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IMPACT OF AGRICULTURAL BIOTECHNOLOGY IN THE EUROPEAN UNION'S SUGAR INDUSTRY

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Since 1995, genetically modified organisms have been introduced commercially into US agriculture. These innovations are developed and commercialised by a handful of vertically coordinated "life science" firms who have fundamentally altered the structure of the seed industry. Enforcement of intellectual property rights for biological innovations has been the major incentive for a concentration tendency in the upstream sector. Due to their monopoly power, these firms are capable of charging a "monopoly rent", extracting a part of the total social welfare. In the US, the first *ex post* welfare studies reveal that farmers and input suppliers are receiving the largest part of the benefits. However, up to now no parallel *ex ante* study has been published for the European Union. Hence, the EUWAB-project (European Union Welfare effects of Agricultural Biotechnology) aims at calculating the total benefits of selected agricultural biotechnology innovations in the EU and their distribution among member countries, producers, processors, consumers, input suppliers and government. This project (VIB/TA-OP/98-07) is financed by the VIB - Flanders Interuniversitary Institute for Biotechnology, in the framework of its Technology Assessment Programme. VIB is an autonomous biotech research institute, founded in 1995 by the Government of Flanders. It combines 9 university departments and 5 associated laboratories. More than 750 researchers and technicians are active within various areas of biotech research. VIB has three major objectives: to perform high quality research, to validate research results and technology and to stimulate a well-structured social dialogue on biotechnology. Address: VIB vzw, Rijvisschestraat 120, B-9052 Gent, Belgium, tel: +32 9 244 66 11, fax: +32 9 244 66 10, www.vib.be

Abstract

We develop a welfare framework, which explicitly recognizes that research protected by intellectual property rights generates monopoly profits. The result is a simulation model, shaped to the European sugar sector, and enabling to assess the size and distribution of the benefits of transgenic sugar beet adoption in the European Union (EU) and the Rest of the World (ROW). Our model results suggest that the ROW captures the largest share of the benefits (53 % of total welfare increase). The EU sugar industry absorbs the next largest share of the benefits (30 %), with the smallest share (17 %) accruing to seed suppliers and gene developers. Since EU intervention prices are exogenously fixed each year, EU consumers do not take part in the distribution of the gains from the innovation. However, consumers outside the EU necessarily gain due to the depressing effect of the technology on world sugar prices. The latter is costly for cane growers in the ROW, while beet producers gain. Our results reveal an apparent contradiction. When modern (bio)technologies are introduced in commodity markets subject to obsolete trade policies, the natural flow of domestic benefits from the input industry, via farmers, to consumers is hampered and biased towards the producing sector (input industry, farmers, and processors), leaving domestic consumers unaffected. Remarkably, given the current Common Market Organization for sugar, consumers outside the EU gain while EU citizens continue to subsidize EU sugar production trough high sugar prices, despite the innovation.

Introduction

Since 1995, genetically modified organisms (GMO's) have been introduced commercially into US agriculture. These innovations are developed and commercialized by a handful of vertically coordinated "life science" firms who have fundamentally altered the structure of the seed industry. Enforcement of intellectual property rights (IPR's) for biological innovations has been the major incentive for a concentration tendency in the upstream sector. On the one hand, this monopolization may increase long-run social welfare through an increased rate of investment in R&D (Schumpeter, 1942). On the other hand, due to their monopoly power, these firms are capable of charging a 'monopoly price', extracting a part of the total social welfare through 'monopoly rents' (Moschini and Lapan, 1997). A popular argument used by the opponents of agricultural biotechnology is the idea of an input industry extracting all benefits generated by these innovations. Are life science firms able to appropriate all benefits or is there a limit to their monopoly power?

In the US, the first published *ex post* welfare studies reveal that both farmers and gene developers, depending on the commodity, can receive the lion share of the benefits (Moschini et al., 2000, Falck-Zepeda et al., 2000b). However, up to now no parallel *ex ante* study has been published for the European Union (EU). Hence, the EUWAB-project (European Union Welfare effects of Agricultural Biotechnology) aims at calculating the total benefits of agricultural biotechnology innovations in the EU and their distribution among member countries, producers, consumers, input suppliers and government. The project tries to answer these questions by means of two carefully selected case studies: (1) herbicide tolerant (HT) sugar beets, and (2) insect resistant (IR) corn.

In this paper, we show that the EU's sugar market can serve as a relevant case study for the calculation of the *ex ante* welfare effects of agricultural biotechnology in the EU. We develop a partial equilibrium welfare framework, which explicitly recognizes that research protected by intellectual property rights generates monopoly profits (Moschini and Lapan, 1997). The result is a simulation model, which is shaped to the characteristics of the EU's Common Market Organization (CMO) for sugar. This model enables to assess the size and distribution of the potential benefits of transgenic sugar beet adoption in the European Union and the Rest of the World.

Arguments Advancing the European Union's Sugar Market as a Case Study

Until now, the few published studies calculating the welfare effects of agricultural biotechnology are applied on typical US export crops like cotton (Falck-Zepeda et al., 2000b) and soybeans (Moschini et al., 2000, Falck-Zepeda et al., 2000a). The major difference with the EU is the fact that these American studies regard an *ex post* setting, while the recent moratoriums on GMO's in the EU and the absence of empirical farm level impact data oblige us to use *ex ante* assumptions about expected yield increases, cost reductions and price premiums of the new technology. However, this limitation makes it particularly interesting, because studying the *potential* welfare effects associated with agricultural biotechnology in the EU reveals the *benefits foregone* or costs of a complete ban of GMO's in the EU.

To illustrate these potential benefits, a representative case study has to be selected. Since the technology is embedded in the seed, an agricultural commodity has to be chosen, which is representative and important for the EU, in terms of production and export, and preferably for the majority of EU member countries. Moreover, the innovation has to be commercialized in other countries or be near commercialization in order to obtain preliminary information about its potential impact via field trial data. Further, a minimal acceptance for the technology is a requisite, so that adoption in the intermediate run is a realistic scenario for the EU. The case of genetically engineered animal growth hormones, such as rBST (recombinant bovine Somatotropin) in the dairy sector, fulfils these criteria, but is unlikely to be accepted by the European society in the coming years. The case of transgenic sugar beets is in line with our criteria, providing a perfect example of agricultural biotechnology in an important European commodity market, parallel with the existing US impact studies mentioned above.

At present, cane sugar accounts for 71 % of global sugar production, with beet sugar accounting for 29 % of global output (Table 1). The EU is the world's largest beet sugar producer, producing 49 % of global beet sugar (Table 2). The European continent even accounts for 79 %. Brazil and the EU are the largest sugar exporters, responsible for 20 % of global traded sugar each (Table 1). Since transgenic sugar beets are not yet adopted on a commercial scale neither in the EU, nor in other parts of the world, no *ex post* studies are available. However up to now, no *ex ante* study has been published yet about the potential welfare effects of agricultural biotechnology in the sugar sector.

Sugar is one of the most heavily traded and highly protected agricultural commodities with a world-wide average Producer Subsidy Equivalent (PSE) of 48 % (International Policy Council, 1996). However, because of the residual nature of world sugar markets, recorded prices not always reflect production costs in some of the largest producing countries. For long periods of time, the world sugar price cycle has been characterized by depressed prices at which even the world's most efficient producers had difficulties to survive without protection. Hence, current PSE calculations are likely to overstate levels of support in the sugar sector, while revealing little about the distorted nature of world markets (Harris and Tangermann, 1993). There is general agreement that EU sugar policies depress the world sugar market price . The EU's Common Market Organization (CMO) for sugar came into full effect in 1968 and has not been substantially altered since that time. The principal mechanism by which producers have been supported is a common internal support price. The quotas were introduced on a temporary basis, to be removed after seven years. They have been maintained ever since, however, subject to periodic review (Harris and Tangermann, 1993). An important implication for our study is that these market interventions distort the flow of benefits from R&D in agriculture, such as biotechnology research (Alston et al., 1995).

