IRREVERSIBILITY, UNCERTAINTY AND THE ADOPTION OF TRANSGENIC CROPS: THE CASE OF BT-MAIZE IN FRANCE

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Paper prepared for presentation at the 11th Congress of the EAAE

(European Association of Agricultural Economists),

The Future of Rural Europe in the Global Agri-Food System, Copenhagen, Denmark,
August 24-27, 2005

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This study applies a real option approach to quantify, ex-ante, the maximum incremental social tolerable irreversible costs that would justify immediate adoption of Bt maize in France. Based on field trials, we find that incremental private reversible benefits in the agricultural sector are -18 million euro yearly for maize for animal feed and 1 million euro yearly for maize for human consumption. Incremental social irreversible benefits from reduced insecticide use are negligible. The maximum incremental social tolerable irreversible costs are -28 million euro yearly for maize for animal feed and 0.4 million Euro yearly for maize for human consumption.

Keywords: Bt Maize, real option, France, field trials, irreversible social costs

JEL: D6, D8, Q1

1. Introduction

Traditional ex-ante assessment of the costs and benefits of a new product of agro biotechnology do not take into consideration that the adoption of a new technology might be associated to higher risks and uncertainty with respect to both its costs and its benefits. Some of this costs and benefits might be irreversible in nature. Irreversible costs and benefits imply that, once the decision is taken, it is not possible to go back to the equilibrium the economy was before such decision. Examples of irreversible costs associated to the adoption of genetically modified organisms (GMOs) are losses in biodiversity and development of resistance. Examples of irreversible benefits are gains in human health due to reduced poisonings from pesticide use and gains in biodiversity from reduced pesticide use. In this context the option to delay the release of a (GMO) until more information on its risks becomes available may become of value to society. The value of the possibility of delaying the decision of releasing transgenic crops into the environment can be explicitly taken into consideration by analysts via a *real option approach*.

The *real option* decision criteria for releasing GMOs immediately requires incremental private reversible benefits from GM crops, such as net-benefits accruing to farmers, to be greater than incremental social irreversible costs by a factor that depends on the uncertainty associated with the adoption of a new technology. This factor is the so called hurdle rate.

Following Dixit and Pindyck (1994) hurdle rates associated to GM crops can be quantified by assuming that additional private net-benefits from transgenic crops follow a geometric Brownian process. The hurdle rate becomes then a well specified function whose parameters can be inferred from time series data on farmer gross margins and secondary literature, by assuming that GM crops constitute a normal technological change.

As hurdle rates are always greater than one, the *real option* decision criteria for releasing transgenic crops immediately, differs from the traditional decision criteria as it requires incremental social reversible benefits to be greater than incremental social irreversible costs. The traditional decision criteria for releasing GM crops immediately, requires, instead, incremental private reversible benefits to be at least equal to incremental social irreversible costs.

Demont et al. (2004) computed hurdle rates for herbicide tolerant (Ht) sugar beet and reassess whether the 1998 moratorium of the European Union (EU) on Ht-sugar beet is justified from a cost-benefit perspective. The authors conclude that such moratorium would be justified if transgenic sugar beet caused annual incremental social irreversible costs above 121 Euro per hectare planted. This means that the maximum incremental social tolerable irreversible costs for Ht-sugar beet are in the order of 103 Million Euro per year. Incremental private reversible benefits from Ht-sugar beet are in the order of 169 Million Euro per year if the moratorium is lifted.

The object of this study is to carry out a similar assessment Bacillus thuringiensis (Bt) maize in France and identify, *ex-ante,* potential social welfare impacts of Bacillus thuringiensis (Bt) maize in France. In section 2 we present some background information on Bt maize and the field trials carried out in France. In section 3 we describe the real option approach. In section 4 we quantify the maximum incremental social tolerable irreversible costs. Section 5 summarizes our findings and conclusion.

2. Background

France is the most important maize producer in the EU. France produces about 42% of the European Union (EU-15) maize. Genetically modified maize is not currently has been currently approved in the EU only for animal feed (Brookes, 2000, The new farm, 2004). In France, especially in the southern area the European Maize Borer (ECB- *Ostrinia nubilalis*) is considered one of the most severe maize pest. The degree of ECB infestation is key to the economic viability of pest control strategies. The ECB can cause severe damage to maize plants by penetrating the stalk and excavating large tunnels into the plant.

Conventional ECB pest control strategies are difficult to manage because a correct timing of insecticide applications is crucial to their effectiveness. Insecticides are effective only when the ECB is in the larval status but it has not yet penetrated the stalk or is migrating to neighbouring plants (see Demont and Tollens, 2004).

Bt maize is maize that has been genetically engineered to contain a gene of the soil bacterium *Bacillus thuringiensis (*Bt). This bacterium produces a crystal-like (Cry) protein that is toxic to ECB. This bacterium is currently used, incorporated into sprays, by organic farmers as a natural crop protection tool. The development of ECB resistance against Bt due to the commercialization of Bt maize, therefore, would be particularly dangerous for organic farmers.

Due to the 1998 EU moratorium against genetically modified crops, Bt maize is currently grown for commercial purposes (only for animal feed) in Spain. For this reason the EU funded project ECOGEN (Soil Ecological and Economic Evaluation of Genetically Modified Crops) carried out field trails in Narbons, France. The data from these trials are largely used in this study to derive an estimate of the maximum incremental social tolerable irreversible costs that would justify immediate adoption of Bt Maize in France.

