Multi-Attribute Modelling of Economic and Ecological Impacts of Agricultural Innovations on Cropping Systems

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ABSTRACT

Modeling of economic and ecological impacts of genetically modified crops is a demanding task. We present some models made for the purpose of the ECOGEN project “Soil ecological and economic evaluation of genetically modified crops”. One of the goals of the project is to develop a computer-based decision support system for the assessment of economic and ecological impacts of using genetically modified crops, with special emphasis on soil biology and ecology. The decision support system is based on a rule-based model incorporating both economic and ecological criteria. In this paper we present an extension to previous results specifying further two sub-models assessing economic impacts of cropping systems at farm and regional level. Following a real option approach we show how both social and private costs and benefits, both at farm and regional level, can be classified in reversible and irreversible, and what irreversibility means for the size of the uncertainty associated to the adoption of agricultural innovations. All the qualitative models are developed using a qualitative multi-attribute modeling methodology, supported by the software tool DEXi.

Keywords: Bt Corn, real option approach, multi-attribute modeling, field trials, irreversibility and uncertainty
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 reversible private net-benefits from GM crops, such as net-benefits accruing to farmers, to be greater than irreversible social net-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.

Hurdle rates associated to GM crops can be quantified by assuming that additional private net-benefits from transgenic crops follow a geometric Brownian process [5]. 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 reversible social net-benefits to be greater than irreversible social net-costs. The traditional decision criteria for releasing GM crops immediately, requires, instead, reversible private net-benefits to be at least equal to irreversible social net-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 [5]. The authors conclude that such moratorium would be justified if transgenic sugar beet caused annual irreversible social costs above 121 Euro per hectare planted. This means that the maximum tolerable amount of irreversible social net costs for Ht-sugar beet amounts to 103 Million Euro per year. Incremental private net-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 apply a real option approach to quantify the value of the option of delaying the adoption of Bt fodder corn in France and to show how this quantitative analysis can be integrated by a qualitative analysis of ecological impacts of Bt corn based on a multi-attribute modelling methodology, supported by the software tool DEXi.

In section 2 we present some background information on Bt corn in France and description of field trials carried out in Narbone, France. This data is largely used in the quantitative analysis. In section 3 we quantify the value of the option of quantitative analysis with a qualitative analysis based on multi-attribute modelling. Section 5 summarizes our findings.

2. BACKGROUND

Corn is grown in France mainly for animal feed (80%), but also for human consumption (20%). Corn for human consumption is used to produce corn oil, starch and sweeteners which are common ingredient in many processed foods such as breakfast cereals and dairy goods, and only a small amount is used for direct consumption [6], [7].

France produces about 1.2% of world corn, and 40% of the total EU-15 corn production. France is a net exporter of corn for human consumption, exporting 45% of its production mainly to other EU-15 member states [11].

*Bacillus thuringiensis (*Bt) corn has been currently approved in the EU only for animal feed and it is currently not grown in France. In the EU Bt corn is grown only in Spain with an adoption rate of about 17.5% (0.1 million hectares), and in Germany (less than 0.05 million hectares) [13]. Bt corn is corn that has been genetically engineered to contain a gene of the soil bacterium *Bacillus thuringiensis (*Bt). This bacterium produces a crystal-like (Cry) proteins that is toxic to the European Corn Borer (ECB- *Ostrinia nubilalis*). In France, especially in the southern area, the ECB is considered one of the most severe corn pests. The ECB can cause severe damage to corn 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 its larval status but it has not yet penetrated the stalk, or is migrating to neighbouring plants. Bt corn is expected to benefit farmers through reduced harvest losses due to ECB infestation. Bt corn is also expected to benefit the environment through reduced insecticide use. At the same time, due to higher costs for Bt-seeds, it is not undisputed that the associated yield improvements will also translate in increased farmer income. The development of ECB resistance against Bt due to the commercialization of Bt corn, furthermore, is particularly dangerous for organic farmers who currently use this bacterium, incorporated into sprays, as a natural crop protection tool [4].

