Maximum Incremental Social Tolerable Irreversible Costs (MISTICs): Assessing Economic and Ecological Impacts of Innovations under Irreversibility and Uncertainty

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ABSTRACT

In this study we introduce the concept of maximum tolerable irreversible social costs (MISTICs) as an indicator of potential welfare impacts of introducing an agricultural innovative technology. The MISTICs identify an upper bound for irreversible social costs beyond which, it would not be socially optimal to postpone the introduction of a new technology. The MISTICs including private as well as social costs and benefits, supports decision making processes that need to consider economic as well as social and environmental factors, offering a broader perspective on potential impacts of introducing technological innovations with unknown irreversible social costs. The MISTICs were computed for the case of introducing genetically modified (GM) corn in France.

Keywords: irreversibility, new technology, real option approach, social benefit-cost-analysis

JEL: D6, D8, Q1

1. INTRODUCTION

Modeling the decision of releasing genetically modified crops in the European Union is a demanding task. The introduction of such a new technology is characterized by a certain level of uncertainty about its environmental and economic impacts. Some impacts might be irreversible in nature implying that, once the decision is taken, it is not possible to go back to the equilibrium the economy was before such decision. Costs and benefits arising from those impacts may be private, i.e., born by an identifiable group of market agents (e.g. farmers) or social if born by society as a whole.

Decision making processes addressing the introduction of new technologies from an environmental as well as socio-economic perspective will have to take into account the uncertainty and irreversibility associated not only to private costs and benefits but also to its social costs and benefits of the technology. In the context of genetically modified organisms (GMOs) an example of reversible private benefit is given by farmers' income. xamples of private irreversible costs are incremental crop protection costs born by farmers due to the development of resistance in targeted pests. Examples of social irreversible costs are losses in biodiversity. Examples of social irreversible benefits are gains in biodiversity from reduced pesticide use.

The object of this study is to apply a real option approach to decision making processes involving environmental as well as socio-economic aspects. In particular, we show how to use a real option approach to quantify the maximum incremental social tolerable irreversible costs (MISTICs) of introducing Bt corn in France immediately. We also show how the MISTICs can be used to assess the immediate release of GM corn in France in the absence of information about the true incremental social irreversible costs of this technology. Preliminary quantitative results based on field trials are offered to help explain our methodological approach.

In section 2 we present some background information on corn in France and description of field trials carried out in Narbons, France. This data is largely used in the quantitative analysis. In section 3 we describe the MISTICs approach. In section 4 we present preliminary results on quantifying the MISTICs. In section 5 we summarize and discuss 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 (see Essential Biosafety, 2004, EUROSTAT, 2005).

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 (FAOSTAT, 2005).

One of the genetically modified corn considered to be allowed for planting in France is Bt corn. Bt corn 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 the European Corn Borer (ECB- *Ostrinia nubilalis*). *(*Bt) corn has been currently approved in the EU only for animal feed. In the EU Bt corn is grown in Spain with an adoption rate of about 17.5% (0.1 million hectares), and in Germany (less than 0.05 million hectares) (James, 2004). Unfortunately no official information is available on Bt corn planting in France. In France, especially in the southern area, the ECB is considered to be one of the most severe corn pests. Figure 1 shows the ECB pressure in France in 2004.