Field trials were organized in 16 plots (20 meters by 12 meters), with four different crop management systems: Bt (MON 810) with Bt crop management; a Bt Isoline with Bt crop management; a Bt Isoline with conventional crop management; and a popular check variety with conventional crop management. Unfortunately one of the four plots with Bt maize was destroyed by protestors. Bt and conventional crop management differ in the application of insecticides to control for ECB: none for Bt maize, Lambda-cyhalothrine (100g/l, 0.15 liters per hectare) and Deltaméthrine (15 g/l, 1.33 liters per hectare).

3. The real option approach

The *real option approach* offers a decision criterion for releasing GMOs immediately. The *real option* decision criteria requires the maximum incremental social tolerable irreversible costs (I^*) to be no greater than the sum of incremental social irreversible benefits (R) and incremental social reversible benefits from GM crops (W^*), such as net-benefits accruing to farmers, weighted by a factor, so called hurdle rate, that depends on the uncertainty associated with the adoption of a new technology, ($\beta/(\beta-1)$):

$$I^* \leq \frac{W}{\beta/(\beta-1)} + R \qquad (1)$$

Since $[\beta/(\beta-1)] > 1$, the *real option* decision criteria is more restrictive than the *traditional* decision criteria:

$$I^* \leq W + R \qquad (2)$$

The use in practice of the *real option* decision criteria specified in (1) requires quantification of the following factors:

1. Incremental social reversible benefits from GM crops (W);
2. Hurdle rate, $\beta/(\beta-1)$.
3. Incremental social irreversible benefits, R;

To simplify the use of terminology, from now on we will call the maximum incremental social tolerable irreversible costs *MISTIC*, the incremental social irreversible benefits *SIIB*, the incremental social reversible benefits *SIRB* and the incremental private reversible benefits *PIRB.*

4. Quantifying maximum incremental social tolerable irreversible costs

The maximum incremental social tolerable irreversible costs, *MISTIC*, is the sum of incremental social irreversible benefits, *SIIB*, and incremental social reversible benefits, *SIRB*, weighted by the hurdle rate. *SIRB* are the sum of incremental private reversible benefits, *PIRB*, such as net-benefits accruing to farmers, and non-private reversible net-benefits such as the reduction of external damages to honeybees due to the use of less harmful pesticides.

To make our results comparable with those of existing studies, the value of *SIRB* over time will be given, in our case, by the present value of those benefits in '95 terms such that:

$$SIRB = SIRB_{95} = \int_0^\infty SIRB(t)e^{-\mu t}dt \tag{3}$$

where $\mu = 10.5$ is the capital asset pricing model (CAPM) risk adjusted rate of return (Demont, et al., 2004).

SIRB at time *t*, $SIRB(t)$, will be given by the maximum amount of social reversible net-benefits obtainable at time *t* at complete adoption, $SIRB_{MAX}(t)$, times the adoption rate at time *t*, $\theta(t)$, such that:

$$SIRB(t) = SIRB_{MAX}(t)\theta(t) \tag{4}$$

As we were not able to identify, based on the available literature, incremental non-private reversible benefits of Bt maize, in this paper the maximum incremental social reversible benefits obtainable at time *t* at complete adoption, $SIRB_{MAX}(t)$, and the present value of incremental social reversible benefits over time, *SIRB*, only entail incremental private reversible benefits, *PIRB*.

To quantify the maximum *PIRB* obtainable at time *t* at complete adoption, $PIRB_{MAX}(t)$, we adopt a partial equilibrium approach of the French market for maize.

Since France is member of the European Union (EU) the model is framed in the EU common agricultural policy. The EU common agricultural policy (CAP), provides a price support system for maize through a regime of levies and export subsidies. This price support system implies that the price paid by maize buyers, is lower than that received by maize sellers. We take this difference into consideration in our model by allowing the price received by maize sellers to differ from the price paid by maize buyers (Katranidis and Velentzas, 2000).

We rely on economic surplus analysis and model the market for maize through maize supply and demand functions. As suggested in existing literature, the maize supply functions is represented in constant elasticity log-linear form with parameters specific to the Bt technology and as Nerlovian type, i.e., a function of the price received by maize sellers in the previous period, the quantity of maize sold in the previous period and the price of substitute crops in the previous period (Moschini et al. 2000; Katranidis and Velentzas, 2000).

In an *ex-ante* analysis of potential social welfare impacts of Bt maize in France, the role of potential maize substitute crops should be taken into consideration. Following a discussion with experts of crop rotation systems in France we identified winter wheat as main substitute crop for maize. Thus, the price of wheat was included in the supply function.

As maize can be used for animal feed (fodder maize) as well as for human consumptions (grain maize), we consider two separate demand functions. The demand for maize for animal feed is modeled following Katranidis and Velentzas (2000) as a function of own price, the price of substitute animal feed components (e.g. fodder wheat) and the quantity produced of animal feed products (e.g. meat and milk). This function is represented in constant elasticity log-linear form (Moschini et al., 2000).

Torres Ledezma et al. (2004) analyze the demand for maize for human consumption with the commonly used almost ideal demand system (AIDS) proposed by Deaton and Muellbauer (1980). The authors analyze French consumer demands for 27 food and beverage products over the period 1985-

1999. Among their findings the authors notice that the AIDS model offers a poor econometric performance in the case of maize. Thus, we choose again to follow Moschini et al. (2000) and represent the demand for maize for human consumption in constant elasticity log-linear form, as a function of own price and the price of substitute goods: wheat and rice. Wheat, rice and maize account for the majority of calories in human diets (Faostat, 2004).