In 2004, for the EU funded project ECOGEN (Soil Ecological and Economic Evaluation of Genetically Modified Crops) field trails were carried out in Narbone, France, to test for costs and benefits of Bt corn on European soil. ECOGEN 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 corn was destroyed by protestors. Bt and conventional crop management differ in the application of insecticides to control for ECB: none for Bt corn, 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* considers all elements of a traditional cost benefit analysis plus temporal flexibility, i.e., the value of the option to delay adoption of Bt corn. The value of this option is particularly important in investment decision characterized by irreversible (sunk) costs and an uncertain flow of future benefits. This option value is given by the difference between total irreversible social costs (*I*) and the sum of irreversible benefits (*R*), such as benefits from reduced pesticide use, and reversible social net-benefits (*W*), such as benefits accruing to farmers, weighted by the size of the uncertainty associated to the adoption of a new technology (or hurdle rate: $\beta/(\beta-1)$). If the value of this option is positive, than the EU should delay adoption of Bt corn until more information is gathered to reduce the uncertainty associated to the new technology. When social irreversible costs cannot be quantified, the real option approach allows researchers to identify at least the maximum incremental social tolerable irreversible costs (MISTICs), *I**, that would justify immediate adoption of Bt corn in France. This amount is to be no greater than the sum of irreversible social benefits and reversible social net-benefits from GM crops weighted by the hurdle rate such that:

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

Since hurdle rates are, by definition, greater than one, the *real option* decision criteria is more restrictive than the *traditional* decision criteria:

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

In the case of transgenic crops net benefits from transgenic crops, reversible and irreversible will depend on the rate of adoption of this new technology, θ , and as these net benefits will accrue to society over an infinite (irreversible net benefits) or finite (reversible net-benefits), future values will have to be discounted to present values using a risk-adjusted discount rate such that:

$$W = W_{04} = \int_0^{\infty} W_{\max}(t)\theta(t)e^{-\mu t}dt \qquad (3)$$

and

$$R = R_{04} = \int_0^{\infty} R_{\max}(t)\theta(t)e^{-\mu t}dt \qquad (4)$$

where the subscript “max” indicates values at complete adoption and *t* represents time.
Thus, the use in practice of the *real option* decision criteria specified in (1) requires quantification of the following factors:

1. Adoption rates, θ , and risk-adjusted discount rates, μ ;
2. Reversible social net-benefits from Bt corn, *W*;

3. Irreversible social benefits from Bt corn, *R*;
4. Hurdle rate, $\beta / (\beta - 1)$.

These four steps are described and quantified for the case of Bt corn in France in the following section.

4. THE MAXIMUM INCREMENTAL SOCIAL TOLERABLE IRREVERSIBLE COSTS (MISTIC)

The maximum amount of tolerable irreversible social costs (MISTICs) is the sum of social irreversible benefits, and social reversible net-benefits weighted by the hurdle rate. Social reversible net-benefits are the sum of private reversible net-benefits, 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. In the following paragraphs we show how these concepts can be quantified.

Adoption rates and risk-adjusted discount rates

The transgenic corn adoption curve is assumed to follow a logistic pattern over time such that:

$$\theta(t) = \frac{\theta_{MAX}(t)}{\exp(-a - bt)} \qquad (5)$$

where $\theta(t)$ represents corn adoption rate at time *t*.

Eq. (13) can be transformed as follows:

$$\ln\left(\frac{\theta(t)}{\theta_{MAX}(t) - \theta(t)}\right) = -a - bt \qquad (6)$$

The coefficients in Eq. (6) can be estimated with ordinary least squares (OLS) using data from Bt corn adoption rates in the United States (James, 2004). To obtain conservative estimates of the social reversible benefits) the speed of adoption, *b*, will be assumed half of that of the U.S. [5].

Assuming an adoption ceiling of 30% for Bt corn we obtained the following adoption curve:

$$\ln\left(\frac{\theta(t)}{0.3 - \theta(t)}\right) = 2.41 - 0.335t \qquad (7)$$

The risk adjusted discount rate is instead taken from Demont et al. (2004) to be equal to 10.5%.

Reversible social net-benefits from Bt corn

Due to data availability, reversible social net-benefits in this study include only private 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. This is common use in the analysis of welfare impacts of transgenic crops [14], [20], [23], [9], [10], [19], [12], [21], [22], [4], [5].

Our model is framed to recognize the presence of the price support system for corn provided, through a regime of levies and export subsidies, by the European Common Agricultural Policy (CAP). This price support system implies that the price paid by corn buyers, is lower than that received by corn sellers. We allow our model to take this difference into consideration.

