Biodiversity versus Transgenic Sugar Beet: The One Euro Question

Matty Demont
Katholieke Universiteit Leuven, Belgium
de Croylaan 42, B-3001 Leuven, Belgium
Tel.: +32 16 32 23 98, Fax: +32 16 32 19 96,
Email: matty.demont@agr.kuleuven.ac.be

Justus Wesseler
Wageningen University, Wageningen, The Netherlands
Hollandseweg 1, 6706 KN Wageningen, The Netherlands
Tel.: +31 317 48 23 00, Fax: +31 317 48 49 33,
Email: justus.wesseler@wur.nl

Eric Tollens
Katholieke Universiteit Leuven, Belgium
de Croylaan 42, B-3001 Leuven, Belgium
Tel.: +32 16 32 16 16, Fax: +32 16 32 19 96,
Email: eric.tollens@agr.kuleuven.ac.be

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Abstract

The decision of whether to release transgenic crops in the EU is one subject to flexibility, uncertainty, and irreversibility. We analyse the case of herbicide tolerant sugar beet and reassess whether the 1998 *de facto* moratorium of the EU on transgenic crops for sugar beet was correct from a cost-benefit perspective using a real option approach. We show that the decision was correct, if households value possible annual irreversible costs of herbicide tolerant sugar beet with about 1 € or more on average. On the other hand, the total net private reversible benefits forgone if the *de facto* moratorium is not lifted are in the order of 169 Mio € per year.

Keywords: uncertainty, irreversibility, biotechnology, sugar beet, social costs, EU

JEL classification: D61, D62, D81, N50, O33, Q16, Q32

1. Introduction

… it is inappropriate to compare the environmental effects of agriculture with GMOs to a nonexistent counterfactual in which agriculture has no negative environmental externalities.

(Ando and Khanna, 2000: 440)

The adoption of the first wave of agricultural biotechnology innovations has progressed at a remarkable speed, mainly in the US, Argentina, and Canada (James, 2001). At the same time, some consumer groups, environmentalists, politicians, and non-governmental organisations oppose the introduction of transgenic crops. The observed divergence of attitudes of different stakeholders in the technology diffusion chain may be the result of a narrow view on technological innovations in the past. For a long time, agricultural technologies have been evaluated, based solely on their private benefit-cost ratio. Much emphasis was put on farm profitability and commodity price declines. In reality, the introduction of new technologies has impacts far beyond the farm or the consumer alone. Some stakeholders are already absorbing externalities of agricultural technologies: the negative effects or 'costs', e.g. of pesticides, are currently 'paid' for by the environment. In other words, the private market optimum of agricultural technological innovations does not include any guarantee for sustainability. Therefore, we might want to reconsider the conventional private welfare framework of agricultural innovations by including social values, such as the environment, consumer attitudes and animal welfare, thus transforming it into a social welfare framework. Placing agricultural biotechnology in such a framework implies abandoning the one-dimensional point of view and recognizing the multi-dimensionality of the problem.

Two dimensions of benefits and costs can be distinguished, defining four quadrants of research (Figure 1). Uncertainty about benefits and costs can be added as a third dimension. The scope dimension defines whether a researcher is looking at the technology-induced direct market (private) effects, or the external non-market (social) effects (horizontal distribution of effects among stakeholders). The reversibility dimension, on the other hand, looks at long-term sustainability issues (temporal distribution of effects). Reversibility refers to non-additional benefits or costs, after an action has stopped. If a farmer stops planting herbicide tolerant (HT) sugar beets, he can use the fertilizer he bought for other crops and reverse the costs. At the social level, the damages on honeybees can be reversed, if harmful pesticides are banned. In both examples, reversing the action does not include sunk costs. Irreversibility refers to additional benefits or costs, after an action has stopped. If a farmer stops planting sugar beet and has to sell his sugar beet harvester, he may receive a price below the original price after depreciation and can not reverse all the costs. The release of HT sugar beet may have a negative impact on biodiversity resulting in irreversible costs as discussed in chapter two below. At the same time, a net reduction of pesticide use in HT sugar beet will have a positive impact on farmer's health and on biodiversity (Antle and Pingali, 1994, Waibel and Fleischer, 1998). The pressure on farmer's health and biodiversity of pesticide application are irreversible. If the introduced transgenic crop results in less pesticide application, the introduction provides additional benefits. Hence, the release of transgenic crops produces not only irreversible costs but also irreversible benefits, a term introduced by Pindyck (2000) in the context of greenhouse gas abatement.