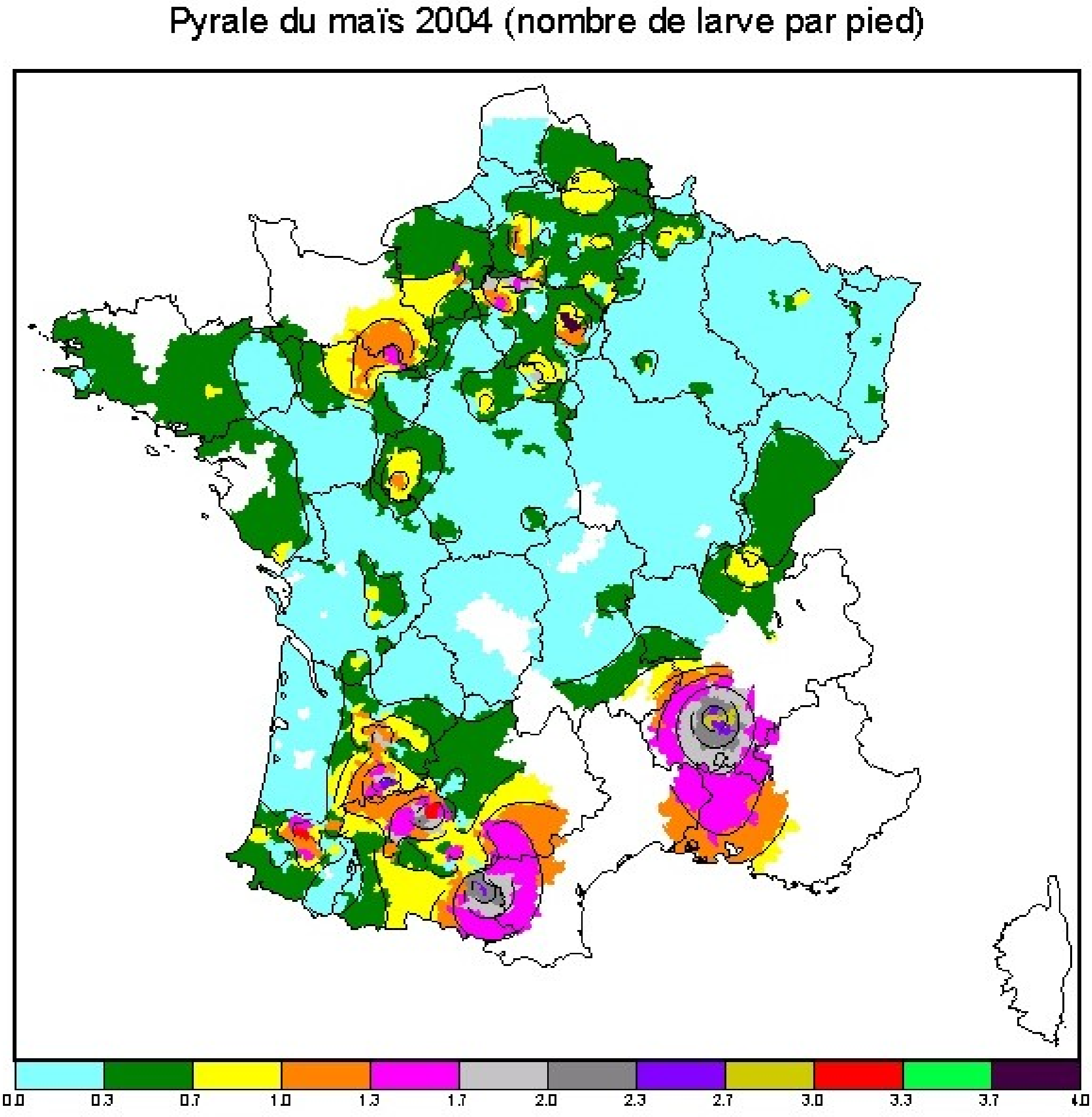

Figure 1: 2004 European Corn Borer Pressure: Number of Larvae per foot. Source: InfLarvaire 2004.

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. (see Demont and Tollens, 2004).

In 2004, for the EU funded project ECOGEN (Soil Ecological and Economic Evaluation of Genetically Modified Crops) field trails were carried out in Narbons, 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).

Concerns about the introduction of Bt-corn include impacts on non-target insects, similar to the concern in the US about impacts on the Monarch butterfly, the development of ECB resistance against Bt due to the commercialization of Bt corn, which might become a problem for organic farmers who currently use this bacterium, incorporated into sprays, as a natural crop protection tool and general concerns about unkown risks of the technology (Ervin and Welsh, 2005). Those concerns, if correct, can be seen as possible irreversible costs of introducing the BT-corn technology. An important question is under what circumstances such kind of irreversible costs would justify a delayed introduction of the technology., where the delay could be used to obtain additional information about benefits and costs of the technology.