Reversible private net-benefits are measured in terms of producer and consumer surplus derived from constant elasticity log-linear demand and supply functions [17]. The French supply function for grain corn, Q^s, is given below:

$$Q^s = A^s \left[P^s\right]^{\varepsilon} \qquad (8)$$

where P^s is the producer (or output) price received by corn sellers; A^s is a technology specific constant term for the associated product and function; ε is the supply elasticity.

The aggregate demand for grain corn, Q^d, is modeled as linear and parallel to the horizontal axes such that the demand elasticity tends to infinity and

$$P^d = P^w \qquad (9)$$

where P^d is the buyers' price paid for grain corn; and P^w is the world price for grain corn.

The market clears with the following requirements:

$$Q^d = Q^s \qquad (10)$$

and

$$P^d\left[1+\tau\right] = P^w\left[1+\tau\right] = P^s \text{ with } \tau = \left[P^s - P^d\right] / P^d \qquad (11)$$

where τ represents the proportional CAP price support coefficient identifying the relative difference between the output and the input price of corn due to the CAP corn price support regime.

(24b)

By using 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 corn sellers per unit of the product does not vary with the quantity produced. The price support system, therefore, reduces marginal production costs for corn sellers causing a parallel downwards shift in the supply function [7].

At any time period the equilibrium sellers' price, P^{s*}, the equilibrium buyers' price, P^{d*}, and equilibrium quantities, Q^*, are given by:

$$P^{s*} = P^{d*}\left[1+\tau\right] \qquad (12)$$

$$P^{d*} = P^{W*} \qquad (13)$$

$$Q^* = A^s\left[P^{s*}\right]^{\varepsilon} \qquad (14)$$

Producer surplus, *PS*, at the equilibrium conditions in Eq. (12) to Eq. (14) is given by:

$$PS = P^{s*}Q^* - P^{d*}Q^* \; \frac{\varepsilon}{\varepsilon + 1} \qquad (15)$$

With a perfectly elastic demand curve the consumer surplus is zero.

We assume that the adoption of a technological innovation, such as Bt corn, causes a pivotal shift in the inverse supply function, changing the value of the technology specific constant term, A^s. The proportional vertical shift in the inverse supply function is the proportional change in the intercept of the inverse supply function [17]. We then note that the vertical proportional shift in the supply function with partial adoption of Bt corn can be written as:

$$\theta(t)K = -\frac{\left[\frac{1}{A_g^s}\right]^{1/\varepsilon} - \left[\frac{1}{A_c^s}\right]^{1/\varepsilon}}{\left[\frac{1}{A_c^s}\right]^{1/\varepsilon}} \tag{16}$$

where K is the vertical proportional shift in the supply function under 100% adoption of Bt corn; the subscript *g* indicates variables associated to Bt corn and the subscript *c* indicates variables associated to conventional corn.

Given Eq. (8) and the fact that in a perfectly competitive market, sellers will set their price equal to marginal costs of production, we can write the K-shift as:

$$K = -\frac{\frac{MC}{y_g^{\;1/\varepsilon}} - \frac{MC}{y_c^{\;1/\varepsilon}}}{\frac{MC}{y_c^{\;1/\varepsilon}}} \tag{17}$$

We aassume that all costs that are relevant to the comparison of Bt corn to conventional corn are variable [5]. In particular we assume that the all relevant costs in the cost function are variable. Under this assumption the marginal costs of production are given by

$$MC = \frac{\partial C}{\partial Q^s} = z = \frac{C}{Q^s} \tag{18}$$

where *Q* is the quantity produced and *z* the variable costs per unit of production We then express marginal costs can per unit of land such that

$$MC = \frac{C/L}{Q/L} = \frac{VC}{y} \tag{19}$$

where *L* represents the amount of land used to produce the quantity *Q*.
Given Eq. (19) and assuming the total amount of land used for corn production does not change after release of Bt corn, we can rewrite the partial adoption K-shift as:

$$\theta(t)K = -\theta(t)\frac{\frac{VC_g}{y_g}\frac{1}{\left[y_g\right]^{1/\varepsilon}} - \frac{VC_c}{y_c}\frac{1}{\left[y_c\right]^{1/\varepsilon}}}{\frac{VC_c}{y_c}\frac{1}{\left[y_c\right]^{1/\varepsilon}}} \tag{20}$$

where the variable *y* represents production per hectare (in metric tons).