Both, the scope and the reversibility dimension are important from an economic point of view as they have an impact on welfare changes. Research quadrant 1 is mainly focused on producer and consumer surplus changes. Private reversible benefits (*PRB*) comprise pecuniary benefits, such as yield increase and pest control cost decrease as well as non-pecuniary benefits like management savings, increase in flexibility, and convenience value engendered by transgenic crops. Transgenic seeds are supplied by an oligopolistic life sciences sector, and protected by intellectual property rights. This enables the latter to charge an oligopolistic price, which is higher than the price that would prevail in a competitive market. This price mark-up translates into a private reversible cost (*PRC*) for the farmer. The private welfare increase *W* is the net effect of both terms. Quadrant 2 falls into the category of reversible social benefits (*SRB*) and costs (*SRC*). In quadrant 3, social irreversible benefits (*R*) are categorised, such as e.g. the decline of environmental externalities associated with a technology-induced decrease in pesticide volume and applications. The second component involves the social irreversible costs (*I*), such as e.g. gene drift, loss of biodiversity, development of herbicide resistance, and negative health externalities, which lack scientific unanimity and certainty. Quadrant 4 comprises effects related to farmers' health, which is especially important for *Bacillus thuringiensis* (Bt) crops, which generate private irreversible benefits (*PIB*) through a reduction of poisonous insecticide use. Private irreversible costs (*PIC*) would be associated with investments, carrying a fixed-cost element. First wave agricultural biotechnology innovations typically only changed on-farm variable costs, but the introduction of a labelling and identity-preservation system could carry an important irreversible fixed-cost element on farm, processing and distribution sectors.

< Insert Figure 1 here. >

While the first published US *ex post* studies concentrate on quadrant 1 (Falck-Zepeda et al., 2000, Moschini et al., 2000), the other research quadrants remain poorly covered. Quadrant 3 and quadrant 4 include irreversibilities, which are important for *ex ante* studies. The few published *ex ante* studies on the costs and benefits of transgenic crops either only looked at net private reversible benefits, e.g. Qaim (1999), or did not include irreversibility, e.g. O'Shea and Ulph (2002). Hence, after seven years of US experience with commercial biotechnology applications, an important research gap remains largely unfilled, correctly raised by Ando and Khanna (2000: 442):

Any complete analysis of the environmental impact of these crops and any decision about how to regulate them must take both direct and indirect environmental effects into account.

In this paper, we undertake an initial attempt to approach the problem by focusing on quadrants 1 and 3 looking at the decision of the EU to put a *de facto* moratorium on transgenic crops. We consider the EU in 1995, one year before the commercial introduction of transgenic crops in US agriculture and reassess whether the decision to approve transgenic herbicide tolerant (HT) sugar beet should be delayed or not. Incorporating an historical part in our analysis, i.e. the period 1996-2002, draws the attention to the *potential benefits*, *benefits forgone* or *costs of the 1998 de facto moratorium* on transgenic crops by the EU.

The paper is structured as follows. In the first part, we describe the biotechnological innovation of our case study. In the second part, the theoretical model is developed using a real option framework and applied to the EU. Finally, the results are presented and discussed.

2. Genetically modified herbicide tolerant sugar beet

Effective weed control is essential for economic sugar beet production in all growing areas of the world (Loock et al., 1998). This was recognized as soon as the crop was first grown (Achard, 1799). Yield losses can be up to 100%, such is the poor ability of beet to compete with the large range of weeds present in arable soils (Dewar et al., 2000). A survey on changes in weed control techniques in Europe between 1980 and 1998 revealed that (1) the number of possibilities to control weeds has increased, while (2) the frequency of sprayings increased, (3) the quantity of herbicides per hectare decreased, and (4) weed control techniques shifted gradually from pre-emergence towards post-emergence applications, combined with reduced tillage practices (Schäufele, 2000). The post-emergence herbicides glyphosate and glufosinate-ammonium provide a broader spectrum of weed control in sugar beet than current weed control systems, while at the same time reducing the number of active ingredients used in the beet crop.

Glyphosate was first introduced as an herbicide in 1971. New genetic modification technology has allowed the production of sugar beet tolerant to these herbicides. The gene that confers tolerance to glyphosate was discovered in a naturally occurring soil bacterium. This bacterium produces an enzyme, which prevents glyphosate from attacking another enzyme called EPSPS that controls the production of essential amino acids in the plant, without which the plant would die. The gene was isolated using microbiological techniques, and introduced into the beet genome using gene transfer technology.

Glufosinate-ammonium was discovered in 1981. The gene that confers tolerance to glufosinate was also discovered from a naturally occurring soil bacterium and introduced into the beet's genome, accompanied by an antibiotic 'marker' gene that confers resistance to kanamycin to allow the selection of transformed cells in tissue culture (Dewar et al., 2000). Two commercial HT sugar beet varieties resulted from these genetic insertion techniques: (1) a Roundup Ready™ variety, tolerant to glyphosate and developed by Monsanto, and (2) a Liberty Link™ variety, tolerant to glufosinate-ammonium and developed by Aventis. These kits composed of a transgenic variety combined with a post-emergence herbicide, offer farmers a number of potential benefits in weed management. Apart from broad-spectrum weed control, it offers flexibility in the timing of applications, compared to the existing programs, and reduces the need for complex compositions of spray solutions. For most growers, herbicide tolerant sugar beet is likely to result in cheaper weed control than current systems (May, 2000).

