T - R_T)$, the EU should delay introduction of the transgenic crop under consideration until more information about benefits and costs of the new technology is available.

In the context of transgenic crops where people are more concerned about the uncertain irreversible costs of the technology, threshold values that indicate the maximum incremental social irreversible costs that an individual or society in general is willing to tolerate for the sake of the benefits of the technology can provide useful information. We have called this value (Scatasta et al., 2006b) the *Maximum Incremental Social Tolerable Irreversible Costs, I*,* or MISTICs for short. Actual social incremental irreversible costs, *I,* are to be no greater than the sum of social incremental irreversible benefits and social incremental reversible net-benefits from transgenic crops, such that:

$$I_T < I^* = \frac{W_T}{\beta/(\beta-1)} + R_T \tag{3}$$

The formulation of the MISTICs, I^*, illustrates the effect of waiting due to combined flexibility, irreversibility, and uncertainty. The total benefits of introducing transgenic crops are the sum of the social incremental irreversible benefits and the social incremental reversible net-benefits, without explicitly recognizing flexibility (the possibility to postpone the decision), irreversibility, and uncertainty. However, when considering flexibility, irreversibility, and uncertainty only a proportion of the social incremental reversible benefits, $1\Big/\frac{\beta}{\beta-1}$ should be taken into account. The proportion $\left(1-1\Big/\frac{\beta}{\beta-1}\right)$ in this context can be interpreted as the economic value of irreversibility and uncertainty under flexibility of releasing transgenic crops. The MISTICs can be summarized as the threshold values below which the irreversible costs have to be for the GM crop to be economically better.

Quantifying social incremental reversible net-benefits (SIRBs) from Bt maize and HT maize

Social incremental reversible net-benefits in this study include private incremental reversible net-benefits for two market agents: buyers and sellers. We limit the analysis to two types of technologies, transgenic and conventional, without taking organic production into consideration (see Klotz-Ingram et al., 1999; Traxler and Falck-Zepeda, 1999; Pray et al., 2001; Frisvold et al., 2003; Demont and Tollens, 2004; Demont et al., 2004).

As mentioned earlier the EU member states are small open economies with respect to grain maize, facing a horizontal demand curve. Following Moschini et al. (2000), social incremental reversible net-benefits are measured in terms of producer surplus derived from constant elasticity log-linear supply functions. The degree to which the price for grain maize changes with an increase grain maize supply, the supply elasticity, was taken from the European Simulation Model (ESIM) where the change is derived from behavioural equations. The suggested elasticity for land allocation to maize is 0.77, so we approximate the supply elasticity to this value in our base case (see Banse et al., 2004). The introduction of a technological innovation, such as *Bt* maize, causes a pivotal shift in the inverse supply function. This shift for a maximum adoption of hundred per cent is calculated as:

$$K_{\max} = \frac{\left[\frac{VC_c}{y_c}\right]\frac{1}{y_c^{1/\varepsilon}} - \left[\frac{VC_g}{y_g}\right]\frac{1}{y_g^{1/\varepsilon}}}{\left[\frac{VC_c}{y_c}\right]\frac{1}{y_c^{1/\varepsilon}}} \tag{4}$$

where VC_c are variable operating costs in Euro per hectare associated with the conventional technology; VC_g are variable operating costs (Euro per hectare) associated with the transgenic technology; y_c is production (in metric tons) under conventional technology and y_g is production (in metric tons) under the transgenic technology and ε the supply elasticity. The expression $\left[VC_i/y_i\right]$ is used to approximate marginal costs of technology *i*. Note that if there is no yield gain from planting transgenic maize, the K-shift in the supply function reduces to $K=\left[VC_c-VC_g\right]/VC_c$ as assumed for the case of HT maize. For *Bt* maize we used data from field trials carried out in Narbons, France in 2004, comparing average yield and cost advantages of the commercial variety (Paolis) with the *Bt* variety MON810 and obtain a value of *K*=0.24. For HT maize we use the values reported by Gianessi et al. (2003) and find a *K*=0.12. Table 1 presents the gross margins for *Bt* maize planted at the Narbons field trial (Andersen et al., 2007) for 2004 and 2005.

Under our assumptions the social incremental reversible net-benefits from transgenic crops are represented by changes in producer surplus (see Scatasta et al., 2006c, unpubl. work, for details of the model). These changes are calculated over an infinite time horizon and then expressed in annuities multiplying their total present value by the risk-adjusted discount rate. All values are expressed in 2004 Euro to control for price changes.