The resulting model follows. The aggregate French supply, excluding grain maize exports (about 8% of total maize production, there is no trade in fodder maize), of maize for animal feed (f) and human consumption (h), $Q^{s}_{f+h,t}$, is modeled as:

$$Q^{s}_{f+h,t} = f\left(P^{s}_{f+h,t-1}, W^{s}_{t-1}, Q^{*}_{f+h,t-1}, time\right) = \alpha^{s}_{f+h}\left[P^{s}_{f+h,t-1}\right]^{\varepsilon_{Pf+h}}\left[W^{s}_{t-1}\right]^{\varepsilon_{W}}\left[Q^{d}_{f,t-1}\right]^{\varepsilon_{Qf}}\left[Q^{d}_{h,t-1}\right]^{\varepsilon_{Qh}}\left[time\right]^{\varepsilon_{time}} \tag{5}$$

where $P^{s}_{f+h,t-1}$ is the producer (or output) price received by maize sellers in France at time *t-1*; W^{s}_{t-1} is the producer (or output) price received by wheat sellers in France at time *t-1*; $Q^{d}_{f,t-1}$ and $Q^{d}_{h,t-1}$ are the French demand for maize for feed and for human consumption at time *t-1* respectively; *time* is a time trend; ε indicates the supply elasticity with respect to the subscript variable; α is a technology specific constant term for the associated product and function.

The aggregate French demand for maize for animal feed, $Q^{d}_{f,t}$, is modeled as:

$$Q^{d}_{f,t} = g_{f}\left(P^{d}_{f,t}, W^{d}_{f,t}, B^{d}_{f,t}, Q^{meat}_{t}, Q^{milk}_{t}, time\right) =$$

$$= \alpha^{d}_{f}\left[P^{d}_{f,t}\right]^{\eta_{Pf}}\left[W^{d}_{f,t}\right]^{\eta_{W}}\left[B^{d}_{f,t}\right]^{\eta_{B}}\left[Q^{meat}_{t}\right]^{\eta_{Q^{meat}}}\left[Q^{milk}_{t}\right]^{\eta_{Q^{milk}}}\left[time\right]^{\eta_{f,time}} \tag{6}$$

where $P^{d}_{f,t}$ is the buyers' (or input) price paid for fodder maize in France at time *t*; $W^{d}_{f,t}$ is the buyers' (or input) price paid for fodder wheat in France at time *t*; $B^{d}_{f,t}$ is the buyers' (or input) price paid for barley in France at time *t*; Q^{meat}_{t} is the quantity of meat produced in France at time *t*; Q^{milk}_{t} is the quantity of milk produced in France at time *t*; η indicates the demand elasticity with respect to the subscript variable. Note that according to Eurostat (2004) and Faostat (2004) there is no trade for fodder maize in France.

The aggregate French demand for maize for human consumption, $Q^{d}_{h,t}$, is modeled as:

$$Q^{d}_{h,t} = g_{h}\left(P^{d}_{h,t}, W^{d}_{t}, R^{d}_{t}, time, E\right) = \alpha^{d}_{h}\left[P^{d}_{h,t}\right]^{\eta_{Ph}}\left[W^{d}_{h,t}\right]^{\eta_{W}}\left[R^{d}_{t}\right]^{\eta_{R}}\left[time\right]^{\eta_{h,time}}\left[E\right]^{\eta_{E}} \tag{7}$$

where $P^{d}_{h,t}$ is the market price for grain maize in France at time *t*; $W^{d}_{h,t}$ is the market price for wheat for human consumption in France at time *t* R^{d}_{t} is the market price for rice; *E* is the consumer expenditure for maize, wheat and rice.

The market clears with the following requirements:

$$Q^{d}_{f,t} + Q^{d}_{h,t} = Q^{s}_{f+h,t} - X_{h,t} + M_{h,t} \tag{8}$$

$$P^{d}_{f,t} = P^{s}_{f,t} + \tau_{f,t} \tag{9}$$

$$P_{h,t}^{d} = P_{h,t}^{s} + \tau_{h,t} \qquad (10)$$

where $X_{h,t}$ represents French exported quantities of grain maize at time *t*; $M_{h,t}$ represents French imported quantities of grain maize at time *t*; $\tau_{f,t}$ and $\tau_{h,t}$ represents the difference between the output and the input price of fodder maize and grain maize respectively, due to the CAP maize regime.

The adoption of a technological innovation, such as Bt maize, causes a pivotal shift in the supply and demand function by changing the value of the technology specific constant term, α . The change in the constant term $\Delta\alpha_{f+h}^{s}$ in the supply function will be given by:

$$\Delta\alpha_{f+h}^{s} = \theta(t)K \qquad (11)$$

with

$$K = \frac{[mc_c / y_c] - [mc_{Bt} / y_{Bt}]}{[mc_c / y_c]} \qquad (12)$$

where mc_c are variable operational costs (Euro per hectare) associated to the conventional technology; mc_{Bt} are variable operational costs (Euro per hectare) associated to the Bt technology; y_c is production (in metric tons) under conventional technology and y_{Bt} is production (in metric tons) under the Bt technology; $\theta(t)$ is the adoption rate.

The Bt maize adoption curve is assumed to follow a logistic pattern such that:

$$\theta(t) = \frac{\theta_{MAX}(t)}{\exp(-a-bt)} \qquad (13)$$

Equation (13) can be transformed as follows:

$$\ln\left(\frac{\theta(t)}{\theta_{MAX}(t) - \theta(t)}\right) = -a - bt \qquad (14)$$

The coefficients in Equation (14) can be estimated with ordinary least squares (OLS) using data from the adoption rates in the United States. Following Demont et al. (2004) the speed of adoption b will then be assumed half of that of the U.S. to obtain conservative estimates of the social reversible benefits.