Moreover, these innovations are entirely coherent with the ongoing trend towards post-emergence weed control and reduced-tillage techniques and the sharpening of the legal constraints for the application of herbicides, especially concerning the protection of the user and the environment (Schäufele, 2000). It is widely known that pesticide use harms the environment and human health (Waibel and Fleischer, 1998). Some of these externalities are irreversible. These are long-term health damage, such as chronic diseases from pesticide application and the negative impact of pesticides on biodiversity. Glyphosate and glufosinate-ammonium have a low toxicity and are metabolized fast and without residues in the soil. As a result, these herbicides have better environmental and toxicological profiles than most of the herbicides they replace (Märländer and Bückmann, 1999, May, 2000) and the introduction of HT sugar beet varieties could provide important social irreversible benefits.

However, pest control strategies based on HT crops potentially entail irreversible environmental externalities, which are, in addition, surrounded by uncertainty. First of all, glyphosate, the herbicide that substitutes for the conventional herbicide mix, has been widely studied for its environmental and human health impacts, extensively documented in Sullivan and Sullivan's (1997) latest compendium of 763 references and abstracts, of which the earlier edition had been criticised by Zammuto (1994). Secondly, the number of biosafety related publications concerning transgenic organisms has increased within the decade 1990–2000 to more than 3,300 citations according to one of the most comprehensive databases, published online by the ICGEB (2002). Regarding transgenic HT sugar beet systems, their impact on field biodiversity is questioned (Elmegaard and Pedersen, 2001, Gura, 2001). However, the major concerns comprise the transfer of genes from transgenic sugar beet by pollen (Saeglitz et al., 2000) to bacteria (Gebhard and Smalla, 1998, Gebhard and Smalla, 1999) or wild relatives (Santoni and Bervillé, 1992, Boudry et al., 1993, Fredshavn and Poulsen, 1996, Madsen et al., 1997, Dietz-Pfeilstetter and Kirchner, 1998, Danish EPA, 1999, Pohl-Orf et al., 1999, Gestat de Garambe, 2000, Darmency et al., 2000, Crawley et al., 2001, Desplanque et al., 2002, Bartsch and Schuphan, 2002) engendering a hybrid offspring invading farm fields. Most of those studies suggest that field trials cannot predict what will happen once HT crops get into the hands of farmers away from the controlled conditions of an experiment and that still more research is needed in order to get a complete picture of all risks involved.

3. Theoretical model

3.1 Defining the maximum tolerable irreversible costs

The decision to release transgenic crops in the EU is one under flexibility, irreversibility and uncertainty (Wesseler, 2002). Irreversibility has been discussed. Flexibility exists, as the *de-facto* moratorium on transgenic crops can be lifted almost any time. Uncertainty exists as future benefits and costs of the technology, like prices and yields, are not known today. Flexibility, irreversibility, uncertainty, and their impact on optimal decision making have been widely analyzed (McDonald and Siegel, 1986, Pindyck, 1991, Dixit and Pindyck, 1994). In comparison to the standard neo-classical decision making criterion where HT sugar beet should be released if the expected net reversible benefits are greater than the net irreversible costs, including irreversibility and uncertainty explicitly, leads to a much higher hurdle rate. The new decision rule is to release HT sugar beet, if the net reversible benefits are greater than the net irreversible costs multiplied by a factor greater than one.

The real option approach allows deriving the new decision rule explicitly. In the literature on real option approaches, the opportunity to act is valued in analogy to a call option in financial markets. The decision maker has the right but not the obligation to exercise an action. This right, the option to act (real option) has a value, which is a result of the option owner's ability to reduce losses by postponing the action, e.g. if new information that arrive over time reveal less than expected net reversible benefits. This is similar to the quasi-option value developed earlier by Arrow and Fisher (1974) and Henry (1974) (Fisher, 2000). But postponing the decision comes at the opportunity cost of forgone reversible net- benefits for the time being. The decision maker has to compare the benefits of an immediate release with those from a postponed decision, i.e. the value to release later. Only if the benefits of an immediate release, the value of the release, outweigh those of the option to release, should the option to release be exercised.

According to Dixit and Pindyck (1994) the value of the option to release transgenic crops, $F(W)$, can be derived using contingent claim analysis. Applying the model assuming the net private reversible benefits, W, follow a geometric Brownian motion results in a stochastic differential equation. Choosing appropriate functions and solutions for the unknown parameters according to the boundary conditions can provide a solution to the stochastic differential equation. This will provide the optimality conditions for an immediate release of transgenic crops in the environment.