Note that if there is no yield gain from planting the transgenic crop, the K-shift in the supply function reduces to

$$K = \left[VC_c - VC_g\right]/VC_c\,. \tag{21}$$

Given Eq. (15) and (20) we can compute changes in the equilibrium price and quantities due to adoption of transgenic corn as a function of the vertical shift in the inverse supply function and the CAP price support coefficient:

$$\Delta P^{s*} = 0 \tag{22}$$

$$\Delta P^{d*} = 0 \tag{23}$$

$$\Delta Q* = \left[\left[1-\theta(t)K\right]^{-\varepsilon} - 1\right]Q_0^* \tag{24}$$

where Δ represents changes in the associated variable after the release of Bt corn.

The change in producer surplus is then given by:

$$\Delta PS = \left[\tau + 1 - \frac{\varepsilon}{\varepsilon + 1}\right]\left[\left[1-\theta(t)K\right]^{-\varepsilon} - 1\right]P^W Q_0^* \tag{25}$$

The change in consumer surplus is zero.

The sum of changes in producer and consumer surplus gives us the reversible private net-benefits from an immediate release of Bt corn. For any time period *t* this means:

$$W(t) = \Delta PS(t) + \Delta CS(t) \tag{26}$$

We project these changes over an infinite time horizon and express the resulting risk adjusted discounted value in terms of annuities such that:

$$W = W_{04} = \int_0^\infty W\,(t)e^{-\mu t}dt \tag{27}$$

for which values will be expressed in 2004 million Euro per year.

To quantify social private net-benefits as in Eq. 27, the supply elasticity was taken from the European Simulation Model (ESIM) where it is derived from behavioural equations. The suggested elasticity of land allocation to corn was 0.77, so we approximated supply elasticity to this value in our base case [2]. Considering France a small open economy with respect to corn for grain implies a perfectly elastic demand function. The risk adjusted discount rate is taken from the literature to be μ = 0.105 [5].

Data on buyers' price, sellers' price, marketed quantity, and number of hectares planted at corn in France in 2004 were taken from Eurostat New Cronos database [7]. Data on yields and cost advantages taken from field trials carried out for the European Union (EU) funded project ECOGEN that studies soil ecological and economic impacts of transgenic crops in the EU. The field trials were carried out in 2004 in Narbons, in the southern of France. Sixteen plots were used to compare the isogenic variety of MON810 and the commercial variety (Paolis) with the Bt variety MON810.

Based on the above data and estimated adoption curve we found that Bt corn would yield in France private net-reversible benefits for 62 million Euro per year. This amount corresponds to 204 Euro per hectare.

Irreversible social net-benefits from Bt corn

Irreversible social net-benefits from Bt corn, *R*, depend on changes in pesticide use and fuel use as well as the adoption rate of Bt corn, such that at any point in time *t* we have:

$$R(t) = \left[\omega \Delta Pest \;\; + \chi \Delta n \;\, De\right] \theta(t) L \tag{28}$$

where $\Delta Pest$ represents changes in volume of active ingredient per adopted hectare; ω indicates social benefits per volume (reduction) of active ingredient; Δn is the change in the number of pesticide applications; D represents fuel use per hectare application; *e* represents tons of CO^2 emission coefficient per litre of fuel; χ indicates external costs per ton CO^2 emissions.

Again we project these changes over an infinite time horizon and express the resulting risk adjusted discounted value in terms of annuities such that:

$$R = R_{04} = \int_0^\infty R(t) e^{-\mu t} dt \tag{29}$$

for which values will be expressed in 2004 million Euro per year.

To quantify social irreversible net-benefits ECOGEN field trials data were used to find out changes in pesticide use and the number of pesticide applications. Narbons field trials suggest a reduction of 0.035 kilogram Active Ingredient (kgAI) insecticide use per hectare and a reduction of 2 applications. Changes in fuel use per application were derived from a comparative technology (soybean), which suggests a reduction of 0.01 tonnes of CO^2 emissions per hectare and application. [5]. Based on secondary literature we considered 0.69 Euro of social irreversible benefits per kgAI reduction and 77.4 Euro of social irreversible benefits per tonnes of CO^2 emissions (1995 values, the real value in 2004 were 0.62 Euro and 70 Euro respectively) [5]. These values give irreversible net-benefits from Bt corn equal to 0.24 million Euro per year or 0.81 Euro per hectare. All values are in 2004 Euro.