With the recent WTO agreements, trade barriers and other market interventions are being reduced gradually. In the case of the sugar sector, the WTO agreement establishes limits on subsidized exports. The EU has agreed to reduce production quotas to meet its subsidized exports obligations (Poonyth et al., 2000). Previous studies (Sudaryanto, 1987, Wong et al., 1989, Roningen and Dixit, 1989, Schmitz and Vercammen, 1990, Leuck and Neff, 1991, Roberts and Wish-Wilson, 1993, Devadoss and Kropf, 1996, Borrell and Pearce, 1999) evaluated the implications of trade liberalization on the world sugar market. The latter would have an important effect on the volume of EU production, although the European beet industry as a whole has shown to be relatively competitive (Haley, 1998, Kennedy and Harrison, 1999).

The sugar industry is facing a slow but steady progress towards greater liberalization of global trade. Over the last 40 years, real world sugar prices have fallen, on average, by between 1.5 % and 2.0 % per year (Duff, 1999). Even in the case of the highly protected European beet industry, growers are paid a fixed ‘green rate’ price, i.e. not corrected for inflation. This means that they have to compete continuously against this real price decline of 1.88 % per year via technological progress[1]. These arguments provide a powerful economic rationale for enhancing competitiveness by exploiting any cost savings that can be achieved through the use of genetically modified (GM) crops. However, Table 3 reveals that, although most European countries have sufficient research experience in GM beets, no authorization or commercialization of these crops is expected before 2002-2005. Yet, most sugar industries have not even adopted a strategy for this technology. GM sugar beet is already approved[2] to be grown in the USA, and will shortly be grown in China. It cannot be long before South Africa follows suite. Clearly, it is wise for the EU to take a careful, rational, science-based look at all the economic, agricultural and environmental issues involved (Dewar et al., 2000). This advances the elaboration of an *ex ante* study about the potential welfare effects of agricultural biotechnology in the sugar sector of the European Union.

Previous Studies Examining the Returns to R&D in the European Sugar Sector

Up to date, only two studies have been published estimating the returns to R&D in European sugar production. Thirtle (1999) uses an R&D production function approach for the Eastern counties of England to explain total factor productivity (TFP) growth in sugar production. He finds a significant influence of R&D on TFP, lagged six and nine years after the research expenditure. The overall rate of return to publicly funded agricultural research amounts to 11 %. However, since R&D in agriculture is progressively managed by the private sector, e.g. with the advent of biotechnology, increased private extension and marketing expenditures could reduce the adoption lag of innovations and significantly increase producers' rate of return.

According to Zimmermann and Zeddies (2000), 58 % of the global productivity progress in the Bavarian region of Germany is attributed to sugar beet seed. Moreover, 80 % of the increase in beet yield can be attributed to seed improvements and approximately 20 % to other production factors, especially plant protection and machinery (Märländer, 1991). These figures suggest that progress in sugar beet breeding can generate remarkable economic benefits, especially biotechnology that marries seed with plant protection improvements.

Transgenic Sugar beets

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 application, 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. As a result, glyphosate and glufosinate-ammonium have better environmental and toxicological profiles than most of the herbicides they replace (May, 2000).

Glyphosate was first introduced as an herbicide in 1971. New genetic modification technology has allowed the production of sugar beets 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, and without which the plant would die. The gene was isolated using microbiological techniques, and introduced into the beet genome using the 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 selection of transformed cells in tissue culture (Dewar et al., 2000).

Two commercial herbicide tolerant (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[3]. 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 will reduce the need for complex compositions of spray solutions. For most growers, herbicide tolerant sugar beets are likely to result in cheaper weed control than current systems (May, 2000).

Moreover, these innovations are entirely coherent within 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). Both herbicides have a low toxicity and are metabolized fast and without residues in the soil. As a result, the introduction of herbicide tolerant sugar beet varieties could be an approach to sustainable sugar beet cultivation (Märländer and Bückmann, 1999).

The Model

Regional Specification

To analyze the welfare effects of the trading and adoption of herbicide tolerant sugar beets in the sugar industry, we need to choose an appropriate spatial model. Therefore, a preliminary look at the geographical distribution of production and trade of sugar is in order. Since we are analyzing a hypothetical adoption period of five agricultural seasons, i.e. 1996/97-2000/01, Table 1 reports the observed average production, exports, net exports, stock changes, and consumption of sugar in the world during this period. A first differentiation into sugar cane and sugar beet appears logic, accounting for respectively 71 % and 29 % of global sugar production. The sugar beet region can be further divided into the EU and the Rest of the World

(ROW), both responsible for half of global beet sugar (Table 2). In this ROW beet region, non-EU Europe is dominant (58 %), followed by the US (21 %). Hence, we believe that we can adequately capture the essence of production and trade in the global sugar market with a three-region model: EU, ROW Beet, and ROW Cane. Since the EU is our study object, we will further disaggregate this region into its 15 Member States.

Parametric Specification

Conventionally, research benefits were estimated assuming that the research is publicly funded and innovated inputs competitively sold in the input market. In contrast, most of the recent agricultural biotechnology innovations have been developed by private firms protected by intellectual property rights (IPR's), such as patents, which confer monopoly rights to the discoverer (with some limitations). This is a new phenomenon in the agribusiness sector. The result is that prices for these inputs are higher than they would be in a perfectly competitive market. Therefore, Moschini and Lapan (1997) bring along some new elements in the conventional analytical framework. They complete it by including the possibility that the innovation is protected by IPR's in the input market. Thus, the benefits from modern biotechnological R&D have to be measured in the input market. However, equivalently to what Falck-Zepeda, Traxler, and Nelson (2000b) pointed out in their study about the welfare effects of Bt cotton in the US, econometric implementation of Marshallian welfare estimations in the input market would require data that are difficult to obtain, particularly for recent innovations and especially for our *ex ante* evaluation.

Therefore, in a more recent paper Moschini, Lapan and Sobolevski (2000) adapt their methodology to a model that is closer to the actual working of the herbicide tolerance innovation and apply it to the case of Roundup Ready™ soybeans. Inspired by the latter, we develop a two dimensional model and apply it on the European Union's sugar industry. The spatial dimension is defined by 16 regions *i*: the sugar cane growers in the Rest of the World (ROW) ($i = 0$), the sugar beet growers in the ROW ($i = 1$), and 14 production blocks[4] in the EU ($i = 2, 3, \ldots, 15$) (Table 4). The temporal dimension includes 7 agricultural seasons *j*: one 'benchmark year' 1996-1997 without adoption ($j = 0$), five sequential years of adoption ($j = 1, 2, \ldots, 5$): 1996-1997, 1997-1998, …, 2000-2001 (Table 5), and one 'evaluation year' 2001-2002 ($j = 6$) to which the aggregate welfare increases engendered during the adoption period, are actualized and aggregated.