Quantifying social incremental irreversible benefits (SIIBs)from *Bt* maize and HT maize

Social incremental irreversible benefits (SIIBs) for *Bt* maize were calculated on the basis of changes in pesticide use and fuel use. In the Narbons field trials 0.035 kilogram less Active Ingredient (kgAI) insecticide per hectare were used for *Bt* maize; the numbers from Gianessi et al. (2003) result in a reduction in herbicide use for HT maize in the order of 1.719 kgAI per hectare. Changes in fuel use are derived from a comparative technology, which suggests a reduction of 0.01 tonnes of CO_2 emissions per hectare (Demont et al., 2004). Following Pretty et al. (2000) we considered 0.69 Euro of social irreversible benefits per kgAI reduction and 77.4 Euro of social irreversible benefits per tonne of CO_2 emissions. These values give irreversible benefits per hectare in the amount of 0.73 Euro for *Bt* maize and 1.78 Euro for HT maize (1995 values, the real value in 2004 changes for each county depending on the deflator).

SIIBs are then found summing the value of benefits from reduced insecticide and herbicide use per hectare and then multiplying this value by the adopted number of hectares. These benefits are calculated over an infinite time horizon and then expressed in annuities multiplying their total present value by a risk-adjusted discount rate. All values are in 2004 Euro.

Quantifying adoption rates, θ

The transgenic maize adoption curve is assumed to follow a logistic pattern over time. The size and speed of adoption can be estimated with ordinary least squares (OLS) using data from the adoption rates in the United States (James, 2004). Following Demont et al. (2004) the speed of adoption is then assumed half of that of the U.S. This allows us to obtain conservative estimates of the social incremental reversible benefits. For the sake of simplicity, transparency and comparison between Member States, we opt for an exogenous adoption curve and assume an adoption ceiling of 30% for *Bt* maize and 40% for HT maize. We obtain:

$$\ln\left(\frac{\theta(t)}{0.3-\theta(t)}\right)_{Bt} = 2.41 - 0.335t \quad Bt \text{ maize} \tag{5a.}$$

$$\ln\left(\frac{\theta(t)}{0.3-\theta(t)}\right)_{Ht} = 2.15 - 0.187t \quad \text{HT maize} \tag{5b}$$

where $\theta(t)$ represents maize adoption rate. For a discussion about adoption rate for *Bt* maize in Europe depending on ECB pressure consult Nillesen et al. (2006b, unpubl. work).

As the speed of transgenic maize adoption is probably important in determining the gains the EU will enjoy from this technology, we take its 95% confidence interval into consideration and allow this parameter to vary between half of the lower bound of this interval (0.14 for Bt and 0 for HT) and the full upper bound of the confidence interval (1.06 for Bt and 0.40 for HT), assigning this parameter a pert distribution with mode 0.335 for Bt maize and 0.187 for HT maize. Results for each scenario represent mean results of 5000 iterations on the simulated speed of adoption. The simulation software used is RiskAmp.

Quantifying maximum incremental social tolerable irreversible costs (MISTICs)

The MISTICs were computed as in equation (1) for 2004. The parameter values for identifying the hurdle rates are estimated from gross margin time series data provided by EUROSTAT (http://europa.eu.int/newcronos) following Demont et al. (2004). Following expert opinions on corn borer infestation levels we analyzed for *Bt* maize in five countries: France, Italy, Spain, Portugal and Greece. We considered for HT maize nine countries: France, Italy, Spain, Portugal, Greece, Austria, Belgium, The Netherlands and Germany.

We performed the analysis using a risk-adjusted discount rate of 10.5% as in Demont, Wesseler and Tollens (2004). We calculated the producer surplus 1) at quantities for prices excluding subsidies (called producer prices in the database) and 2) at quantities for prices including subsidies (called basic prices in the EUROSTAT database).

Results and Discussion

Tables 2 and 3 show the social incremental reversible as well as irreversible benefits and costs for introducing *Bt* maize and HT maize for grain maize production in selected countries of the EU-15. The first two columns show the calculated average annual social incremental reversible benefits. Those benefits are enormous. They are about 62 million Euros on average per year for France in the case of *Bt* maize with CAP subsidies and about 36 million Euros per year in the case of *Bt* maize without CAP subsidies. Nevertheless, the SIRBs are about 29 million Euros per year in the case with CAP subsidies and about 17 million Euros per year in the case without subsidies. In general, HT maize offers lower potential gains than *Bt* maize. Without CAP subsidies potential gains are reduced by about 40-50%. This is simply due to the absence of the subsidies as a revenue component and indicates the land allocation effect of the CAP subsidy.