Now, if the option to release transgenic crops in the environment, $F(W)$, is exercised, the value of the option to release transgenic crops will be exchanged against the value of net private reversible benefits from transgenic crops in present value terms, W, plus the irreversible benefits, R, minus the irreversible costs, I, of releasing transgenic crops. The objective can be described as maximizing the value of the option to release transgenic crops. Assuming that an asset or a portfolio of assets exists that allows the tracking of the risk of the net private reversible benefits, the arbitrage pricing principle can be applied to value the portfolio that includes the net private reversible benefits from transgenic crops (Pindyck, 1991). In this case, a portfolio can be constructed consisting of the option to release transgenic crops in the environment, $F(W)$, and a short position of $n = F'(W)$ units of the net private reversible benefits of transgenic crops. The value of this portfolio is $F = F(W) - F'(W)W$. A short position will require a payment to the holder of the corresponding long position of $dF'(W)Wdt$, where d is the convenience yield. The total return from holding this portfolio over a short time interval $(t, t+dt)$ holding $F'(W)$ constant will be:

$$dF = dF(W) - F'(W)dW - dWF'(W)dt \quad (1)$$

Applying Ito's Lemma to $dF(W)$, assuming dW follows a geometric Brownian motion[1] with drift rate a and variance rate s, equating the return of the riskless portfolio to the risk free rate of return $r[F(W)-F'(W)W]dt$ and rearranging terms results in the following differential equation:

$$\frac{1}{2}s^2W^2F''(W) + (r-d)WF'(W) - rF(W) = 0 \quad (2)$$

A solution to this homogenous second order differential equation is:

$$F(W) = A_1W^{b_1} + A_2W^{b_2}\text{, with } b_1 > 1 \text{ and } b_2 < 0. \quad (3)$$

As the value of the option to release transgenic crops in the environment is worthless if there are no net private reversible benefits, A_2 has to be 0. The other boundary conditions are the 'value matching' (equation 4) and the 'smooth pasting' (equation 5) conditions:

$$F(W^*) = W^* - I + R \quad (4)$$

$$F'(W^*) = 1 \quad (5)$$

[1] It can also be argued that dW follows a mean reversion process. Wesseler (2002) discussed one way of addressing the uncertainty about the correct process. We recognize that choosing a geometric Brownian motion will result in lower maximal tolerable irreversible costs.

Solving equation 4 according to the boundary conditions provides the following solutions:

$$W^* = \frac{b_1}{b_1 - 1}(I - R) \qquad (6)$$

$$A_1 = \frac{(b_1 - 1)^{b_1 - 1}}{(I - R)^{b_1 - 1}(d b_1)^{b_1}} \qquad (7)$$

$$\text{with } b_1 = \frac{1}{2} - \frac{r - d}{s^2} + \sqrt{\left[\frac{r - d}{s^2} - \frac{1}{2}\right]^2 + \frac{2r}{s^2}} > 1 \text{ and } I > R. \qquad (8)$$

The result of equation 6 provides the rule that it is optimal to release transgenic crops if the net private reversible benefits are equal to the difference between the irreversible costs and benefits multiplied by the factor $b/(b-1)$. As equation 4 indicates, the full value of releasing transgenic crops in the environment *W** not only has to include the irreversible costs and benefits but also the real option value *F(W*)* of the release.

The irreversible costs and benefits of transgenic crops are highly uncertain as explained before. Nevertheless, in the following it will be assumed that they are known with certainty. The relevance of uncertainty about irreversible costs can be reduced by solving equation 6 for the irreversible costs. This provides:

$$I^* = R + W \bigg/ \frac{b}{b - 1} \qquad (9)$$

Instead of identifying the net private reversible benefits required to release transgenic crops in the environment, the maximum tolerable irreversible costs under given net private reversible benefits are identified. If net private reversible benefits can be identified, a space can be designed showing areas of rejection and approval of releasing transgenic crops.

3.2. Defining the net private reversible benefits W

Estimates for *W* are obtained using the model 'EUWABSIM' developed by Demont and Tollens (forthcoming). This is a partial equilibrium model assessing the welfare effects in the sugar output market due to the introduction of transgenic sugar beet. The model is based on the large open-economy framework of Alston *et al.* (1995), but explicitly recognizes that research protected by intellectual property rights generates monopoly profits (Moschini and Lapan, 1997). It is framed to the policy and market features of the EU Common Market Organization (CMO) for sugar (Bureau et al., 1997, Combette et al., 1997). The model starts from non-linear constant-elasticity (NLCE) supply functions, developed by Moschini *et al.* (2000), incorporating technology-specific parameters, which enable the detailed parameterization of the herbicide tolerance technology. Sixteen regions are included, each of them modelled by a NLCE supply function: fourteen EU regions[2], the Rest of the World[3] (ROW) beet region, and the ROW cane region. This specification allows technology spillovers to be included for the ROW beet[4] region. The fourteen EU and two ROW supply functions are aggregated, respectively into an EU and a ROW aggregate supply function. The model is non-spatial, since intra-EU trade flows are not modelled; only aggregate EU and ROW demand for sugar are taken into account.