Profit per hectare in region *i* in period *j* according to sugar price *p* is written as

$$\pi^c_{i,j}(p) = A_{i,j} + \frac{G_{i,j}}{1+\eta_i} p^{1+\eta_i} - \delta w_{i,j} \qquad \text{conventional} \quad (1)$$

$$\pi^g_{i,j}(p) = A_{i,j} + \alpha_{i,j} + \frac{(1+\beta_i)G_{i,j}}{1+\eta_i} p^{1+\eta_i} - \delta w_{i,j}(1+\mu_{i,j}) \qquad \text{HT} \quad (2)$$

Average profit per hectare is a function of sugar price and the adoption rate $\rho \in [0,1]$, which acts as a technology-induced supply curve shifter:

$$\overline{\pi}_{i,j}(p,\rho) = A_{i,j} + \rho\alpha_{i,j} + \frac{(1+\rho\beta_i)G_{i,j}}{1+\eta_i} p^{1+\eta_i} - \delta w_{i,j}(1+\rho\mu_{i,j}) \qquad (3)$$

This specification means that

$\overline{\pi}_{i,j}(p,0) = \pi^c_{i,j}(p)$, and

$\overline{\pi}_{i,j}(p,1) = \pi^g_{i,j}(p)$.

Supply of land to the sugar industry by country i in year j is written in constant-elasticity form as a function of average land rents, which depend on output price and the adoption rate, that is

$$L_{i,j}[\bar{\pi}_{i,j}(p,\rho)] = \lambda_{i,j}[\bar{\pi}_{i,j}(p,\rho)]^{\theta_{i,j}} = L_{i,j}(p,\rho) \tag{4}$$

The result is a region- and year-specific supply function incorporating four technology-specific parameters enabling to parameterize the herbicide tolerance innovation in detail: (5)

$$Q_{i,j}(p,\rho) = \underbrace{\lambda_{i,j}\left[\underbrace{A_{i,j} + \rho\alpha_{i,j} + \frac{(1+\rho\beta_i)G_{i,j}}{1+\eta_i}p^{1+\eta_i} - \delta w_{i,j}(1+\rho\mu_{i,j})}_{\text{average profit per hectare } \bar{\pi}}\right]^{\theta_{i,j}}}_{\text{aggregate supply of land to sugar beet production}} \underbrace{(1+\rho\beta_i)G_{i,j}p^{\eta_i}}_{\text{(optimal) yield function}}$$

General Parameters	Technology-Specific Parameters
p = sugar price λ = 16x6 matrix of scale parameters A, G = 16x6 matrices of parameters subsuming all other input prices, presumed constant η = 16x1 vector of elasticities of yield with respect to sugar price δw = 16x6 matrix of seed costs (δ = constant optimal density of seeds and w = seed price) θ = 16x6 matrix of elasticities of land supply with respect to sugar profit per hectare	α = 16x6 matrix of coefficients of unit profit increase due to the HT technology β = 16x1 vector of coefficients of yield change due to the HT technology $\rho \in [0,1]$ = adoption rate μ = 16x6 matrix of markups on HT seed price (reflecting technology fee)

Aggregation of supply functions will allow us to model the effect on world sugar prices of the interaction between two aggregate blocks, the EU and the ROW, as a consequence of the introduction of the HT technology. However, the structure of these functions implies that all 16 regions in the model are able to participate in the aggregate supply response to prices. While all regions certainly respond to a certain region-specific 'incentive price', in reality not all of them respond to world prices, due to price interventions interfering in their domestic market[5]. This means that the technology-induced production surplus of those regions will not be exported on the world market, but will free up land allocated to sugar beets instead, so that their total production remains unchanged[6]. For those regions, we include this possibility by equaling their supply functions to their (constant) observed total production:

$$Q_{i,j}(p,\rho) = \overline{Q}_{i,j} \tag{6}$$

For regions i responding to world prices, we parameterize the introduction of HT sugar beets using equation 5. The aggregate EU sugar[7] supply function in year j can be modeled by imputing the country- and year-specific adoption rates $\rho_{i,j}$ in the variable ρ and adding up all country-specific supply functions. Note that this aggregate supply function contains a constant term and a variable term, which is a function of world prices:

$$Q_{EU,j}(p,\rho_{EU,j}) = \sum_{i=2}^{15} Q_{i,j}(p,\rho_{i,j}) = \sum \overline{Q}_{i,j} + \sum Q_{i,j}(p,\rho_{i,j}) \tag{7}$$

In equation (7) $\rho_{EU,j}$ represents the 14x1 adoption vector of the new technology in the EU in year j, with elements $\rho_{i,j}$ (i = 2, 3, …, 15). This aggregate sugar supply function is very detailed in that it contains 10 parameters per country, totaling 140 parameters, of which 56 are related to the new technology. In an analogous way, ROW aggregate supply in year j can be modeled as a function containing a constant term and a variable term, which is a function of world prices:

$$Q_{ROW,j}(p,\rho_{ROW,j}) = \sum_{i=0}^{1} Q_{i,j}(p,\rho_{i,j}) = \sum \overline{Q}_{i,j} + \sum Q_{i,j}(p,\rho_{i,j}) \tag{8}$$

This function contains 20 parameters, of which 8 are technology-specific. In equation (8) $\rho_{ROW,j}$ represents the 2x1 adoption vector of the new technology in the ROW in year j with elements $\rho_{i,j}$ (i = 0, 1). The 16x1 adoption vector in the whole world in year j will be denoted by $\rho_{W,j}$, containing elements $\rho_{i,j}$ (i = 0, 1, …, 15).

Next, we model the innovation as occurring in a large, open economy with technology spillovers and shape the two-region framework of Alston, Norton and Pardey (1995) (p. 219) to the specific features of the European Union's Common Market Organization (CMO) for sugar (Figure 1). For each country, the four technology-specific parameters engender a pivotal, divergent shift of the supply curve. Depending on the pricing system (two-tier or mixed price) which Member States apply, the research benefits can differ (Demont and Tollens, 2001). In this paper however, we do not attempt to model different pricing systems and assume that their effect on the flow of R&D benefits is negligible. It is clear that in all cases, producers extract a part of research benefits, which is protected from price depreciations[8] due to guaranteed EU intervention prices. At the center of the analysis is the calculation of a counterfactual world price p_j (after decline) in year j to isolate the effect of the technology-induced supply shift from other exogenous changes in supply and demand. It is important to note that this price change would differ from the observed change in world price if the technology had been adopted as assumed. It rather represents what the world price would have been if all supply and demand conditions had been identical except for the introduction of the new technology (Falck-Zepeda et al., 2000b). Hence, in our analysis we will represent the world price as a function of the worldwide adoption vector: $p_j(\rho_{W,j})$.

If we assume a constant elasticity EU demand function for sugar:

$$D_{EU,j}(p) = \kappa_{EU,j}\, p^{-\varepsilon_{EU,j}}\,, \qquad (9)$$

the EU's export supply curve in year j can be modeled as

$$ES_j(p,\rho_{EU,j}) = Q_{EU,j}(p,\rho_{EU,j}) - D_{EU,j}(p) = Q_{EU,j}(p,\rho_{EU,j}) - C_j \quad (10)$$

with C_j the fixed consumption level in year j, due to yearly fixed intervention prices.