The SIIBs are very small. For France they reach about 240,000 Euro on average per year for *Bt* maize. In general, they are about one Euro per hectare and year for the five countries considered for *Bt* maize. The social incremental irreversible benefits are slightly larger for HT maize mainly because of larger savings in CO_2 emissions.

The sum of the SIRBs and the SIIBs can be seen as the average benefits per year foregone by postponing the introduction of *Bt* maize (HT maize) for another year. Take the case of France. France foregoes about 29 million Euros per year for postponing the introduction of HT maize and about 62 million Euro per year for postponing the introduction of *Bt* maize for grain maize production.

The hurdle rates indicate the percentage of compensation in the form of social incremental reversible plus irreversible benefits for one Euro of incremental irreversible costs. The hurdle rates are highest for Belgium followed by The Netherlands. The case for Belgium needs to be considered with care because of the database. The example for The Netherlands indicates that one Euro of incremental irreversible costs needs to be compensated by about 5.50 Euro of social incremental reversible plus irreversible benefits and shows more then one unit of reversible benefits is needed to compensate for one unit of irreversible costs. The comparison of the situation with and without the CAP is mixed.

For some countries the hurdle rates increase (Austria, Belgium, France, Greece, and Italy) while for others the hurdle rates decrease (Germany, Netherlands, Portugal, and Spain).

The higher the hurdle rates are, the lower the MISTICs will be (see equation 3). The MISTICs are the threshold values below which the irreversible costs have to be for the GM to be economically profitable. The MISTICs in million Euros per year range from about 2 million Euro per year for Portugal to up to 54 million Euro per year for France for the case of *Bt* maize. As expected the values for HT maize are lower. They range from about 20 thousand Euro per year for Belgium to up to 26 million Euros per year for France.

The important question is whether or not actual incremental irreversible costs will exceed the MISTICs. The irreversible cost of pesticide use provides some insights. *Bt* maize and HT maize are approaches to control insect pests and weeds and have similar implications for the environment and human health as pesticides themselves. A comparison between the social incremental irreversible benefits and the MISTICs shows that the MISTICs are higher than the SIIBs by a factor of two for Belgium and at least by a factor 12 for the other countries in the case of HT maize. For the case of *Bt* maize the MISTICs for each country are at least by a factor of 72 higher than the SIIB. These high factors cast doubts about the actual social incremental irreversible costs being as high as the MISTICs. The results provide a good argument for immediately introducing *Bt* maize and HT maize into the countries included in Tables 2 and 3.

The picture changes if the MISTICs are calculated on a per capita level. In that case the MISTICs are very small. For all countries and all cases considered the MISTICs are below one Euro a year. The results by Chern et al. (2003) support the expectation that consumers' willingness-to-pay for Bt maize and HT maize is more than one Euro per year. In our model, all benefits from the introduction of transgenic maize accrue to a small group of maize farmers. Distributing the total MISTICs among this small group generates higher

MISTIC than distributing them among all European citizens as indicated in the last column in Tables 2 and 3.

The results of the sensitivity analysis for the speed of adoption and a lower k-shift (0.16 for Bt-maize and 0.06 for HT maize) do not change the main conclusions (results available upon request from the authors).

Conclusions

The use of the real option approach to value the economic benefits and costs of introducing *Bt* maize and HT maize considers potential irreversible costs of the introduction explicitly. Using the real option approach demonstrates that it is possible to consider long-term effects of GM crops in an economic analysis. Those concerns are captured by the *Maximum Incremental Social Tolerable Irreversible Costs* or *MISTICs* for short of introducing *Bt* maize and HT maize for grain maize production in the EU-15.

The results quantify the decision makers' dilemma: on the one hand there are good economic reasons for introducing *Bt* maize and HT maize immediately, if one analyzes at the national economy and farmholder scale, but on the other hand there are good reasons for postponing the decision considering the low MISTICs per capita. This indicates the introduction of *Bt* maize and HT maize does not increase the welfare of all citizens or in economic terms is a Pareto improvement.

The EU has addressed concerns of citizens by introducing a labelling and tracking and tracing system for GMOs, as well as coexistence rules governing the planting of transgenic crops. Those policies can be seen as a compensation for those citizens that are concerned about introduction of transgenic crops. From that perspective the decision by the European Commission to postpone further approvals of GM crops until labelling and tracking systems for GMOs are in place and coexistence rules established can be considered a wise decision albeit this decision came at high economic costs. Spain that introduced *Bt* maize early, about five years ago, gained about 135 million Euros, while France, e.g., forwent economic gains of about 310 million Euros over the same period, *ceteris paribus*.

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