3. IDENTIFYING THE MAXIMUM INCREMENTAL SOCIAL TOLERABLE IRREVERSIBLE COSTS (MISTICs) FOR Bt CORN IN FRANCE

The *real option approach* offers a way to quantify the value of the option to delay adoption of Bt corn in France. The value of this option 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 introduction of a new technology (or hurdle rate: $\beta/(\beta-1)$). When social irreversible costs cannot be quantified, the real option approach allows researchers to identify at least the maximum amount of tolerable irreversible social costs (*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, such that:

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

Since $\left[\beta/(\beta-1)\right] > 1$, 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. Reversible social net-benefits from GM crops, *W*;
2. Hurdle rate, $\beta/(\beta-1)$;

3.Irreversible social benefits, *R*;

Total changes in reversible and reversible costs and benefits will also depend on the rate of adoption of 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 (see Klotz-Ingram et al., 1999, Qaim, 1999, Traxler and Falck-Zepeda, 1999, Falck-Zepeda et al. 2000a,b, Pray et al., 2001, Frisvold et al., 2003, Qaim, 2003, Qaim and de Janvry, 2003, Demont and Tollens, 2004; Demont et al., 2004).

Following Moschini et al. (2000), reversible private net-benefits are measured in terms of producer and consumer surplus derived from constant elasticity log-linear demand and supply functions. Supply elasticities were taken from the European Simulation Model (ESIM) where they are derived from behavioural equations. Suggested elasticities of land allocation to corn are 0.77, so we approximated supply elasticities to this value in our base case (see Banse et al., 2004). As we consider France of a small open economy for corn, we took into consideration a perfectly elastic demand function. Details of the chosen partial equilibrium model can be found in the Appendix.

We assume that the adoption of a technological innovation, such as transgenic corn, causes a pivotal shift in the inverse supply function. This shift is calculated on data from Narbons field trials and it is given by:

$$K = \frac{\left[\frac{1}{A_c^s}\right]^{1/\varepsilon} - \left[\frac{1}{A_g^s}\right]^{1/\varepsilon}}{\left[\frac{1}{A_c^s}\right]^{1/\varepsilon_{Pf}}} = \frac{\left[\frac{MC_c}{y_c}\right]\frac{1}{y_c^{1/\varepsilon}} - \left[\frac{MC_g}{y_g}\right]\frac{1}{y_g^{1/\varepsilon}}}{\left[\frac{MC_c}{y_c}\right]\frac{1}{y_c^{1/\varepsilon}}} = 0.24 \qquad (3)$$

where MC_c are variable operational costs (Euro per hectare) associated to the conventional technology; MC_g are variable operational costs (Euro per hectare) associated to 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.

The transgenic corn 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 (ISAAA, 2004). Following Demont et al. (2004) the speed of adoption will then be assumed half of that of the U.S. This allows us to obtain conservative estimates of the social reversible benefits. Assuming an adoption ceiling of 30% for Bt corn we obtain:

$$\ln\left(\frac{\theta(t)}{0.3-\theta(t)}\right)_{Bt} = 2.41 - 0.335t \qquad (4)$$

where $\theta(t)$ represents the adoption rate of Bt corn.

In our analysis we assume that the introduction of transgenic corn does not cause shifts in the demand function, and it should be taken into consideration that problems of consumer acceptance of GM foods could change the results of our analysis.

Based on a small open economy partial equilibrium model for the market for corn for grain recognizing the European Common Agricultural Policy price support system modelled as a producer price wedge and on 2004 data Eurostat New Cronos database and the FAOSTAT-Agriculture database (Eurostat, 2005; Faostat, 2005). From Eurostat (2005) we found a gain in private net reversible benefits from adoption of Bt corn in France equal to 47 million Euro per year or 167 Euro per hectare.

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

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left[\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2r}{\sigma^2}} \tag{5}$$

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 $\mu = 10.5$ and β the positive root of the solution for a Fokker-Planck equation.