The world price reduction (from $p_j(0)$ to $p_j(\rho_{W,j})$ in Figure 1) is a synergy of two forces. First, the EU's export supply expansion[9] (from $ES_j(p,0)$ to $ES_j(p,\rho_{EU,j})$), due to a technology-induced pivotal shift of the EU's aggregate supply function (from $Q_{EU,j}(p,0)$ to $Q_{EU,j}(p,\rho_{EU,j})$), would cause the world price to decline from $p_j(0)$ to $p_j(\rho_{EU,j})$. This price decrease can be determined using a reduced form equation, extracted from the FAPRI's world sugar model by Poonyth et al. (2000), which calculates the world sugar price as a function of actual and lagged EU net sugar exports: (11)

$$\log[p_j(\rho_{EU,j})] = -1.0\log[ES_j(p,\rho_{EU,j}) - M_j] + 0.46\log[ES_{j-1}(p,\rho_{EU,j}) - M_{j-1}]$$

with M_j the sugar imports in year j. By taking the first differential, and if we assume that imports are not affected by the innovation, due to fixed ACP import arrangements, we can calculate the world price as a function of the EU's technology-induced export supply expansion. For each year j the model transforms the observed world price $p_j(0)$ into the world price $p_j(\rho_{EU,j})$ that would result from the EU's technology-induced export expansion in year j and j-1:

$$p_j(\rho_{EU,j}) = p_j(0)\left[1 + \sigma_1 \frac{ES_j(p_j(0),\rho_{EU,j}) - ES_j(p_j(0),0)}{ES_j(p_j(0),0)} + \sigma_2 \frac{ES_{j-1}(p_{j-1}(0),\rho_{EU,j-1}) - ES_{j-1}(p_{j-1}(0),0)}{ES_{j-1}(p_{j-1}(0),0)}\right]$$

with σ_1 = -1.0 and σ_2 = 0.46 (12)

The short-run flexibility σ_1 is -1 and the long-run flexibility is approximately half that of the short-run ($\sigma_1 + \sigma_2$ = -0.54), reflecting sugar export demand elasticities that are approximately twice as large in the long run as in the short run (Poonyth et al., 2000). The positive value for the coefficient σ_2 of the lagged technology-induced export supply expansion term reflects the output contraction of the ROW as a reaction on the world price decline from $p_j(0)$ to $p_j(\rho_{EU,j})$. Inclusion of this reaction transforms our static model into a dynamic equilibrium displacement model.

Secondly, the ROW technology-induced output expansion, which equals the export demand contraction, would further reduce the world price from $p_j(\rho_{EU,j})$ to the counterfactual world price $p_j(\rho_{W,j})$. We assume a constant elasticity ROW demand function for sugar:

$$D_{ROW,j}(p) = \kappa_{ROW,j}\, p^{-\varepsilon_{ROW,j}} \tag{13}$$

The positive ROW supply shift (from $Q_{ROW,j}(p,0)$ to $Q_{ROW,j}(p,\rho_{ROW,j})$ in Figure 1) translates into a negative export demand shift (from $ED_j(p,0)$ to $ED(p,\rho_{ROW,j})$):

$$ED_j(p,0) = D_{ROW,j}(p) - Q_{ROW,j}(p,0) \tag{14}$$

$$ED_j(p,\rho_{ROW,j}) = D_{ROW,j}(p) - Q_{ROW,j}(p,\rho_{ROW,j}) \tag{15}$$

Market clearing at equilibrium in the world market implies:

$$MC_j(p,\rho_{W,j}) = ES_j(p,\rho_{EU,j}) - ED_j(p,\rho_{ROW,j}) = 0 \tag{16}$$

Root calculation of the market clearing constraint in equation 18 finally yields an estimate of the counterfactual world price $p_j(\rho_{W,j})$, which is essentially a function of the global adoption vector $\rho_{W,j}$:

$$p_j(\rho_{W,j}) = \mathrm{root}[MC_j(p,\rho_{W,j}),p] \tag{17}$$

The overall world price change (from $p_j(0)$ to $p_j(\rho_{W,j})$) can now be transmitted to EU domestic prices using the principles of the European Union's Common Market Organization (CMO) for sugar. The basic Regulation for the organization is

Regulation (EEC) No 1785/81 (European Commission, 1996). Regulation (EC) No 1101/95 extends the production arrangements to the marketing year 2000-2001. The marketing year runs from 1 July to 30 June. Each year *j*, the Council fixes *intervention*[10] ($p^i_{EU,j}$) and *target prices* (about 5 % higher) for sugar and prices for beet. Intervention is opened for limited quantities under a quota for which the price guarantee is almost full (A quota) and a quota for which the price guarantee is partial (B quota). The *basic beet price* is fixed annually in the light of the intervention price for white sugar and standard amounts representing the processing margin, the yield, the receipts of refineries from sales of molasses and, where appropriate, the cost incurred in delivering beet to refineries. The *minimum price* is fixed each year for beet processed into sugar and is the minimum price that sugar manufacturers are obliged to pay to producers for the purchase of beet. Since the EU production quotas are based on historic national production levels, their relationship varies widely between European member countries. Anticipating an increase in consumption, the quotas $\overline{Q}_{a,j}$ for A sugar and $\overline{Q}_{b,j}$ for B sugar) are set at a higher level than internal consumption C_j, the internal demand ($D_{EU,j}$) at the intervention price $p^i_{EU,j}$ (Figure 1). This overproduction $\overline{Q}_{d,j}$ (= $\overline{Q}_{a,j}$ + $\overline{Q}_{b,j}$ − C_j), although receiving a guaranteed B sugar price $p^b_{EU,j}$, is exported on the world market and hence subsidized. This export subsidy system is completely auto-financed by levies on A and B quota production. Consumers, who pay a high internal intervention price $p^i_{EU,j}$, subsidize the internal within-quota production. A levy τ^a_j of maximum 2 % of the intervention price applies on the entire (A + B) within-quota production. Moreover, B quota production receives an additional, more variable, levy τ^b_j of maximum 37.5 % of the intervention price.

Sugar manufacturers and sugar beet growers pay the levies in accordance with the income they obtain from sugar, i.e. 40 % and 60 % respectively (European Commission, 1996). Both levies serve to satisfy the auto-financing constraint AFC_j, which is a function of the world price, while the latter is a function of world-wide adoption of the new technology (Combette et al., 1997):

$$AFC_j(p_j(\rho_{W,j})) = p^i_{EU,j}\tau^a_j(p_j(\rho_{W,j}))(\overline{Q}_{a,j} + \overline{Q}_{b,j}) + p^i_{EU,j}\tau^b_j(p_j(\rho_{W,j}))\overline{Q}_{b,j} - (\overline{Q}_{a,j} + \overline{Q}_{b,j} - C_j)(p^i_{EU,j} - p_j(\rho_{W,j})) = 0 \quad (18)$$

The levies have to fill the gap between the world price $p_j(\rho_{W,j})$ and the high internal price $p^i_{EU,j}$ for within-quota production in excess of consumption that has to be exported on the world market. If the auto-financing constraint does not solve by combining (18) and (19), the system (18) and (20) is solved. Finally, when the latter neither yields a solution, a multiplicator α is defined solving the system (18) and (21).

$$\left|\begin{array}{l} \tau^a_j(p_j(\rho_{W,j})) \in [0, 0.02] \\ \tau^b_j(p_j(\rho_{W,j})) = 0 \end{array}\right. \quad (19)$$

$$\left|\begin{array}{l} \tau^a_j(p_j(\rho_{W,j})) = 0.02 \\ \tau^b_j(p_j(\rho_{W,j})) \in [0, 0.375] \end{array}\right. \quad (20)$$

$$\left|\begin{array}{l} \tau^a_j(p_j(\rho_{W,j})) = (1+\alpha)\, 0.02 \\ \tau^b_j(p_j(\rho_{W,j})) = (1+\alpha)\, 0.375 \end{array}\right. \quad (21)$$