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[2] Belgium and Luxembourg are united in one region.

[3] During the agricultural seasons 1996/97-2000/01, cane sugar and beet sugar accounted, on average, for 71% and 29% of global sugar production respectively. The EU is the world's largest beet sugar producer, responsible for half of global beet sugar supplies, and the largest sugar exporter together with Brazil, exporting each 20% of the world's traded sugar (Demont and Tollens, forthcoming).

[4] Since the model only analyzes the introduction of a biotechnology innovation in the sugar beet sector, no technology spillovers to the sugar cane sector are assumed.

The differentials between aggregate supply and demand functions result in an EU export supply function and a ROW export demand function, since the EU is a net exporter and the ROW a net importer of sugar. By imputing a hypothetical adoption curve for HT sugar beet into the model, the technology-specific parameters engender a pivotal shift of the regional NLCE supply functions and hence of the export supply and demand functions. The world price is modelled as the intersection of both functions on the world market. Changes in the world price are transmitted to domestic EU prices through the auto-financing constraint of the CMO for sugar (Combette et al., 1997). Finally, the welfare changes (producer and consumer surplus) are calculated via standard procedures (Just et al., 1982). EUWABSIM is written in MathCad 2001i and embedded into Excel XP, together with an @Risk 4.5 module incorporating prior distributions for all uncertain parameters and generating posterior distributions for the model results, following the recommendations of Davis *et al.* (1998).

In this paper, we chose to build our model on a per hectare basis, i.e. all benefit and cost estimates are expressed per unit of land. Running EUWABSIM requires imputing a hypothetical *ex ante* adoption curve for the new technology. Equivalently to Griliches (1957) we assume a logistic functional form:

$$r_i(t) = \frac{r_{\max,i}}{1 + \exp(-a_{r,i} - b_{r,i}t)} \tag{10}$$

where the slope parameter $b_{?,i}$ is known as the natural rate of diffusion, as it measures the rate at which adoption $?_i$ increases with time t. The parameter $a_{?,i}$ is a constant of integration and the ceiling $?_{max,i}$ is the long-run upper limit on adoption. EUWABSIM's regional welfare estimates $W_i(t)$ are direct functions of domestic as well as world-wide adoption rates, the latter through world price changes (Demont and Tollens, forthcoming). Therefore, it is reasonable to assume that the welfare function $W_i(t)$ follows a similar logistic pattern with parameters $a_{W,i}$, $b_{W,i}$, and $W_{max,i}$:

$$W_i(t) = \frac{W_{\max,i}}{1 + \exp(-a_{W,i} - b_{W,i}t)} \tag{11}$$

Demont *et al.* (2001) place the current agricultural biotechnology innovations in a historical perspective, emphasizing the agricultural revolutions of the last century. They argue that the specific features of typical 'first wave' or output-trait oriented innovations, such as herbicide tolerance and insect and virus resistance, are entirely coherent with the paradigm of the second agricultural revolution of Modern Times, starting at the end of the nineteenth and in the beginning of the twentieth century, since they simply consist in a refinement of the already existing techniques. Hence, we may consider the new technology 'herbicide tolerance' as being part of a larger, underlying 'weeding technology path' in sugar beet production, which started as soon as the crop was first grown (Achard, 1799). As a result, the new technology, which starts with the advent of biotechnology, has to be interpreted as one of the two options for continuation of this technology path: with or without biotechnology. This historical reflection justifies our assumption that the 'herbicide tolerance technology path' will proceed with the same characteristics as the underlying 'weeding technology path'. Since technologies are continuously being updated, we consider the new technology path as being extended until infinity. The 1995 present value of the net private reversible benefits $W_{95,i}$ can be written as:

$$W_{95,i} = \int_0^\infty W_i(t) e^{-m_i t} dt \tag{12}$$

with m the risk adjusted rate of return derived from the capital asset pricing model (CAPM).[5]