Due to the CAP price support regime for maize we reasonably assume that the price received by maize sellers will not change after adopting the Bt technology. Figure 1 presents a graphical representation of the economic model used to derive private reversible benefits of transgenic maize in France. The details of the model are laid out in the appendix. In Figure 1 French demand for maize, *D*, intersects the supply curve of French maize for the French market before the introduction of Bt maize, *S*, at point b. Producers receive a direct subsidy per hectare maize illustrated by the parallel upward shift of the supply curve to S’. The difference between S and S’ at the horizontal axis indicates the amount of direct payment converted to a payment per unit of quantity produced before the introduction of Bt maize (in this study only the domestic market is considered). The introduction of Bt maize reduces the marginal production cost and results in a pivotal downward shift of the supply function *S* to S_g. The new quantity produced is the amount at equilibrium point *d*. The subsidy is indicated by the parallel shift from S_g to S'_g. The subsidy paid per unit of maize decreases as the yield of Bt maize increases. The consumer surplus of the introduction of Bt maize is the area $PbdP_g$, the producer surplus is the difference between $0P'_g cd$ and $0P'ab$ and the welfare gain the sum of the two.

The consumer surplus is the surplus that will be distributed over the whole supply chain. If final consumers will benefit due to lower prices will depend on the competitiveness of the downstream food processing and retailing sector. Therefore, the interpretation of the consumer surplus without considering a change in agriculture policies is as a surplus that remains within the agriculture sector. We apply this model to maize for animal feed as well as to maize for human consumption.

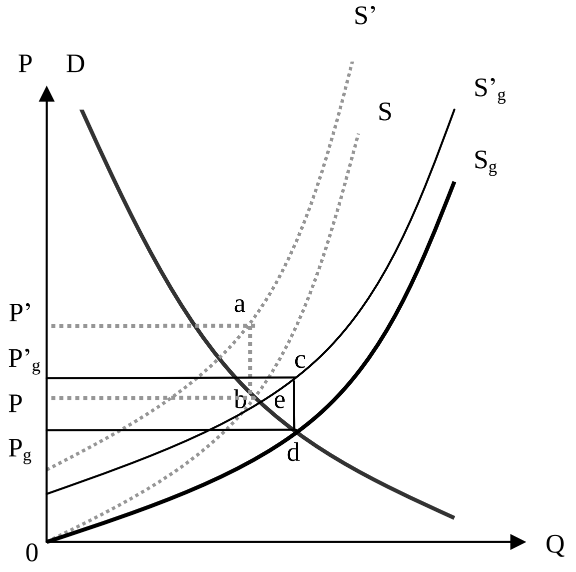

Figure 1: Partial equilibrium displacement model for maize in France

4.1 Data

The data used for this analysis comes from Eurostat New Cronos database and the FAOSTAT-Agriculture database (Eurostat, 2004; Faostat, 2004). From Eurostat (2004) we obtained data on produced quantities and values of production at basic prices and producer prices for maize, fodder maize, wheat and spelt, soft wheat and spelt, barley, and rice. From Eurostat (2004) we also obtained data on import and export quantities for soft wheat and spelt. From Faostat (2004) we obtained data on import quantities, import values, export quantities and export values for maize, wheat, barley and rice. From Faostat (2004) we also obtained produced quantities of milk and meat. All of the data obtained were French data.

Output prices received by maize and wheat sellers (i.e. including subsidies to agricultural producers) were obtained were obtained from the Eurostat Cronos database. Input prices paid by fodder maize and fodder wheat buyers (i.e. without subsidies to agricultural producers) were obtained from the Eurostat Cronos database. Domestic demand quantities for maize for human consumption, wheat for human consumption, rice and barley were calculated as the sum of produced quantities minus exports plus imports (data from Eurostat, 2004). Values of domestic demand for maize for human consumption, wheat for human consumption, rice and barley were calculated as the sum of the value of production at market prices (i.e. without subsidies to agricultural producers), minus the value of exports plus the value of imports. Demand prices (i.e. market prices) for maize for human consumption, wheat for human consumption, rice and barley were obtained by dividing the value of domestic demand by the associated demanded quantities (data from Faostat, 2004). Since FAOSTAT-agriculture data is given in U.S. dollars, the data were converted into Euro using the exchange rate given in the Eurostat New Cronos database. Data was deflated using the GDP deflator from Worldbank (2002), with 1995 base. In this respect all results presented in this study are based on the year 1995.[1]

Data for quantities is expressed in 100kg units. Data for prices are expressed in EURO per 100kg units. The database obtained refers to the time period 1973-1998. Data for estimating the Bt maize adoption curve was obtained from ISAAA(2004). Data for estimating the proportionate vertical supply shift, *K*, in the supply function was obtained from field trials the EU funded project in Narbone, France.

4.2 Empirical results

The log-linear form of Equations (5)-(7) was estimated using a two-stage procedure and an instrumental variable approach. In the first stage we considered endogeneity problems related to W^s_{t-1}, the producer (or output) price received by wheat sellers in France at time *t-1*; $Q^d_{f,t-1}$, the French demand for maize for animal feed at time *t-1*, and $Q^d_{h,t-1}$ the French demand for maize for human consumption at time *t-1*. To solve endogeneity problems related to W^s_{t-1} the best instrument revealed to be a simple time trend. The variable *time* therefore, disappears from the explanatory variables explicitly included in the supply function. Instead, the resulting predicted value, $\tilde{W}^s_{t-1}$ is used to estimate the supply function in 5. [2]

To avoid endogeneity problems related to $Q^d_{f,t-1}$, and $Q^d_{h,t-1}$ we obtained OLS estimate of the demand functions in Equations (6) and (7) and used the associated predicted values, $\tilde{Q}^d_{f,t-1}$ and $\tilde{Q}^d_{h,t-1}$ to estimate the supply function in Equation (5). First stage estimates of the demand functions in Equations (6) and (7) are presented below:

Table 1. Estimated demand function for maize for animal feed

Variable	Description	Estimated coefficient	t-statistic
$\ln \alpha^d_f$	Intercept	5.40	0.40
η_{Pf}	Own price elasticity	-0.20	-0.88
η_{Wf}	Cross price elasticity (wheat)	- 0.56***	-2.99
η_B	Cross price elasticity (barley)	0.23	0.79
$\eta_{Q^{meat}}$	Relationship with meat produced quantity	-0.22	-0.38
$\eta_{Q^{milk}}$	Relationship with milk produced quantity	0.99**	2.73
$\eta_{f,time}$	Relationship with time trend	0.02	1.30
R^2 :Goodness of fit		85.08	
Exact Durbin's h (P-value)		0.65	
Degrees of Freedom		18	

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[1] For welfare calculation we used data on prices and quantities in 1998, but prices are still expressed in 1995 Euro per 100 Kg. This makes our results comparable to those of exiting studies (Demont and Tollens, 2004; and Demont, Wesseler and Tollens, 2004)

[2] The time trend explains 98.54 percent of the variation in the producer (or output) price of wheat, W^s_{t-1}.

Table 2. Estimated demand function for maize for human consumption

Variable	Description	Estimated coefficient	t-statistic
$\ln\alpha_h^d$	Intercept	-4.05	-0.63
η_{Ph}	Own price elasticity	-0.55*	-2.04
η_{Wh}	Cross price elasticity (wheat)	- 0.05	0.15
η_R	Cross price elasticity (rice)	0.69*	2.02
η_E	Expenditure elasticity	0.86***	3.44
$\eta_{h,time}$	Relationship with time trend	-0.03*	1.82
R^2 :Goodness of fit			45.51
Exact Durbin's h (P-value)			0.26
Degrees of Freedom			18

In the second stage we estimated Equation (5). The results in log-linear form are reported in table 3:

Table 3. Estimated supply function for maize for human consumption and animal feed

Variable	Description	Estimated coefficient	t-statistic
$\ln\alpha_{f+h}^s$	Intercept	4.98	1.05
ε_{Ph+f}	Own price elasticity	0.32*	1.97
ε_W	Cross price elasticity (wheat)	- 0.35**	-2.55
ε_{Qf}	Relationship with produced quantity of maize for animal feed	0.57***	3.15
ε_{Qh}	Relationship with produced quantity of maize for human consumption	0.20	1.49
R^2 :Goodness of fit			72.57
Exact Durbin's h (P-value)			0.45
Degrees of Freedom			18

In tables 1-3 "*" means significant at the 90% level of confidence; "**" means significant at the 95% level of confidence and "***" means significant at the 99% level of confidence (because of the low number of degrees of freedom we consider here 90% level of confidence acceptable).

The econometric analysis above shows a supply elasticity for maize for human consumption and animal feed, ε_{Pf+h}, equal to 0.32. The demand elasticity for maize for animal feed, η_{Pf}, is not significantly different from zero. This might be due to the presence of a milk quota system in the EU fixing the demand for milk, the most important purchasing sector for maize for animal feed. The demand elasticity for maize for human consumption, η_{Ph}, is -0.55. These values are not far from those suggested by the European Simulation Model (ESIM), which suggests a value of -0.85 for the maize demand elasticity and 0.77 for the maize supply elasticity (see Banse et al., 2004).

From field trials (16 plots) carried out for the ECOGEN project in Narbons, France, in 2004 we obtained the following information about the percent shift in the supply function:

$$K = \frac{mc_c / y_c - mc_{Bt} / y_{Bt}}{mc_c / y_c} = \frac{729/11.37 - 727/12.4}{729/11.37} = 0.0852 \qquad (15)$$

Variable operational costs for conventional technology are calculated as average over the 8 plots managed with the conventional technology using conventional seeds. Costs for the Bt technology are taken as average over the 3 plots (1plot was destroyed by protestors) managed with the Bt technology. Variable operational costs are expressed in Euro per hectare. Yields are calculated in the same manner and expressed in tonnes per hectare.

An estimate of the adoption curve for Bt maize was obtained assuming an adoption rate ceiling of 30% as follows:

$$\ln\left(\frac{\theta(t)}{0.3-\theta(t)}\right) = 2.41 - 0.335t \tag{16}$$

were we considered half the speed of the U.S. adoption, for which the original estimated speed of adoption was $b_{US} = 0.67$.

Given the information in Tables 1-3 and equation (15) and (16) we computed private reversible net benefits of Bt-maize in France assuming no change in the consumer demand for maize for human consumption. Incremental private reversible benefits are presented in annuities, $SIRB_a$ (in million Euro) for maize for human consumption as:

$$\left[SIRB_a = \mu SIRB_{95} = \mu \int_0^\infty \Delta PS(t) + \Delta CS(t) e^{-\mu t} dt\right]_{Bt,h} = 1.16 \text{ million euro per year} \tag{17}$$

or about 83 Euro per hectare cultivated with Bt maize for human consumption.

Incremental private reversible benefits are presented in annuities, $SIRB_a$ (in million Euro) for maize for animal feed as:

$$\left[SIRB_a = \mu SIRB_{95} = \mu \int_0^\infty \Delta PS(t) + \Delta CS(t) e^{-\mu t} dt\right]_{Bt,f} = \text{-18.2 million euro per year} \tag{18}$$

or about -53 Euro per hectare cultivated with Bt maize for animal feed. Note that with ESIM values of supply and demand elasticity there would be a gain of 2.3 million euro for maize for human consumption and a gain of 32 million euro for maize for animal consumption. Thus, reliable estimates of reversible benefits largely depend on reliable estimate of supply and demand elasticities for maize.