The hurdle rate

Benefits from normal technological change in agriculture, from which hurdle rates are derived, are assumed to follow a geometric Brownian motion such that

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left[\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2r}{\sigma^2}} \tag{30}$$

where *r* is the risk free interest rate of return; δ is the difference between mean annual rate of return α, and the risk adjusted rate of return μ. In particular:

$$\alpha = mean_t \left[\ln\left(\frac{\pi_{i,t} / \pi_{i,t-1}}{\pi_{i,t+1} / \pi_{i,t}} \right) \right] \tag{31}$$

where $\pi_{i,t}$ represents real farmer value of production at time t, and

$$\sigma^2 = \left(stddev_t \left[\ln\left(\frac{\pi_{i,t} / \pi_{i,t-1}}{\pi_{i,t+1} / \pi_{i,t}} \right) \right] \right)^2 \tag{32}$$

To quantify hurdle rates for Bt corn in France we used the EUROZONE 3-month EURIBOR (EURo InterBank Offered Rate) [7]. For the year 2004, this interest rate was equal to 0.21.The parameters α and σ^2 were computed on the basis of time series data on the value of corn production in France from 1973 to 2004 from the Eurostat New Cronos Database (see Eurostat 2005). The parameter μ was taken from the literature equal to 10.5% [5]. Finally the hurdle rate for corn in France in 2004 was found to be 1.14. This means that benefits from Bt corn have to be 1.14 times higher than costs to justify the immediate release of Bt corn in France.

Maximum incremental social tolerable irreversible costs (MISTICs) for Bt corn

We quantified the MISTICs following Eq. (1). Based on results shown in the previous paragraphs of this section and the assumptions embedded in our model we found that an immediate release of Bt corn in France is justified if the irreversible costs associated to such action are no greater than are not than 54 million Euro per year, or 179 Euro per hectare. These figures correspond to 467 Euro per farmer but only 0.9 Euro per person per year. These differences across groups show that a conflict of interests may arise when consumers express negative attitudes toward transgenic crops.

Sensitivity Analysis

Existing literature reports supply elasticities between 0.1 and 1 [1]. We found that for a value of 0.1 of the supply elasticity, the maximum tolerable amount of social irreversible costs decreases for 80%. For a value of 1 of the supply elasticity the maximum tolerable amount of social irreversible costs decreases for about 10%.

One percent increase (decrease) in the vertical shift of the supply curve causes a 1% percent increase (decrease) in the MISTICs.

As the speed of transgenic corn adoption is probably important in determining the gains France will enjoy from this technology, we take its 95% confidence interval into consideration (0.28 to 1.06) and allow this parameter to vary between half of the lower bound of this interval and the full upper bound of the confidence interval (that is between 0.14 and 1.06), assigning this parameter a pert distribution with mode 0.335. We used mean results of 5000 iterations on the simulated speed of adoption to build confidence intervals for our estimates based on a supply elasticity of 0.77 and a K-shift of 0.24. We found that reversible social net-benefits vary between 39 and 84 million Euro per year. Irreversible net-benefits vary between 0.16 and 0.33 million Euro per year. The MISTICs vary between 35 and 74 million Euro.

The simulation software used is RiskAmp.

5. THE REAL OPTION APPROACH AND MULTI-ATTRIBUTE MODELING OF ECONOMIC AND ECOLOGICAL IMPACTS OF CROPPING SYSTEMS

As shown in sections 3 and 4, the real option approach offers a measure of the MISTICs. If actual irreversible costs are below the MISTIC threshold, immediate release Bt corn in France is justified. Yet to estimate, ex-ante, the actual amount of irreversible social costs actually associated to Bt corn adoption we should rely on models that are able to capture the intricate relationship between Bt corn and ecosystem functioning.

Qualitative multi-attribute modelling supported by the decision support ssystem DEXi might be a suitable technique for this purpose offering a way to build an integrated rule-base model for assessing the sustainability of Bt corn farming. This modelling technique would allow the researcher to take into account both quantitative and qualitative ecological and economic aspects of Bt corn adoption.