3.3. Defining the social irreversible benefits R

The irreversible benefits r_i per hectare transgenic sugar beet are approximated as:

$$r_i = w_i \Delta A_i + y \Delta n_i Dc \qquad (13)$$

with $?A_i$ the change in volume of pesticide active ingredients (AI) per unit of land by switching from conventional crop protection to HT sugar beet, ? the average external social cost of pesticide application per unit of active ingredient, $?n_i$ the change in the number of weeding applications per hectare, D the average diesel use per application and per unit of land, c the average CO_2 emission coefficient per unit of diesel, and ? the average external social cost per unit CO_2 emission. We assume that the per hectare social irreversible benefits function is proportional to the adoption function:

$$R_i(t) = r_i \frac{r_{\max,i}}{1+\exp(-a_{r,i} - b_{r,i}t)} \qquad (14)$$

The 1995 present value of the social irreversible benefits $R_{95,i}$ can be written as:

$$R_{95,i} = \int_0^\infty R_i(t) e^{-m_i t} dt \qquad (15)$$

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[5] The motivation for choosing the risk adjusted rate of return is that the risk of the additional benefits could be tracked with a dynamic portfolio of market assets: $m = r + fsr_{bm}$, where r is the risk-free interest rate, f the market price of risk, s the variance parameter, and r_{bm} the coefficient of correlation between the asset or portfolio of assets that track W and the whole market portfolio. See Dixit and Pindyck (1994: 147-150) for an elaboration of this assumption.

4. Data

Since HT sugar beet are not yet adopted we estimate the adoption parameters of a comparable technology in the US, i.e. HT Roundup Ready™ soybeans (Fernandez-Cornejo and McBride, 2002).[6] Therefore, we first transform equation 10 into its log-linear form:

$$\ln\left(\frac{r_i(t)}{r_{\max,i} - r_i(t)}\right) = a_{r,i} + b_{r,i}t \qquad (16)$$

By assuming a ceiling of $?_{max,US}$ = 75%, the estimated OLS parameters using linear regression are $a_{?,US}$ = -2.76, and $b_{?,US}$ = 0.85. As a benchmark for HT sugar beet in the EU we assume a logistic adoption curve with the same ceiling $?_{max,i}$ and constant of integration $a_{?,i}$, but with half the speed of US soybean adoption, i.e. $b_{?,i}$ = 0.43. Assuming the same adoption curve in all EU Member States will enable comparisons to be made between Member States regarding the potential reversible and irreversible benefits and costs of HT sugar beet, regardless of the expected adoption pattern.

Estimates for the net private reversible benefits are generated by EUWABSIM. Due to the CMO for sugar, which fixes domestic prices at the beginning of each marketing year, no increases in consumer surplus are found for the EU despite the introduction of HT sugar beet. The net private reversible benefits in the EU consist only of a domestic

[6] We believe that the US case of HT Roundup Ready™ soybeans is comparable to the EU case of HT sugar beet, because of (1) the common embedded technology of herbicide tolerance, (2) the ubiquitous importance of each crop on both continents, and (3) the importance of exports of the refined products.

producer surplus increase.[7] Since our model is constructed on a per hectare basis, we slightly rewrote EUWABSIM to generate estimates of $W_i(t)$ as the net private reversible benefits per unit of land in region i and year t, by dividing the technology-induced welfare changes by the land allocated to sugar beet, in which adoption of the technology is also endogenous. As a result, EUWABSIM returns estimates for $W_i(t)$ in 14 EU regions and 5 successive agricultural seasons (t = 1996/97, …, 2000/01). To estimate the parameters $a_{W,i}$ and $b_{W,i}$ of the logistic welfare function (equation 11), we need an estimate of the ceiling $W_{max,i}$, which we obtain by re-running EUWABSIM with $?_i(t)$ = $?_{max,i}$ = 75% and taking the maximum of the five estimates (i = 1, …, 5).[8]

For the technology-induced change in volume of pesticide active ingredients, $?A_i$, we use the estimates reported by Coyette *et al.* (2002) for six European Member States (Belgium, France, Germany, Netherlands, UK, and Spain), covering 72% of total EU sugar beet area. Estimates for the other Member States are obtained by comparing the volume in conventional crop protection (Eurostat, 2000) with that of HT sugar beet (Bückmann et al., 2000). Regarding the social costs of pesticide use, $?$, Pretty *et al.* (2001) review and adapt three studies on the external costs of agriculture, respectively for the UK (Pretty et al., 2000), the US (Pimentel et al., 1992), and Germany (Waibel and Fleischer, 1998). By aggregating the estimates for (1) the annual human health costs and

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[7] We do not include the rent creation on the supply side of the technology, as this would result in a hidden subsidy in the case of negative net reversible benefits.

[8] Given the adoption rate, welfare estimates vary from year to year, due to world price, area, yield, and production differences.

(2) loss of biodiversity due to the application of pesticides in agriculture[9], we obtain social costs of 0.87 €/kg AI for the UK, 0.88 €/kg AI for the US, and 0.69 €/kg AI for Germany. For our analysis, we use the third estimate as a conservative proxy for the social costs of pesticide use. The change in the number of weeding applications, $?n_i$, is calculated by taking the difference in the number of applications between conventional (Schäufele, 2000) and HT sugar beet farming (Bückmann et al., 2000).[10] Rasmusson (1998) estimates the average diesel use in sugar beet cultivation, *D*, at 1.43 litre per weeding application and per hectare. The average CO_2 emission coefficient per unit of diesel is calculated at c = 3.56 kg/l, based on the estimates of Phipps (2002). For the average external social cost of CO_2 emission we use the estimate of $?$ = 77.4 €/tonne CO_2, reported by Pretty *et al.* (2000).