In particular:

$$\alpha = mean_t\left[\ln\left(\frac{\pi_{i,t}/\pi_{i,t-1}}{\pi_{i,t+1}/\pi_{i,t}}\right)\right] \tag{6}$$

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

$$\sigma^2 = \left(stddev_t\left[\ln\left(\frac{\pi_{i,t}/\pi_{i,t-1}}{\pi_{i,t+1}/\pi_{i,t}}\right)\right]\right)^2 \tag{7}$$

Time series data on farmer gross-margins from 1973 to 2004, from the Eurostat dataset Agris were used to calculate α and σ^2. We find for France, as a result, a hurdle rate equal to 1.35, meaning that reversible net-benefits needs to be 1.35 times higher than irreversible net-costs to justify immediate adoption of transgenic corn.

Irreversible social benefits were calculated on the base of changes in pesticide use in Narbons field trials, i.e., a reduction of 0.035 kilogram Active Ingredient (kgAI) per hectare; as well as changes in fuel use from a comparative technology (sugar beet), a reduction of 0.01 tonnes of CO^2 emissions per hectare. (Demont et al., 2004). Following Pretty et al. (2000) we considered 0.84 Euro of social irreversible benefits per kgAI reduction and 93.93 Euro of social irreversible benefits per tonnes of CO^2 emissions and found, based on projected adoption curves, about 300,000 Euro per year social irreversible benefits or 1.09 Euro per hectare per year.

The maximum tolerable amount of social irreversible costs (MISTIC) that would justify immediate adoption of Bt corn in France would be equal to about 35 million Euro per year. This figure corresponds to 125 Euro per hectare or 1.43 Euro per household, or 291 Euro per farmer.

As noted by Alston et al. (1998) existing literature reports supply elasticities between 0.1 and 1. We found that for a value of 0.1 of the supply elasticity, the maximum tolerable amount of social irreversible costs decreases for about 80%. For a value of 1 of the supply elasticity the MISTIC increases for about 20%.

Doubling the hurdle rate reduces the MISTIC by 50%. Reducing the hurdle rate by a half doubles the MISTIC.

One percent increase (decrease) in the vertical shift of the supply curve causes about 10% percent increase (decrease) in the MISTIC. Finally, doubling the speed of adoption increases the maximum tolerable MISTIC by about 35% for Bt corn. The analysis carried out in this section can be extended to other European Union (EU) countries, preliminary results in this direction are offered in table 1.

The MISTICs were computed in the case of Bt corn in France using data from field trials carried out in 2004 in Narbone, France. Private reversible net-benefits due to adoption of Bt corn were found to be positive and equal to about 47 million per year (167 Euro per hectare). Social irreversible benefits from reduced insecticide and fuel use also have been taken into account and were found to be about 0.30 million Euro (1.09 Euro per hectare). The total amount of tolerable irreversible social costs is, therefore, 35 million Euro (125 Euro per hectare).

This amount corresponds to 1.43 Euro per household and 291 Euro per farmer. The low amount of MISTICs per household suggests that the value of the option to delay adoption 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 associated to private reversible net-benefits or to identify the exact actual amount of social irreversible costs. The difference between MISTICs per household and MISTICs per farmer shows how different groups of market agents may have different willingness to bear irreversible social costs, indicating that these group might express different opinions regarding the immediate introduction of transgenic crops in the EU.

4. THE REAL OPTION APPROACH AND THE MISTICs

The example for the release of Bt-corn in France illustrated, how the real option approach can be used to assess new technologies from a social point of view. The real option approach suggests to differentiate between reversible and irreversible benefits and costs. The social benefit costs analysis further suggests to differentiate between private and public (external) benefits and costs. Figure 1 illustrates those two dimensions that are important within an ex-ante social benefit – cost analysis.