A hierarchical model can be build with submodels capturing different aspects (ecological and economic) of GM and non-GM cropping systems [3]. Each submodel is based on several given *inputs* (such as crop type, soil preparation, weed control strategy, pest control strategy, soil characteristics, climate characteristics, variable production costs) that are aggregated by a multi-attribute model into overall ecologic and economic evaluation. For each cropping system the model would deliver two scores (one for the economic aspects, one for the ecological aspects). These two scores are then represented in a bi-dimensional scale that can be used to compare different cropping systems. The advantage of this type of model with respect to traditional parametric approaches is that it makes structured use of both quantitative and qualitative information [3]. The basic hierarchical structure of the model at farm level is presented in figure 1:

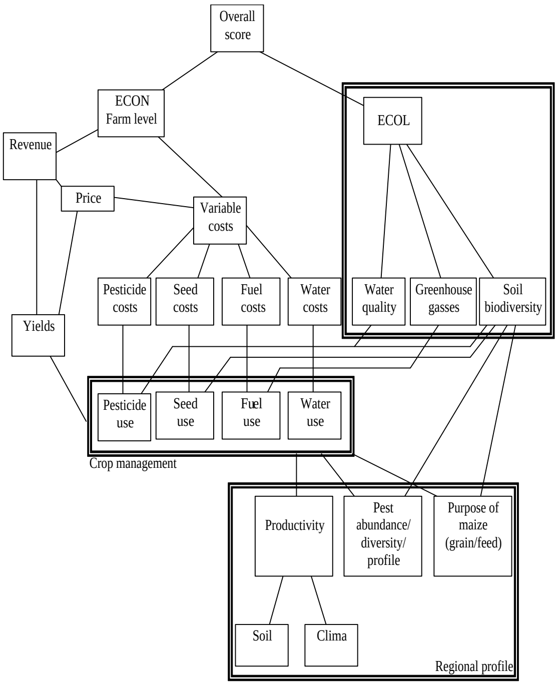

Figure 1: Hierarchical structure of the model (BT-corn, farm level).Source: Bohanec et al. 2004.

The spatial scope of the model is then extended to consider impacts at the regional level as shown in figure 2:

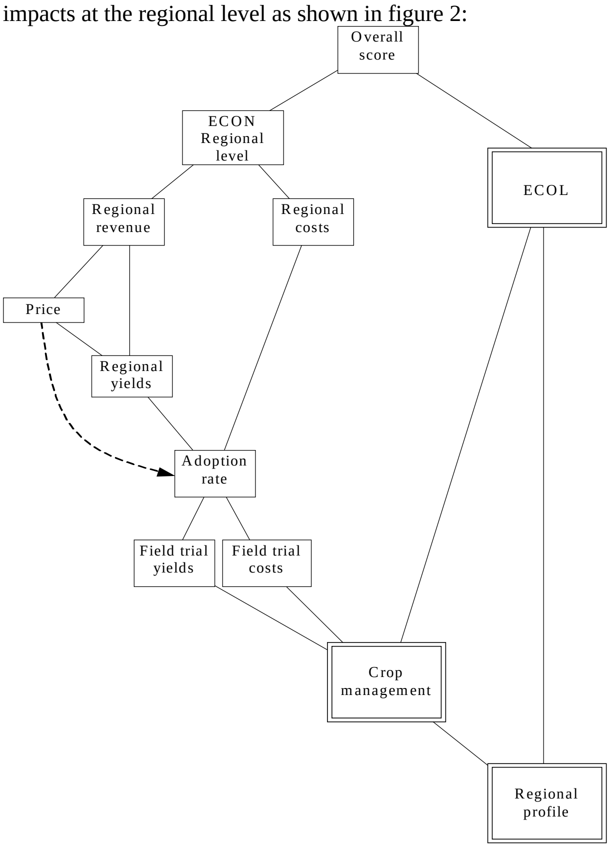

Figure 2: Hierarchical structure of the model(BT-corn, regional level). Source: Bohanec et al. 2004.

In figure 2 ECOL, crop management and regional profile represents sub-models. ECOL is a submodel of ecosystem functioning modelling the relationship between crop management and ecosystem function through water quality, greenhouse gases emissions and soil biodiversity. Crop management is a submodel based on insecticide use, herbicide use, seed use, diesel use and water use. Finally, regional profile is a submodel based on soil and clima characteristics, pest abundance and diversity, corn purpose (for animal feed or human consumption) and policy regime (such as price support systems).

The regional model in figure 2 is further specified to integrate elements of the real option approach as shown in Figure 3. In figure 3 elements of the real option approach are used to extend the economic sub-model ECON at regional level to consider uncertainty associated to the adoption of new technologies.