Hurdle rates, $\beta/(\beta-1)$, are assumed to follow a geometric Brownian motion such that

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left[\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2r}{\sigma^2}} \tag{19}$$

where r is the riskless rate of return equal to 0.045; δ is the difference between mean annual rate of return, α , and the risk adjusted rate of return $\mu = 10.5$. In particular:

$$\alpha = mean_t\left[\ln\left(\frac{\pi_{i,t}/\pi_{i,t-1}}{\pi_{i,t+1}/\pi_{i,t}}\right)\right] \tag{20a}$$

where $\pi_{i,t}$ represents real farmer gross margins at time t, and

$$\sigma^2 = \left(stddev_t \left[\ln \left(\frac{\pi_{i,t} / \pi_{i,t-1}}{\pi_{i,t+1} / \pi_{i,t}} \right) \right] \right)^2 \qquad (20b)$$

Hurdle rates were computed using time series data on farmer gross-margins from 1973 to 1998, from the EU-Spell dataset:

$$\frac{\beta}{\beta - 1} = 1.70 \qquad (21)$$

This means that total social reversible net-benefits need to be at least 1.70 times higher than total social irreversible net-costs to justify immediate adoption of Bt maize.

Incremental social irreversible social benefits under a 100% adoption , $SIIB_{MAX,i}$, depend on changes in pesticide use and fuel use. The total amount of irreversible social benefits in region i is given by the net 95 present value of $SIIB_{MAX,i}$ times the adoption rate:

$$SIIB = SIIB_{95} = \int_0^\infty SIIB(t) e^{-\mu t} dt \qquad (22)$$

where

$$SIIB(t) = SIIB_{MAX} \frac{\theta_{MAX}(t)}{1 + \exp\left(-a_\theta - b_\theta t\right)} \qquad (23)$$

and

$$SIIB_{MAX} = \omega \Delta A + \chi \Delta n \; Dc \qquad (24)$$

where

ΔA = changes in volume of active ingredient under 100% adoption = 0.186 kg active ingredient per tonne;
ω = social benefits per volume (reduction) of active ingredient = 0.69 Euro per kg active ingredient;
Δn = change in the number of insecticide/herbicide applications;
D = fuel use per application (No information available from field trials);
c = kg of CO2 emission coefficient per liter of diesel = 3.56 kg/l;
χ = external costs per tonne CO2 emissions = 77.4 Euro/Tonne;

(see Pretty et al. 2000)

We computed the present value, in annuities of incremental social irreversible benefit, *SIIB*, based on information on pesticide use from the ECOGEN field trials in Narbons, France. We found *SIIB* for 17.5 thousand euro per year for maize for animal feed and 710 Euro for maize for human consumption (i.e. 2.5 Euro per hectare grown at Bt maize). The extremely low figure for maize for human consumption is due to the limited amount of hectares grown at maize for human consumption in France (only 20% of the total maize cultivated area). *SIIB* values do not depend on the values of demand and supply elasticities.

The maximum incremental social tolerable irreversible costs, *MISTIC*, are given, in annuities, by -27.62 million Euro for maize for animal feed (about -58 Euro per hectare) and 0.37 million Euro per hectare (60 Euro per hectare grown at Bt maize - this figure is higher than that for maize for animal feed due to the fact that the price for maize for human consumption is higher than the price for maize for animal feed. The total is instead lower due to the low number of hectares grown at maize for human consumption.) These figures increase when ESIM elasticities are used (see table 1). The distribution of benefits among consumers and producers largely depend on the elasticity of demand. It can be shown that if the demand is elastic (demand elasticity is greater than 1) the loss in producer surplus shown in table 1 for maize for animal feed becomes a gain. In tables 1 consumer surplus is to be interpreted as a surplus within the agricultural sector.

Table 4. Hurdle rates, annual social incremental reversible net benefits ($SIRB_a$), social incremental irreversible benefits ($SIIB_a$), and maximum incremental social tolerable irreversible costs ($MISTIC_a$) per hectare of Bt-maize, per household and per maize growing farmer.

Member State: France	$SIRB_a$ (€/ha)	$SIIB_a$ (€/ha)	Hurdle Rate	$MISTIC_a$ (€/ha)	$MISTIC_a$ (Mio. €)	$MISTIC_a$ (€/household)	$MISTIC_a$ (€/farmer)
Maize for animal feed *Supply elasticity 0.32* *Demand elasticity 0*	-53	2.50	1.70	-58	-27.62	-1.21	-202
Maize for animal feed (ESIM) *Supply elasticity 0.77* *Demand elasticity -0.85*	92	2.50	1.70	71	13.19	0.58	96
Maize for human consumption *Supply elasticity 0.32* *Demand elasticity -0.55*	83	2.50	1.70	60	0.37	0.02	3
Maize for human consumption *Supply elasticity 0.77* *Demand elasticity -0.85*	170	2.50	1.70	129	1.00	0.04	7

5 Conclusion

In this study we estimated the maximum incremental social tolerable irreversible costs, *MISTIC*, associated with the immediate adoption of Bt maize in France using a real option approach and data from field trials carried out in 2004 in Narbons, France. The *MISTIC* were derived as the amount that would cover incremental social irreversible benefits from Bt maize and incremental social reversible private benefits weighted by an estimated hurdle rate. Incremental private reversible benefits accruing to producers and consumers (buyers) within the agricultural sector were found, according to our own demand and supply elasticity estimates, to be about -18.2 million per year (-53 Euro per hectare grown at Bt maize) for maize for animal feed and about 1.16 million euro per year (83 Euro per hectare grown at Bt maize) for maize for human consumption.