For estimating he drift rate a and the variance rate s of the new technology 'herbicide tolerance', we compute the maximum likelihood estimator assuming continuous growth (Campbell et al., 1997: Chapter 9.3). We use historical data on annual gross margin differentials in sugar beet production from 1973 up to 1995 as a proxy for estimating the

[9] One might argue the water control costs for pesticides should be included. We did not consider them, as the pesticides used in HT and non-HT sugar beet are also used on other crops and the water authorities have to continue testing the water, regardless of the adoption of the new technology.

[10] For the Northern countries (Belgium, Luxembourg, Denmark, Germany, France, Ireland, Italy, the Netherlands, Austria, Finland, Sweden, and the UK), characterized by a herbicide application rate of at least 2.5 applications, the HT system is based on a glyphosate dose of 6 litre, sprayed through an average of 2.5 applications (2 x 3 l of 3 x 2 l). For Southern countries (Greece, Spain, and Portugal), the average application rate is at most 1.5 applications. In these cases, the counterfactual HT system is assumed to be a one-pass application of 3 litre glyphosate.

growth and variance characteristics of the underlying 'weeding technology path'. The data are extracted from the EU/SPEL dataset (Eurostat, 1999) for all EU-15 Member States and deflated and converted into real terms using the GDP deflators published by the World Bank (2002). The country-specific hurdle rate is calculated using the estimated drift and variance rate per country and choosing a risk-free rate of return, r, of 4.5% and a risk-adjusted rate of return, m, of 10.5% for all countries. Finally, data on areas planted to sugar beet, numbers of sugar beet holdings, and currency rates are extracted from the AGRIS dataset (Eurostat, 2002), while household data are reported by the EEA (2001).

5. Results and discussion

For each region i, the five data points of $W_i(t)$ and the estimate of $W_{max,i}$ are used to estimate the parameters $a_{W,i}$ and $b_{W,i}$ of the logistic welfare function (equation 11), using OLS linear regression on the log-linear transformation, analogous to equation 16. In Table 1 we report the OLS results, $W_{max,i}$, the hurdle rates, and the values of W, R, and I^*, presented as annuities ($W_a = mW_{95}$, $R_a = mR_{95}$, and $I^*_a = mI^*_{95}$). As expected, the estimates for a_W and b_W, ranging from -3.19 to -2.75 and 0.34 to 0.45 respectively, are very closely related with the adoption parameters (-2.76 and 0.43 respectively). The estimated hurdle rates are entirely coherent with the expectations. We observe a bimodal distribution. Favoured areas such as France, Belgium, the Netherlands, Germany, Denmark, the UK, and Italy have low hurdle rates (1.25-1.82), while less-favoured areas like Spain, Ireland, Austria, Sweden, Greece, and Finland have higher ones (2.10-3.69), requiring higher values of W to justify a release of HT sugar beet.

The maximum tolerable social irreversible costs range from an annual 50-212 € per hectare planted to transgenic sugar beet, i.e. in the range of 27-80% of the annual net private reversible benefits. Depending on whether the EU's hurdle rate is calculated from the aggregate EU gross margins (case a in Table 1), or as an area-weighted average of the individual Member States' hurdle rates (case b in Table 1), the estimates for I^*_a change substantially. In the second case, which is more representative for EU decision making, maximum tolerable social irreversible costs are 121 € per ha transgenic sugar beet and per year, totalling 103 Mio € per year. In the last two columns of Table 1 we distributed the maximum tolerable annual social irreversible costs among all EU households and sugar beet holdings. An average household would at most tolerate an annual cost of about 1 €. If we take loss of biodiversity as the major irreversible cost, it is questionable whether the average willingness to accept the perceived loss of biodiversity due to the introduction of HT sugar beet would be inferior to this threshold. This is in line with the observed reluctant attitude of EU citizens regarding transgenic crops and the extent to which this translates into a relatively high willingness to pay to avoid these products. Burton *et al.* (2001) show the relative importance of different aspects of the food system in forming preferences, and that transgenic food is only one of a number of concerns, albeit a significant one. Finally, if we distribute the cost among the 'responsible' sugar beet growers, as if the externality remained on the farm, logically much higher values are found. The total net private reversible benefits forgone if the *de facto* moratorium is not lifted are in the order of 169 Mio € per year.