By imputing the technology-induced world price $p_j(\rho_{W,j})$ into the auto-financing constraint (equation 18), the system of equations (18) to (21) yields an estimate of the levies $\tau^a_j(p_j(\rho_{W,j}))$ and $\tau^b_j(p_j(\rho_{W,j}))$ that have to be imposed on quota-production to satisfy the auto-financing constraint. This specification clearly visualizes how the levies are a function of the world price, while the latter is a function of world-wide adoption of the new technology. A technology-induced decline in the world price would widen the gap between the world and the intervention price, and hence engender an increase in A and B levies. The CMO for sugar allows some Member States to apply higher intervention prices. For each Member State, A and B quota prices can be deducted from the country-specific intervention prices $p_{i,j}^{i}$ and the EU-specific A and B levies:

$$p_{i,j}^{a}(p_j(\rho_{W,j})) = p_{i,j}^{i}[1-\tau_j^{a}(p_j(\rho_{W,j}))] \text{ , and} \quad (22)$$

$$p_{i,j}^{b}(p_j(\rho_{W,j})) = p_{i,j}^{i}[1-\tau_j^{a}(p_j(\rho_{W,j}))-\tau_j^{b}(p_j(\rho_{W,j}))] . \quad (23)$$

By imputing $p_j(\rho_{W,j})$ into equations 22 and 23, the model allows us to transform technology-induced changes in world price into domestic quota price changes. This auto-financing system explains why B quota prices are more variable and sensitive to world prices. For 1992-1993 for example, Combette, Giraud-Héraut and Réquillart (1997) report price transmission coefficients between 0 and 0.11 for A sugar and between 0.11 and 0.62 for B sugar. This is consistent with Devadoss and Kropf (1996), who find an overall price transmission coefficient of 0.48. Thus, the producer price is endogenous since it depends on sugar production, internal demand and the gap between the intervention and the world price. In some EU Member States (Spain, Ireland, Italy, Greece, the Netherlands, and the UK) processors pay a weighted-average price for beet covering all within-quota sugar, based on domestic quota prices and world prices (Combette et al., 1997). In those cases, the impact of changes in minimum producer prices is masked for farmers, though it is fully felt by processors (Harris and Tangermann, 1993). All out of quota production is called ‘C sugar’ and can either be (1) stocked[11] to be carried over to the following marketing year, enabling to smooth out annual production variations, or (2) exported on the world market at the world price, i.e. without[12] export subsidies.

Finally, the EU's CMO for sugar contains some additional features, such as the ACP import arrangements, conferring free access to the EU market for ACP countries, up to a certain maximum limit. These arrangements are essentially aid flows accruing to ACP countries and are omitted from our welfare framework, since they do not[13] affect the flow of research benefits. The same argument holds for the EU's stocking and carrying-over policy. Since this policy is not likely to affect the flow of research benefits, at least in the medium[14] and long run, it is omitted from our model.

The opposite effects of cost-reduction and depression of world and domestic prices, both engendered by the new technology, are transmitted to average land rents through equation (3) by imputing the corresponding prices and adoption rates. Note that the land rents are a function of (1) the region-specific and (2) the world-wide adoption rates, the latter through the world price: $\bar{\pi}_{i,j}\left[p^{a}_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right]$ for A quota, $\bar{\pi}_{i,j}\left[p^{b}_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right]$ for B quota, and $\bar{\pi}_{i,j}\left[p_j(\rho_{W,j}),\rho_{i,j}\right]$ for C sugar beets. The corresponding surplus changes can now be computed using standard procedures (Just et al., 1982). If $L_{i,j}(\bar{\pi})$ denotes the optimal allocation of land to sugar beets in country i in year j, the variation in producer surplus (relative to the benchmark without adoption) due to the innovation can be calculated according to an elegant methodology of Moschini, Lapan, and Sobolevski (2000), and adapted to the EU's CMO for sugar. Figure 2 shows graphically how innovation rents can be measured in the land market. The producer surplus change strongly depends on the competitiveness of the country in sugar production. Therefore, we introduce a new categorical parameter $\varphi_{i,j}$ to denote the region's production efficiency. Depending on the value this parameter takes, the model chooses the appropriate formula for the calculation of the welfare effects. The change in producer surplus of a high-cost country i that only produces A sugar, without fulfilling it's A quota ($\varphi_{i,j}$ = 0, S_0 in Figure 2), can be computed as:

$$\Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) = a = \int_{\bar{\pi}_{i,j}\left[p^a_{i,j}(p_j(0)),0\right]}^{\bar{\pi}_{i,j}\left[p^a_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right]} L_{i,j}(\bar{\pi})d\bar{\pi} \tag{24}$$

Note that the benefit resulting from the technology not only depends on the adoption within the region, but also on world-wide adoption rates through the technology-induced world price depreciation. The innovation rents of medium-cost countries, fulfilling their A quota but not their B quota ($\varphi_{i,j}$ = 1, S_1 in Figure 2), can be calculated as follows:

$$\Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) = a+b-c-d-e+e+d+j = (a+b)-c+j \tag{25}$$

$$= \frac{\overline{Q}^a_{i,j}}{(1+\rho_{i,j}\beta_i)G_{i,j}p_j^{\eta_i}(\rho_{W,j})}\left[\bar{\pi}_{i,j}\left(p^a_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right)-\bar{\pi}_{i,j}\left(p^a_{i,j}(p_j(0)),0\right)\right]$$

$$-\frac{\rho_{i,j}\beta_i\overline{Q}^a_{i,j}}{(1+\rho_{i,j}\beta_i)G_{i,j}p_j^{\eta_i}(\rho_{W,j})}\left[\bar{\pi}_{i,j}\left(p^a_{i,j}(p_j(0)),0\right)-\bar{\pi}_{i,j}\left(p^b_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right)\right]$$

$$+\int_{\bar{\pi}_{i,j}\left[p^b_{i,j}(p_j(0)),0\right]}^{\bar{\pi}_{i,j}\left[p^b_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right]}\left[L_{i,j}(\bar{\pi})-\frac{\overline{Q}^a_{i,j}}{G_{i,j}p_j^{\eta_i}(0)}\right]d\bar{\pi}$$

$\overline{Q}^a_{i,j}$ and $\overline{Q}^b_{i,j}$ represent respectively the A and B quota. For exporting low-cost EU countries responding to world prices ($\varphi_{i,j}$ = 3, S_3 in Figure 2), the change in producers' surplus is:

$$\Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) = a+b-c-d-e-f-g-h-i \tag{26}$$