Generally, citizens express concerns about new technologies. Many of the concerns are a result of ignorance and non-familiarity with the new technology. The calculation of the MISTICs provides an attempt to consider such concerns within a social benefit-cost analysis. They can be calculated for different stakeholder groups. Differences between stakeholders offer an explanation, why some stakeholders support the technology, while others are more reluctant to accept the technology. A comparison of benefits and costs between different stakeholders can, of course, be achieved within a standard social benefit-cost analysis, but the MISTICs approach allows to consider the effect of irreversible costs explicitly, costs many people are most concerned about.

The MISTICs on a per person level provide a boundary value for the maximum willingness-to-pay for not having the new technology being introduced. The MISTICs can be compared with results from willingness-to-pay studies. This can provide additional information for decision makers facing the problem of whether or not to allow the introduction of a new technology.

5. CONCLUSION

In this study we introduce the concept of maximum tolerable irreversible social costs (MISTICs) as an indicator of potential welfare impacts of introducing an agricultural innovative technology. The MISTICs identify an upper bound for irreversible social costs beyond which, it would not be socially optimal to postpone the introduction of a new technology. The MISTICs including private as well as social costs and benefits, supports decision making processes that need to consider economic as well as social and environmental factors, offering a broader perspective on potential impacts of introducing technological innovations with unknown irreversible social costs. The MISTICs were computed for the case of introducing genetically modified (GM) corn in France.

It should be noticed that this analysis does not take into account potential shifts in the demand function due to problems of consumer acceptance of GM fed cow milk for example. Such shifts could significantly change our welfare assessment.

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Table 1. The Maximum Social Tolerable Irreversible Costs (MISTICs) for Bt corn in France.

Member State	*Private reversible net-benefits* (€/ha)	*Social irreversible benefits* (€/ha)	*Hurdle Rate*	*MISTICs* (€/ha)	*MISTICs* (Million€)	*MISTICs* (€/household)	*MISTICs* (€/farmer)
France	**167.72**	**1.09**	**1.35**	**125.33**	**35.35**	**1.43**	**291**

N/A = Not Available

*** = countries that do not have problems with the European Corn Borer

Scope / Reversibility	**Private**	**External (Public)**
Reversible	**Quadrant 1** Private Reversible Benefits (PRB) Private Reversible Costs (PRC)	**Quadrant 2** External Reversible Benefits (ERB) External Reversible Costs (ERC)
Irreversible	**Quadrant 2** Private Irreversible Benefits (PIB) Private Irreversible Costs (PIC)	**Quadrant 4** External Irreversible Benefits (EIB) External Irreversible Costs (EIC)

Source: Demont, Wesseler, and Tollens (2004)

Figure 1: The two dimensions of an *ex ante* analysis of social benefits and costs of a new technology

Appendix A

Specification of the partial equilibrium model for corn in a small open economy

We assume that there are only two technologies represented by the subscript *i* = *g* (Bt corn) , *c* (conventional corn). Country *j*'s supply of corn with technology *i*, Q_i^s , is given by:

$$Q_i^s = A_i^s \left[P_i^s \right]^{\varepsilon} \tag{A1}$$

where the subscript *j* is dropped for ease of notation; P_i^s is the producer (or output) price received by corn sellers; A_i^s is a technology specific constant term for the associated product and function.

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

$$P^d = P^w \tag{A2}$$

where P^d is the buyers' (or input) price paid for corn; and P^w is the world price for corn do not depend on what technology is used in country j's corn production, that is country j is assumed to be a small open economy.

The market clears with the following requirements:

$$Q_i^d = Q_i^s \tag{A3}$$

$$P^d \left[1+\tau\right] = P^w \left[1+\tau\right] = P^s \tag{A4}$$

where $\tau = \left[P^s - P^d \right] / P^d$ 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. Note that in this preliminary version of this study we model CAP subsidies as price support measures, further research is needed to include in the model CAP area payment as well.

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 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.