5. Conclusion

In this paper we showed the multi-dimensional features of cost-benefit analysis on genetically modified crops. While most literature on the economic impact of transgenic crops remains entirely focused on the estimation of net private reversible benefits, our study tries to fill a gap in literature, by assessing the social irreversible benefits and costs of a biotechnology innovation in the sugar industry. Historical time series data on gross margins allows us to estimate the maximum tolerable social irreversible costs, given the net private reversible benefits estimated in *ex ante* using the model by Demont and Tollens (forthcoming). From the viewpoint of an average EU household, the annual social irreversible costs should not exceed a threshold of roughly 1 € to justify the release of transgenic HT sugar beet in the EU. As soon as the average households' perceived loss of biodiversity caused by HT sugar beet exceeds 1 € per year, they would not benefit from the new technology and the *de facto* moratorium of the EU on transgenic crops would be right for the case of HT sugar beet. The benefits forgone are about 169 Mio € per year. Favoured areas in sugar beet cultivation, such as the central EU regions have high hurdle rates and will impose weaker constraints on the maximum tolerable social irreversible costs than less-favoured areas, i.e. the extreme Southern and Northern EU regions.

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Scope Reversibility	Private	Social
Reversible	**Quadrant 1** Private Reversible Benefits (*PRB*) Private Reversible Costs (*PRC*) Net Private Reversible Benefits (*W*): $W = PRB\text{-}PRC$ EUWABSIM (Demont and Tollens, forthcoming)	**Quadrant 2** Social Reversible Benefits (*SRB*) Social Reversible Costs (*SRC*)
Irreversible	**Quadrant 4** Private Irreversible Benefits (*PIB*) Private Irreversible Costs (*PIC*)	**Quadrant 3** Social Irreversible Benefits (*R*) Social Irreversible Costs (*I*)

Figure 1: Two dimensions in benefit-cost analyses of agricultural technologies

Table 1: Parameter estimates generated by EUWABSIM, hurdle rates, and annual net private reversible benefits (W_a), social irreversible benefits (R_a), and maximum tolerable social irreversible costs (I^*_a) per hectare transgenic sugar beet, per household and per sugar beet growing farmer

Member State	a_W	b_W	W_{max} (€/ha)	W_a (€/ha)	R_a (€/ha)	Hurdle Rate	I^*_a (€/ha)	I^*_a (€)	I^*_a (€/household)	I^*_a (€/sugar beet farmer)
Austria	-2.80	0.41	261	251	3.36	2.88	91	1,842,164	0.56	156
Belgium/Lux.	-2.85	0.39	187	168	2.09	1.26	135	5,852,023	1.38	379
Denmark	-2.83	0.41	186	178	2.06	1.73	105	2,864,870	1.25	363
Finland	-2.75	0.39	265	251	0.74	3.69	69	976,108	0.46	249
France	-2.89	0.41	193	179	1.05	1.25	145	24,964,742	1.09	737
Germany	-2.83	0.41	188	179	1.57	1.36	134	27,846,376	0.75	527
Greece	-2.81	0.34	312	264	7.97[c]	3.12	93	1,771,502	0.49	84
Ireland	-2.78	0.39	123	116	-0.96[c]	2.29	50	691,951	0.61	164
Italy	-3.19	0.40	420	330	2.32	1.82	183	22,682,730	1.02	361
Netherlands	-2.87	0.38	137	121	0.83	1.31	94	4,630,433	0.72	241
Portugal	-3.02	0.45	380	354	-0.65[c]	1.67[d]	212	615,218	0.17	769
Spain	-2.82	0.41	264	252	0.53	2.10	121	7,258,219	0.48	260
Sweden	-2.79	0.40	157	150	0.18	3.01	50	1,226,127	0.31	233
UK	-2.82	0.39	139	127	1.78	1.76	74	5,135,522	0.24	461
EU[a]	-2.90	0.41	217	199	1.59	1.04	192	163,363,615	1.10	587
EU[b]	-2.90	0.41	217	199	1.59	1.67	121	102,628,681	0.69	369

[a] The hurdle rate is estimated based on the aggregate EU gross margins. The low value can be explained by the fact that aggregating largely averages out fluctuations, resulting in a lower variance in comparison with the individual Member States. Decisions based upon this hurdle rate have to be interpreted as being made by one decision-maker who decides for the whole EU as a region.

[b] In this case, the hurdle rate is a sugar beet area-weighted average of the Member States' estimates. This provides a more realistic rule of thumb for decision-making in the EU, which is based on weighted votes from the individual Member States. We conservatively assumed area-weighing, directly related to the importance of the sugar beet industry in each State, but also other political weighing factors can be considered.

[c] The extreme estimates for Greece, Ireland and Portugal are probably due to data inconsistencies in the Eurostat (2000) dataset. These countries only cover 4% of total EU area allocated to sugar beets, such that the EU average is almost not affected.

[d] For Portugal, no data on margins has been found. The EU area-weighted average has been used as a proxy for its hurdle rate.