$$+i+h+g+f+e+d+j+k-s-t-u-v+v+u+x+\alpha+\gamma$$

$$=(a+b)-c+(j+k)-(s+t)+(x+\alpha+\gamma)$$

$$\left.\begin{aligned}
&=\frac{\overline{Q}^{a}_{i,j}}{(1+\rho_{i,j}\beta_i)G_{i,j}p_j^{\eta_i}(\rho_{W,j})}\left[\overline{\pi}_{i,j}\left(p^{a}_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right)-\overline{\pi}_{i,j}\left(p^{a}_{i,j}(p_j(0)),0\right)\right]\\
&-\frac{\rho_{i,j}\beta_i\overline{Q}^{a}_{i,j}}{(1+\rho_{i,j}\beta_i)G_{i,j}p_j^{\eta_i}(\rho_{W,j})}\left[\overline{\pi}_{i,j}\left(p^{a}_{i,j}(p_j(0)),0\right)-\overline{\pi}_{i,j}\left(p^{b}_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right)\right]\\
&+\left[\frac{\overline{Q}^{a}_{i,j}+\overline{Q}^{b}_{i,j}}{(1+\rho_{i,j}\beta_i)G_{i,j}p_j^{\eta_i}(\rho_{W,j})}-\frac{\overline{Q}^{a}_{i,j}}{G_{i,j}p_j^{\eta_i}(0)}\right]\left[\overline{\pi}_{i,j}\left(p^{b}_{i,j}(p_j(\rho_{W,j})),\rho_{i,j}\right)-\overline{\pi}_{i,j}\left(p^{b}_{i,j}(p_j(0)),0\right)\right]\\
&-\frac{\rho_{i,j}\beta_i(\overline{Q}^{a}_{i,j}+\overline{Q}^{b}_{i,j})}{(1+\rho_{i,j}\beta_i)G_{i,j}p_j^{\eta_i}(\rho_{W,j})}\left[\overline{\pi}_{i,j}\left(p^{b}_{i,j}(p_j(0)),0\right)-\overline{\pi}_{i,j}\left(p_j(\rho_{W,j}),\rho_{i,j}\right)\right]
\end{aligned}\right\}\text{within-quota}$$

$$\left.+\int_{\overline{\pi}_{i,j}[p_j(0),0]}^{\overline{\pi}_{i,j}[p_j(\rho_{W,j}),\rho_{i,j}]}\left[L_{i,j}(\overline{\pi})-\frac{\overline{Q}^{a}_{i,j}+\overline{Q}^{a}_{i,j}}{G_{i,j}p_j^{\eta_i}(0)}\right]d\overline{\pi}\right\}\text{out-of-quota}$$

Figure 1 illustrates graphically how the benefits are split up in (1) a within-quota (area $b-a$), and (2) an out-of-quota part (area $d-c$), earned on the world market. For regions in the ROW responding to world prices ($\varphi_{i,j}=5$), innovation rents can be calculated as:

$$\Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) = \int_{\overline{\pi}_{i,j}(p_j(0),0)}^{\overline{\pi}_{i,j}(p_j(\rho_{W,j}),\rho_{i,j})} L_{i,j}(\overline{\pi})d\overline{\pi} \tag{27}$$

In specifying equation (6), we assumed that exporting low-cost EU or ROW regions not responding to world prices have no possibilities for output expansion. Instead, they will respond to new technologies by freeing up land allocated to sugar beets, so that their total production remains unchanged. For those regions, we include this possibility by equaling their land supply function to their constant total production, divided by the (optimal) yield function:

$$L_{i,j}(p,\rho_{i,j}) = \frac{\overline{Q}_{i,j}}{(1+\rho_{i,j}\beta_i)G_{i,j}p^{\eta_i}} \tag{28}$$

The change in producers' surplus for exporting low-cost EU regions not responding to world prices ($\varphi_{i,j}$ = 2) can be graphically visualized in Figure 2. The land supply function S_2 shows that these regions would normally not supply C-sugar, since the rents of the latter are not sufficient to cover production costs. However, in order to ensure that his quotas are fulfilled, even in low-yield years, farmers choose to accept a minimal precautionary overproduction. This overproduction leads to a financial loss (areas $w + x + \alpha + \beta$ in the pre-innovation case and areas $t + w$ in the post-innovation case), which can be considered as a risk premium, paid by the farmer to ensure his quota-fulfillment. Graphically, innovation rents would be calculated as:

$$\Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) = a+b-c-d-e-f-g-h+h+g+f+e+d \tag{29}$$

$$+\,j+k-s-t-w+w+x+\alpha+\beta = (a+b)-c+(j+k)-(s+t)+(x+\alpha)+\beta$$

Note that these innovation rents equal the innovation rents of price-responsive regions minus the area γ, plus the area β. The area γ can be interpreted as the rents that would be captured by having the possibility to expand land (from L_c to $\hat{L}_c$ in Figure 2), purely in response of the profit increase, disregarding any yield-effect. The area β is a part of the risk premium that is eliminated by the land-contracting effect of the new technology. Area β is difficult to measure and depends strongly on farmers' and processors' risk aversion. While we observe full quota fulfilment and C-sugar production for these countries, we know that their land supply function is more closely related to S_2 than to S_3. Since data is lacking for precise vertical positioning of the latter, we will assume the same land supply function for price-responsive and price-irresponsive regions. The measurement error that results from this simplification equals area β minus area γ and is assumed to be small for price-irresponsive regions[15]. Therefore, the change in producers' surplus of these regions will be calculated with equation (26). For regions in the ROW not responding to world prices ($\varphi_{i,j}$ = 4) finally, innovation rents are computed with equation (27) for the same reason.

The EU's aggregate producer surplus change is simply the sum of all production blocks' producer surplus changes:

$$\Delta PS_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j}) = \sum_{i=2}^{15} \Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) \qquad (30)$$

In Figure 1, the aggregate benefit for the EU can be assessed by a pivotal shift of the aggregate EU supply function (from $Q_{EU,j}(p,0)$ to $Q_{EU,j}(p,\rho_{EU,j})$). Q_d (= $Q_a + Q_b - C$) represents the within-quota production in excess of domestic consumption C, which is exported on the world market. This exported production is subsidized, since it receives the guaranteed B quota price, while it is exported at the world price. Decline of the world price from $p_j(0)$ to $p_j(\rho_{W,j})$, due to the technology-induced shift of EU aggregate supply, raises subsidy costs up to Q_d ($p_j(0) - p_j(\rho_{W,j})$), represented by the lower area a. These extra costs have to be borne by the producers via increased levies on their within-quota production (equations 18 to 23). In most cases, adapting only the B quota levy is sufficient, visualized in Figure 1 through a decline of the B quota price from $p^b_{i,j}(p_j(0))$ to $p^b_{i,j}(p_j(\rho_{W,j}))$. This means that the cost for the producers is $Q_b[p^b_{i,j}(p_j(0)) - p^b_{i,j}(p_j(\rho_{W,j}))]$, represented by the upper area a, which is essentially the same as the lower area *a*. Thus, the total within-quota benefits equal the difference between areas *b* and *a*. To these rents, out-of-quota benefits have to be added, represented by the difference between areas *d* and *c*. The EU's change in consumer surplus can be modeled as:

$$\Delta CS_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j}) = \int_{p^i_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j})}^{p^i_{EU,j}(p_j(0),0)} D_{EU,j}(p)dp = 0 \qquad (31)$$

In our model however, the EU's intervention price is fixed, so it is neither a function of the world price, nor the adoption rate within the EU:

$$p^i_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j}) = \overline{p}^i_{EU,j} \qquad (32)$$

This means that technology-induced welfare effects for consumers would only be possible within the CMO for sugar if the EU endogenized[16] world prices and/or technology adoption rates in their intervention price.