The hurdle rate was estimated at 1.70, meaning that incremental private reversible benefits need to be at least 1.7 times higher than incremental social irreversible costs to justify immediate adoption of Bt maize in France. This hurdle rate is slightly higher than that found in Demont et al. (2004) for sugar beet (1.25).

Incremental social irreversible benefits from reduced insecticide use also have to be taken into account and were found to be very low and about 17.5 thousand euro per year for maize for animal feed and only 710 euro per year for maize for human consumption (about 2.5 Euro per hectare grown at Bt maize).

As a result the *MISTIC* was found to be -27.62 million Euro per year for maize for animal feed (-58 Euro per hectare grown at Bt maize) and 0.37 thousand euro per year for maize for human consumption (60 Euro per hectare grown at Bt maize). It should be noticed that if we divide the *MISTIC* for maize for human consumption by the number of households in France we obtain 2 cents per household per year for maize for animal feed. The same *MISTIC* divided by the number of farmers in France gives 3 Euro per farmer, showing that farmers may be willing to bear higher *MISTIC* than households would. Furthermore, the low *MISTIC* per household for maize for human consumption and the negative *MISTIC* for maize for animal feed provide a strong economic argument for prohibiting the immediate introduction of Bt maize in France. The validity of the argument largely depends on consumer attitudes towards transgenic crops. Consumer attitudes may change over time, e.g. if scientific evidence shows higher environmental benefits or lower irreversible costs of transgenic crops.

We conclude by reminding the reader that reliable estimates of the size and distribution of benefits from Bt maize in France largely depend, in this methodological approach, on reliable estimates of maize demand and supply elasticities. The comparison carried out in this study between our estimates and estimates used in ESIM show that further research is needed to identify a reliable range of variation for these parameters. Future work is also needed to extend the geographical scope of this analysis.

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Appendix

Specification of the partial equilibrium model for maize

Given $Q^s_{f+h,t} = \alpha^s_{f+h,t}\left[P^s_{f+h}\right]^{\varepsilon_{Pf+h}}\left[W^s\right]^{\varepsilon_W}\left[Q^d_f\right]^{\varepsilon_{Qf}}\left[Q^d_h\right]^{\varepsilon_{Qh}}\left[time\right]^{\varepsilon_{time}} = A^s_t\left[P^s_{f+h}\right]^{\varepsilon_{Pf+h}}$

Due to lack of data to perform a disaggregated analysis for the supply curve, we assume that the parameters of the estimated aggregate supply function apply also to the disaggregated supply function for maize for animal feed (f) and maize for human consumption (h) such that $Q^s_{f,t} = A^s_t\left[P^s_{f,t}\right]^{\varepsilon_{Pf+h}}$ and $Q^s_{h,t} = A^s_t\left[P^s_{h,t}\right]^{\varepsilon_{Pf+h}}$. Below we derive consumer and producer surplus measures for fodder maize (f). The economic surplus measures for maize for human consumption (h) can be derived analogously.

Country *j*'s supply of maize for animal feed (f), $Q^s_{i,t}$, is given below:

$$Q^s_{f,t} = A^s_{f,t}\left[P^s_{f,t}\right]^{\varepsilon_{Pf+h}} \tag{A1}$$

where the subscript *j* is dropped for ease of notation; $P^s_{f,t}$ is the producer (or output) price received by maize sellers at time *t*; $A^s_{f,t}$ is a technology specific constant term for the associated product and function.

The aggregate demand for fodder maize, $Q^d_{f,t}$, is modeled as a constant elasticity function of fodder maize price,

$$Q^d_{f,t} = A^d_{f,t}\left[P^d_{f,t}\right]^{\eta_{Pf}} \tag{A2}$$

where $P^d_{f,t}$ is the buyers' (or input) price paid for maize at time *t*; and $A^d_{f,t}$ is a parameter capturing qualitative aspects of the product such as the type of technology used in its production process.

The market clears with the following requirements:

$$Q^d_{f,t} = Q^s_{f,t} \tag{A3}$$

$$P^d_{f,t}\left[1+\tau_{f,t}\right] = P^s_{f,t} \tag{A4}$$

where $\tau_{f,t} = \left[P^s_{f,t} - P^d_{f,t}\right] \Big/ P^d_{f,t}$ represents the proportional CAP price support coefficient identifying the relative difference between the output and the input price of maize due to the CAP maize price support regime.

Based on Eurostat data on the value of production calculated at the seller's price and the value of production calculated at the buyer's price, we observe that the variation in support received by maize sellers per unit of the product does not vary with the quantity produced. The price support system, therefore, reduces marginal production costs for maize sellers causing a parallel downwards shift in the supply function.

At any time period the equilibrium price, $P^*_{f,t}$ and quantities, $Q^*_{f,t}$, are given by:

$$\begin{cases} P^{s*}_{f,t} = P^{d*}_{f,t}\left[1+\tau_{f,t}\right] \\ P^{d*}_{f,t} = \left[\dfrac{A^{d}_{f,t}}{A^{s}_{f,t}}\right]^{\frac{1}{\varepsilon_{Pf+h}-\eta_{Pf}}} \left[\dfrac{1}{1+\tau_{f,t}}\right]^{\varepsilon_{Pf+h}} \\ Q^{*}_{f,t} = \left[A^{d}_{f,t}\right] \left[\dfrac{A^{d}_{f,t}}{A^{s}_{f,t}}\right]^{\frac{\eta_{Pf}}{\varepsilon_{Pf+h}-\eta_{Pf}}} \left[\dfrac{1}{1+\tau_{f,t}}\right]^{\eta_{Pf}\varepsilon_{Pf+h}} \end{cases} \tag{A5}$$