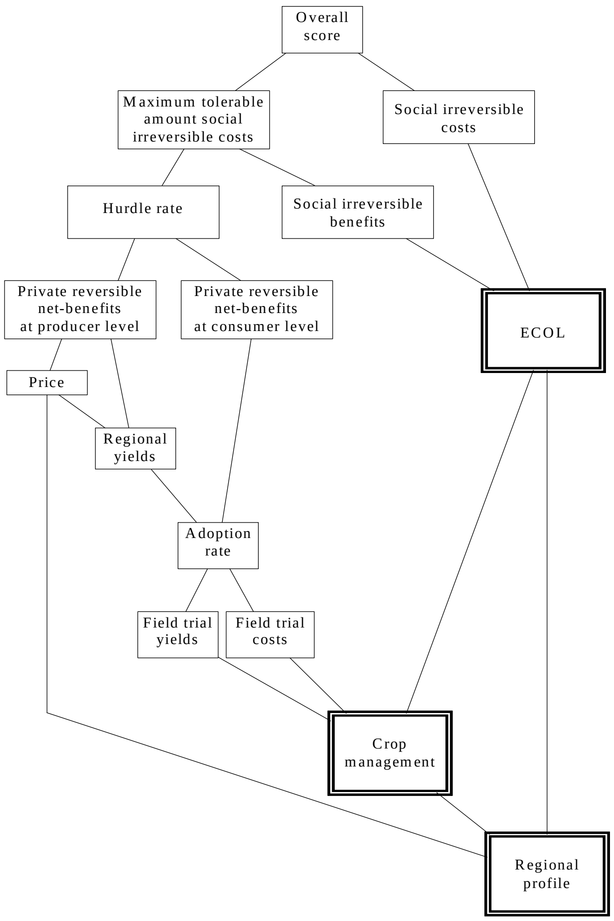

Figure 3: Hierarchical structure of multi-attribute model to compare GM and non-GM cropping systems

6. CONCLUSION

In this study we estimated the maximum incremental social tolerable irreversible costs (MISTICs) associated with the immediate adoption of Bt corn in France. A real option approach and data from field trials carried out in 2004 in Narbons, France, were used for the analysis. The MISTICs is a threshold below which immediate release of Bt corn would be justified in France. This threshold is quantified as sum of irreversible benefits from Bt corn and irreversible private net-benefits weighted by an estimated hurdle rate. Private reversible net-benefits due to adoption of Bt corn were found to be positive and equal to about 62 million per year (204 Euro per hectare).

Social irreversible benefits from reduced insecticide and fuel use also have been taken into account and were found to be about 0.24 million Euro per year (0.81 Euro per hectare). The hurdle rate for corn was found to be 1.14. This means that social benefits form Bt-corn have to be 1.14 times higher than its social costs if Bt corn is to be released in France. Thus, the MISTICs were in the order of 54 million Euro per year, or 179 Euro per hectare. These amounts correspond to 467 Euro per farmer but only 0.9 Euro per person per year. These differences across groups show that a conflict of interests may arise when consumers express negative attitudes toward transgenic crops.

In particular, the low amount of maximum tolerable irreversible social costs per capita suggests that the value of the option to delay release of Bt corn in France might indeed be positive. This means that from a purely economic perspective there might be a social gain in waiting to adopt Bt corn until more information is gathered to reduce the uncertainty associate to private reversible net-benefits, or more information is given to consumers that might change their attitudes toward transgenic crops.

We also presented in this study some ideas for further research towards new modelling techniques that would be able to make use not only of quantitative, but also qualitative information. The qualitative multi-attribute modelling technique supported by the software tool DEXi is one such technique.

7. REFERENCES

[1] Alston, J. M., Norton, G. and Pardey, P. G., **Science under scarcity: Principles and Practice for agricultural research evaluation and priority setting**, U.K : Wallingford, CAB International, 1998.

[2] Banse, M., H. Grethe, and S. Nolte, **European Simulation Model** (ESIM) in GAMS: User Handbook. Goettingen and Berlin. 2004.

[3] Bohanec, M., Džeroski S., Žnidaršič M., Scatasta S. and Wesseler J., “Multi-attribute modelling of economic and ecological impacts of cropping systems. ” **Informatica,** Vol. 28, 2004, pp. 387-392.