Analogous to equation (31), the ROW aggregate innovation rents (area *g* – area *e* in Figure 1) are simply the sum of cane (i = 0) and beet (i = 1) producers' surplus changes:

$$\Delta PS_{ROW,j}(p_j(\rho_{W,j}),\rho_{ROW,j}) = \sum_{i=0}^{1} \Delta PS_{i,j}(p_j(\rho_{W,j}),\rho_{i,j}) \qquad (33)$$

The ROW consumers' surplus change (area *e* + area *f* in Figure 1) equals:

$$\Delta CS_{ROW,j}(p_j(\rho_{W,j}),\rho_{ROW,j}) = \int_{p_j(\rho_{W,j})}^{p_j(0)} D_{ROW,j}(p)dp \qquad (34)$$

Finally, to calculate the profit of the input suppliers, we need an estimate for all regions i of the supply of land to the sugar beet industry in equilibrium: $L_{i,j}[p_j(\rho_{W,j}),\rho_{i,j}]$. Note again the double dependence of land supply on local as well as global adoption rates, the latter through the technology-induced world price depreciation. Again, through equation (28), we include the possibility for some regions not responding to world prices, to respond to the new technology by freeing up land allocated to sugar beets instead. An apparent contradiction now emerges: in some regions belonging to a quota system, the yield-increasing effect of both a new technology either a higher price, the latter through the (optimal) yield function, can negatively affect its demand through a reduction of allocated land. The profit of the input suppliers can now be computed as:

$$\Pi_j(p_j(\rho_{W,j}),\rho_{W,j}) = \sum_{i=0}^{15}\rho_{i,j}L_{i,j}(p_j(\rho_{W,j}),\rho_{i,j})\mu_{i,j}\delta w_{i,j} \tag{35}$$

Total welfare increase is simply: (36)

$$W_j(p_j(\rho_{W,j}),\rho_{W,j}) = \Delta PS_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j}) + \Delta CS_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j})$$

$$+\Delta PS_{ROW,j}(p_j(\rho_{W,j}),\rho_{ROW,j}) + \Delta CS_{ROW,j}(p_j(\rho_{W,j}),\rho_{ROW,j}) + \Pi_j(p_j(\rho_{W,j}),\rho_{W,j})$$

Finally, by using a risk adjusted rate of return derived from the capital asset pricing model (CAPM), d, we can aggregate all year-specific welfare changes and actualize them to the year 2001-2002:

$$\Delta PS_{EU}(p(\rho_W),\rho_{EU}) = \sum_{j=1}^{5}(1+d)^{6-j}\Delta PS_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j}) \tag{37}$$

$$\Delta CS_{EU}(p(\rho_W),\rho_{EU}) = \sum_{j=1}^{5}(1+d)^{6-j}\Delta CS_{EU,j}(p_j(\rho_{W,j}),\rho_{EU,j}) = 0 \tag{38}$$

$$\Delta PS_{ROW}(p(\rho_W),\rho_{ROW}) = \sum_{j=1}^{5}(1+d)^{6-j}\Delta PS_{ROW,j}(p_j(\rho_{W,j}),\rho_{ROW,j}) \tag{39}$$

$$\Delta CS_{ROW}(p(\rho_W),\rho_W) = \sum_{j=1}^{5}(1+d)^{6-j}\Delta CS_{ROW,j}(p_j(\rho_{W,j}),\rho_{W,j}) \tag{40}$$

$$\Pi(p(\rho_W),\rho_W) = \sum_{j=1}^{5}(1+d)^{6-j}\Pi_j(p_j(\rho_{W,j}),\rho_{W,j}) \tag{41}$$

$$W(p(\rho_W),\rho_W) = \sum_{j=1}^{5}(1+d)^{6-j}W_j(p_j(\rho_{W,j}),\rho_{W,j}) \tag{42}$$

In equations (37) to (42) $p(\rho_W)$ is a 1x6 vector of functions $p_j(\rho_{W,j})$. ρ_{EU}, ρ_{ROW}, and ρ_W are respectively a 14x6 matrix, 2x6 matrix, and 16x6 matrix of adoption rates.

EUWABSIM

Our theoretical framework is materialized in the simulation model 'EUWABSIM'. This software package is made up of three interlaced components: (1) an Excel module for data management, (2) a Mathcad module, containing the mathematical body of the model, and (3) an @Risk module, containing the 'uncertainty element' of the model, for carrying out sensitivity and scenario analyses. Using stochastic sensitivity analysis via @Risk, subjective prior distributions of non-deterministic parameters (elasticities, yield increases, cost reductions, technology price markup, etc.) are included to generate posterior distributions of the outcomes (counterfactual world price and research benefits) of the model (Davis and Espinoza, 1998). In this paper however, we only report the means of the obtained distributions.

Data and Model Calibration

In our simulation model we assume hypothetically[17] that the European Union's sugar industry, as a competitive player in the world market, and the ROW Beet region embraced the new technology since the marketing year 1996/97, and progressively adopted it up to 2000/01. Since we use an *ex ante* research framework, our model is calibrated on the observed production data from this period, i.e. without adoption of the new technology[18]. First of all we need a rough[19] estimate of the observed initial (before adoption) land rent $\hat{\pi}_{i,j}$ in all regions. Then, observed yields ($y_{i,j}$), 'incentive prices' ($\hat{p}_{i,j}$ which can be $p^a_{i,j}(p_j(0))$, $p^b_{i,j}(p_j(0))$ or $p_j(0)$), quantities ($\overline{Q}_{i,j}$) and quota ($\overline{Q}^{a}_{i,j}$ and $\overline{Q}^{b}_{i,j}$) are taken from various sources (European Commission, 1999, F.O.Licht, 2000, European Commission, 2000, F.O.Licht, 2001, FAO, 2002).

The estimate of the cost reduction induced by the introduction of the new technology is crucial to the economic surplus calculation. Due to the absence of farm-level adoption in the EU, we combine information from field trials with production cost data from national farm surveys and Eurostat to calibrate the technology-specific parameters $\alpha_{i,j}$ and β_i. Field trials suggest that yield boosts (β_i) vary from 0 % to 8 % (Wevers, 1998, Richard-Molard and Gestat de Garambe, 1998, Dewar, 2000, Bückmann et al., 2000, Jassem, 2000). Hence, for this parameter we define a conservative triangular distribution with a minimum of zero, a most likely value of 2 % and a maximum of 5 %.

Average herbicide costs and application costs for all EU countries are reported by Hermann (1996, 1997). The change in weeding costs ($\alpha_{i,j}$) is calculated by taking the difference between the conventional reported average herbicide and application costs and the costs that would be generated in a comparable system in which the combination of glyphosate[20] and GT sugar beet seed is used. For the Northern countries (Belgium + Luxembourg, Denmark, Germany, France, Ireland, Italy, the Netherlands, Austria, Finland, Sweden, UK), characterized by a herbicide application rate of at least 2.5 applications, the GT system is based on a glyphosate dose of 6 liter, sprayed through an average of 2.5 applications (2 times 3 liter of 3 times 2 liter). For Southern countries (Greece, Spain, and Portugal), the average application rate is at most 1.5 applications. In these cases, the counterfactual GT system is assumed to be a one-pass application of 3 liter glyphosate. We further assume an exogenously fixed price decline of 20 % in the market of conventional herbicides, due to the competition effect between the conventional and the new technology. The fixed per-hectare profitability parameter $\alpha_{i,j}$ is a result of the before-mentioned factors. As a first step, we do not include any distribution for this parameter, but shift all uncertainty to the potential price markup of HT sugar beets. Due to the very close connection between $\alpha_{i,j}$, the adoption pattern, the conventional herbicide price decline, and the potential price markup, a wide distribution for the latter is used to incorporate all uncertainty regarding the potential average per-hectare profitability of the new technology.