At any time period the equilibrium price, P^* and quantities, Q^*, are given by:

$$\begin{cases} P^{s*} = P^{d*}\left[1+\tau\right] \\ P^{d*} = P^{W*} \\ Q^* = A^s\left[P^{s*}\right]^{\varepsilon} \end{cases} \tag{A5}$$

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

$$PS_i = P^{d*}\left[1+\tau\right]Q_i^* - \int_0^{Q_i^*}\left[\frac{Q_i^s}{A_i^s}\right]^{\frac{1}{\varepsilon}}\frac{1}{\left[1+\tau\right]}dQ_i^s = P_i^{s*}Q_i^* - P_i^{d*}Q_i^*\ \frac{\varepsilon}{\varepsilon\ +1} \tag{A6}$$

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

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

$$\frac{\left[\frac{1}{A_0^s}\right]^{1/\varepsilon_{Pf}}-\left[\frac{1}{A_1^s}\right]^{1/\varepsilon_{Pf}}}{\left[\frac{1}{A_0^s}\right]^{1/\varepsilon_{Pf}}}=1-\frac{\left[\frac{1}{A_1^s}\right]^{1/\varepsilon_{Pf}}}{\left[\frac{1}{A_0^s}\right]^{1/\varepsilon_{Pf}}}=1-\left[\frac{A_0^s}{A_1^s}\right]^{1/\varepsilon_{Pf}}=\theta\left(t\right)K\rightarrow$$

$$\rightarrow\frac{A_1^s}{A_0^s}-1=\left[1-\theta\left(t\right)K\right]^{-\varepsilon_{Pf}}-1 \qquad \text{(A8)}$$

$\theta\ (t)$ is the transgenic corn adoption rate over time, *t*; A_0^s is the direct supply function constant coefficient with conventional technology; A_1^s is the direct supply function constant coefficient with transgenic technology and

$$K=\frac{\left[\frac{MC_c}{y_c}\right]\frac{1}{y_c^{1/\varepsilon}}-\left[\frac{MC_g}{y_g}\right]\frac{1}{y_g^{1/\varepsilon}}}{\left[\frac{MC_c}{y_c}\right]\frac{1}{y_c^{1/\varepsilon}}} \qquad \text{(A9)}$$

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 corn as a function of the vertical shift in the inverse supply function and the CAP price support coefficient:

$$
\begin{cases}
\Delta P^{s*} = 0 \\
\Delta P^{d*} = 0 \\
\Delta Q* = Q_1^* - Q_0^* = \left[A_1^s - A_0^s \right] \left[P^{w*} \right]^{\varepsilon} = \dfrac{A_1^s - A_0^s}{A_0^s} Q_0^* = \left[\left[1 - \theta(t) K \right]^{-\varepsilon} - 1 \right] Q_0^*
\end{cases}
\tag{A10}
$$

In Equation (A10) the subscripts *f* and *t* are dropped again to simplify notation.

The change in producer surplus, in particular, will be given by:

$$
\begin{aligned}
&\Delta PS = PS_1 - PS_0 = P^W (1+\tau) Q_1^* - P^W Q_1^* \frac{\varepsilon}{\varepsilon + 1} - \left[P^W (1+\tau) Q_0^* - P^W Q_0^* \frac{\varepsilon}{\varepsilon + 1} \right] = \\
&\left[P^W (1+\tau) - P^W \frac{\varepsilon}{\varepsilon + 1} \right] \left[Q_1^* - Q_0^* \right] = \left[\tau + 1 - \frac{\varepsilon}{\varepsilon + 1} \right] \left[\left[1 - \theta(t) K \right]^{-\varepsilon} - 1 \right] P^W Q_0^*
\end{aligned}
\tag{A11}
$$

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

$$
\theta(t) = \frac{\theta_{MAX}(t)}{\exp\left(-a - bt\right)} \tag{A13}
$$

Equation (A13) can be transformed into:

$$
\ln\left(\frac{\theta(t)}{\theta_{MAX}(t) - \theta(t)} \right) = -a - bt \tag{A14}
$$

The coefficients in Equation (A14) can be estimated with ordinary least squares (OLS) using data from the adoption rates in the United States. Following Demont, Wesseler, and Tollens (2004) the speed of adoption *b* will be assumed to be half of the speed of adoption of the U.S. to obtain conservative estimates of the social reversible benefits.