[4] Demont, M. and Tollens, E., “First Impact of Biotechnology in the EU:Bt Corn Adoption in Spain.”, **Annals of Applied Biology,** Vol. 145, No. 3, 2004, pp. 197-207.

[5] Demont, M., Wesseler, J. and Tollens, E., “Biodiversity versus transgenic sugar beet: the one euro question.”, **European Review of Agricultural Economics,** Vol. 31, No. 1, 2004, pp.1-18.

[6] Essential Biosafety , **Crop Database**: DBT418. 2004.
http://www.essentialbiosafety.info/
Last consulted February, 21, 2005.

[7] Eurostat, **Eurostat New Cronos database-theme 5**. 2005
http://europa.eu.int/newcronos
Last consulted September 2006.

[8] Falck-Zepeda, J. B., G. Traxler, and Nelson, R. G., “Rent Creation and Distribution from the First three Years of Planting Bt Cotton.” **ISAAA Briefs,** No**.** 14, 1999.

[9] Falck-Zepeda, J. B., G. Traxler, and Nelson, R. G., “Surplus Distribution from the Introduction of a Biotechnology Innovation.”, **American Journal of Agricultural Economics,** Vol. 82, No. 2, 2000, pp. 360-69.

[10] Falck-Zepeda, J. B., G. Traxler, Nelson, R. G., “Rent Creation and Distribution from Biotechnology Innovation: the Case of Bt Cotton and Herbicide-Tolerant Soybeans in 1997.” **Agribusiness,** Vol. 16, No. 1, 2000, pp. 21-32.

[11] Faostat (2005). Faostat-Agriculture.
http://faostat.fao.org/faostat/
Last consulted February 2006.

[12] Frisvold, G. B., J. Sullivan, and Raneses, A., “Genetic Improvements in Major US Crops: the Size and Distribution of Benefits.”, **Agricultural Economics,** Vol. 28, No. 2, 2003, pp. 109-119.

[13] James, C., “Global Status of Commercialized Biotech/GM Crops 2004. International Service for the Acquisition of Agri-Biotech Applications.”, **ISAAA Briefs** No. 32-2004.

[14] Klotz-Ingram, C., Jans, S., Jorge, F.-C. and William D. M., “Farm-level Production Effects Related to the adoption of Genetically Modified Cotton for Pest Management.”, **AgBioForum,** Vol. 2 No.2, 1999, pp. 73-84.

[15] Lekakis, J.N., and Pantzios. C., “Agricultural Liberalization and the Environment in Southern Europe: the Role of the Supply Side.”, **Applied Economics Letters,** Vol.6, 1999, pp.453-58.

[16] Moschini, G. and Lapan, H., “Intellectual Property Rights and the Welfare Effects on Agricultural RandD.”, **American Journal of Agricultural Economics**, Vol. 79, 1997, pp. 1229-1242.

[17] Moschini, G., Lapan, H. and Sobolevsky, A., “Roundup ready Soybeans and Welfare Effects in the Soybean Complex.”, **Agribusiness,** Vol. 16, No.1, 2000, pp. 33-35 .

[18] Pray, C. E., R. H. Huang, Hu, R. and Rozelle, S., “Five Years of Bt-Cotton in China - The Benefits Continue.”, **The Plant Journal,** Vol. 31, No. 4, 2002, pp. 423-430.

[19] Pray, C. E., Ma, D., Huang, J. and Qiao, F., “Impact of Bt Cotton in China.”, **World Development,** Vol. 29, No.5, 2001, pp. 813-25.

[20] Qaim, M., “Potential Benefits of Agricultural Biotechnology: an Example from the Mexican Potato Sector.”, **Review of Agricultural Economics,** Vol. 21, No.2, 1999, pp. 390-408.

[21] Qaim, M., “Bt Cotton in India: Field Trial Results and Economic Projections.”, **World Development,** Vol. 31, No. 12, 2003, pp. 2115-2127.

[22] Qaim, M. and De Janvry A., “Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' adoption: the Case of Bt Cotton in Argentina.”, **American Journal of Agricultural Economics**, Vol. 85, No. 4, 2003, pp. 814-828.

[23] Traxler, G. and Falck-Zepeda J., “The Distribution of Benefits from the Introduction of Transgenic Cotton Varieties.”, **AgBioForum,** Vol**.** 2, No. 2, 1999, pp. 94-98.