Producer surplus, $PS_{f,t}$, at the equilibrium conditions in (A5) is given by:

$$PS_{f,t} = P^{d*}_{f,t}\left[1+\tau_{f,t}\right]Q^{*}_{f,t} - \int_{0}^{Q^{*}_{f,t}} \left[\frac{Q^{s}_{f,t}}{A^{s}_{f,t}}\right]^{\frac{1}{\varepsilon_{Pf+h}}} \frac{1}{\left[1+\tau_{f,t}\right]} dQ^{s}_{f,t} = P^{s*}_{f,t}Q^{*}_{f,t} - P^{d*}_{f,t}Q^{*}_{f,t}\ \frac{\varepsilon_{Pf+h}}{\varepsilon_{Pf+h}+1} \tag{A6}$$

Consumer surplus, $CS_{f,t}$, at the equilibrium conditions in (9) is given by:

$$CS_{f,t} = \int_{P^{d*}_{f,t}}^{\infty} A^{d}_{f,t}\left[P^{d}_{f,t}\right]^{\eta_{Pf}} dP^{d}_{f,t} \tag{A7}$$

Following Moschini, Lapan, and Sobolevsky we assume that the adoption of a technological innovation, such as transgenic maize, causes a pivotal shift in the inverse supply function by changing the value of the technology specific constant term, α. The proportional vertical shift in the inverse supply function, *f* and *t* will be given by:

$$\frac{\left[\dfrac{1}{A^{s}_{0}}\right]^{1/\varepsilon_{Pf+h}} - \left[\dfrac{1}{A^{s}_{1}}\right]^{1/\varepsilon_{Pf+h}}}{\left[\dfrac{1}{A^{s}_{0}}\right]^{1/\varepsilon_{Pf+h}}} = \theta(t)K \tag{A8}$$

where subscripts *f* and *t* are dropped to simplify notation; $\theta\ (t)$ is the transgenic maize adoption rate over time, *t*; A^{s}_{0} is the direct supply function constant coefficient with conventional technology; A^{s}_{1} is the direct supply function constant coefficient with transgenic technology and

$$K = \frac{\left[mc_c / y_c\right] - \left[mc_g / y_g\right]}{\left[mc_c / y_c\right]} \tag{A9}$$

where mc_c are variable operating costs (Euro per hectare) associated with the conventional technology; mc_g are variable operational 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 Bt technology.

Given Equations (A5) to (A7) we can compute changes in the equilibrium price and quantities due to adoption of transgenic maize as a function of the vertical shift in the inverse supply function and the CAP price support coefficient:

$$\begin{cases} \Delta P^{s*} = \Delta P^{d*} * \left[1+\tau\ \right] \\ \Delta P^{d*} = P_1^{d*} - P_0^{d*} = \left[\left[1-\theta(t)K\right]^{\frac{\varepsilon_{Pf+h}}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] P_0^* \\ \Delta Q* = Q_1^* - Q_0^* = \left[\left[1-\theta(t)K\right]^{-\frac{\varepsilon_{Pf+h}\eta_{Pf}}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] Q_0^* \end{cases} \tag{A10}$$

In Equation (A10) the subscripts *f* and *t* are dropped again to simplify notation.
The change in producer surplus is given by:

$$\Delta PS = PS_1 - PS_0 = \left[\tau + 1 - \frac{\varepsilon_{Pf+h}}{\varepsilon_{Pf+h}+1} \right] \left[\left[1-\theta(t)K\right]^{\frac{\varepsilon_{Pf+h}\left[1+\eta_{Pf}\right]}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] Q_0^* P_0^{d*} \tag{A11}$$

The total change in producer surplus can be decomposed in two parts: the change in producer surplus accruing from the government due to the price support system, ΔPS^{gov}; and the change in producer surplus accruing from the market:

$$\Delta PS^{gov} = PS_1^{gov} - PS_0^{gov} = \tau \left[P_1^{d*} Q_1^* - P_0^{d*} Q_0^* \right] = \tau \left[\left[1-\theta(t)K\right]^{\frac{\varepsilon_{Pf+h}\left[1+\eta_{Pf}\right]}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] Q_0^* P_0^{d*} \tag{A11.a}$$

and

$$\Delta PS^{mkt} = PS_1^{mkt} - PS_0^{mkt} = \Delta PS\ \ - \Delta PS^{gov} = \left[1 - \frac{\varepsilon_{Pf+h}}{\varepsilon_{Pf+h}+1} \right] \left[\left[1-\theta(t)K\right]^{\frac{\varepsilon_{Pf+h}\left[1+\eta_{Pf}\right]}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] Q_0^* P_0^{d*} \tag{A11.b}$$

Assuming that the introduction of transgenic maize does not cause shifts in the demand function, the consumer surplus changes as follows:

$$\begin{aligned} \Delta CS = CS_1 - CS_0 &= \left[P_0^{d*} - P_1^{d*} \right] Q_0^* + \int_{Q_0^*}^{Q_1^*} \left[\frac{Q^d}{A^d} \right]^{\frac{1}{\eta_{Pf}}} dQ^d = \\ &= \left[\left[1-\theta(t)K\right]^{\frac{\varepsilon_{Pf+h}\left[1+\eta_{Pf}\right]}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] P_0^{d*} Q_0^* \frac{\eta_{Pf}}{\eta_{Pf}+1} - \left[\left[1-\theta(t)K\right]^{\frac{\varepsilon_{Pf+h}}{\varepsilon_{Pf+h}-\eta_{Pf}}} - 1 \right] P_0^{d*} Q_0^* \end{aligned} \tag{A12}$$