Since nowhere in the world any market has developed yet, no information is available on price premiums in this non-competitive market. We assume that the observed price markup of 40 % for US Roundup Ready™ soybeans consists in an upper limit. Using a static framework for France, Lemarié et al. (2001) also find an optimal price markup of 40 % for the commercialization of HT sugar beets. We expect price premiums to be lower in the EU, compared to the US, due to the negative public opinion and the hesitant behavior of EU Member States regarding transgenic crops. We also assume that the input industry would sufficiently lower its prices in the early adoption stage (even to zero) to penetrate the market. Due to the large uncertainty regarding price premiums ($\mu_{i,j}$), we incorporate a wide triangular distribution of potential price premiums with a minimum of zero, a most likely value of 20 % and a maximum of 40 %. Inspired by the Roundup Ready™ soybeans case in the US, we assume that the input supplier will not apply any regional price differentiation in the EU, but instead we allow price differentiation between the EU and the ROW. Hence, in this paper we only focus on technological uncertainties, such as the potential yield boost β_I and price markup $\mu_{i,j}$.[21]

Supply and demand elasticities and their respective standard errors are taken from literature. The work of Poonyth et al. (2000) is particularly interesting since it reports very reliable estimates for each EU member country's elasticity of land supply with respect to sugar beet prices, defined as $\psi = (\partial L/\partial p)(p/L)$. Given these estimates, the parameter θ is calibrated as (Moschini et al., 2000):

$$\theta_{i,j} = \frac{\psi_i \hat{\pi}_{i,j}}{\hat{p}_{i,j} y_{i,j}} \tag{43}$$

Devadoss and Kropf (1996) report supply elasticities for all major sugar producers in the world. For the ROW Cane and ROW Beet regions in our model, a production-weighted average is calculated of the reported supply elasticities. Since these elasticities already incorporate yield response to prices, we set $\eta_i = 0$ in these regions. For EU regions we set $\eta_i = 0.05$, inspired by Moschini, Lapan, and Sobolevski (2000).

Given the assumed, estimated and retrieved parameters, structural parameters, such as $A_{i,j}$, $G_{i,j}$, and $\lambda_{i,j}$ will be calibrated so as to retrieve acreage, quantity, yield and price data for the period 1996/97-2000/01:

$$A_{i,j} = \hat{\pi}_{i,j} + \delta w_{i,j} - \frac{\hat{p}_{i,j} y_{i,j}}{1+\eta_i} \tag{44}$$

$$G_{i,j} = \frac{y_{i,j}}{\hat{p}_{i,j}^{\eta_i}} \tag{45}$$

$$\lambda_{i,j} = \frac{\overline{Q}_{i,j}}{\hat{\pi}_{i,j}^{\theta_{i,j}} y_{i,j}} \tag{46}$$

The sugar demand elasticity of the ROW $\varepsilon_{ROW,j}$ is calibrated on the export demand elasticities in FAPRI's world sugar model (equations 11 and 12), reported by Poonyth et al. (1998, 2000). For this calibration step we force the market to clear (equation 16) after the EU technology-induced world price decline, without adoption in the ROW:

$$MC_j(p_j(\rho_{EU,j}),\rho_{EU,j}) = ES_j(p_j(\rho_{EU,j}),\rho_{EU,j}) - ED(p_j(\rho_{EU,j}),0) = 0 \qquad (47)$$

The scale parameter κ_j is calibrated on the observed sugar demand in the ROW $\hat{D}_{ROW,j}$ and the 'incentive price' $\hat{p}_{i,j}$:

$$\kappa_i = \frac{\hat{D}_{ROW,j}}{\hat{p}_{i,j}^{-\varepsilon_{ROW,j}}} \qquad (48)$$

The sugar demand elasticity of the ROW $\varepsilon_{ROW,j}$ can now be endogenously calibrated:

$$\varepsilon_{ROW,j} = \frac{-\ln\left(\dfrac{ES_j(p_j(\rho_{EU,j}),\rho_{EU,j}) + \overline{Q}_{ROW,j}}{\hat{D}_{ROW,j}}\right)}{\ln\left(\dfrac{p_j(\rho_{EU,j})}{p_j(0)}\right)} \qquad (49)$$

We finally introduce technological change into the model by assuming an exogenous logistic adoption curve (Griliches, 1957):

$$\rho_{i,j} = K_i \big/ (1 + e^{a_i + b_i j}) \qquad (50)$$

To have a comparing point, we first estimate the parameters of the adoption curve of a comparable biotechnology innovation in the US. We believe that the US case of HT Roundup Ready™ soybeans is comparable to the EU's case of HT sugar beets, because of (1) the common herbicide tolerance technology, (2) the importance of the crop in total production and in most Member States, and (3) the importance of the export of the refined products of both crops. Assuming an adoption ceiling of 75 % we find estimates of 2.76 for *a* and -0.85 for the adoption speed *b*. Since we do not have any information on the potential adoption curve of HT sugar beets in the EU, we assume that the observed adoption pattern of Roundup Ready™ soybeans in the US is an upper limit. Since no significant adoption is expected to occur before 2005 (Table 3), we assume a hypothetical adoption pattern with half the speed, i.e. b = -0.43, of the observed adoption pattern of Roundup Ready™ soybeans in the US. In Figure 3, both curves are visualized. We allow technology spillovers to the ROW Beet region, subject to the same hypothetical adoption pattern, but assume a *ceteris paribus* without adoption in the ROW Cane region[22]. Due to the exogeneity of adoption in our model, our welfare calculations have to be interpreted as functions, conditional on this adoption pattern. In other words, we calculate the 'average welfare effects foregone', associated with a hypothetical logistic adoption pattern at half the speed of US Roundup Ready™ soybean adoption.

A final crucial parameter to be assessed is $\varphi_{i,j}$, the region's production efficiency. Portugal and Greece are the only countries that not consistently fulfill their A quotas ($\varphi_{i,j}$ = 0). On the other extreme, Frandsen et al. (2001) argue that in the EU, only four countries can be considered responding significantly to world sugar prices ($\varphi_{i,j}$ = 3): Austria, France, Germany, and the UK. Depending on the marketing year, the other EU countries exhibit a production efficiency somewhere between these two extremes ($\varphi_{i,j}$ = 1, 2). Among the sugar beet producing regions, the EU is considered to be one of the most efficient producers (Haley, 1998). Moreover, the US sugar sector, belonging to the ROW beet region is highly protected by a tariff quota system, eliminating any link between domestic prices and supply and world prices (Roberts and Wish-Wilson, 1991). Therefore, we assume that the highly protected ROW beet region will not export its technology-induced surplus on the world market, but instead will free up land allocated to sugar beets ($\varphi_{i,j}$ = 4). The ROW cane industry is assumed to respond to world prices ($\varphi_{i,j}$ = 5), but due to the *ceteris paribus* assumption in the cane sector, no technology-induced surplus is generated by the model.

Results

In Table 6 the effects of the introduction of HT sugar beets in the EU and the ROW on world and domestic EU prices as well as on producers' and consumers' welfare and input suppliers' profits are summarized. The second column represents the benchmark year 1996/97 in which no adoption is assumed. The next five columns represent the five subsequent agricultural seasons of adoption. The last column represents the aggregation of the welfare effects, actualized to the year 2001/02, using a risk adjusted rate of return of 10.5%.

Surprisingly, the model results suggest that the largest share (53 %) of the benefits is accruing to the ROW if we assume that beet producers in these (mostly industrial) countries (1) are able to achieve the same efficiency-enhancing effects through the use of the new technology and (2) are not able to export the technology-induced surplus on the world market and further significantly erode world market prices. Total producers' surplus increase is 949 million €. Despite the fact that the EU and the ROW produce roughly the same quantity of sugar, the technology rents are not equally shared among these regions. EU producers absorb 345 million €, while ROW beet growers extract 605 million €, respectively 36 % and 64 % of total producers' surplus. This is due to the fact that the innovation engenders an important fixed per-hectare benefit $\alpha_{i,j}$, such that, to some extent, the benefit sharing reflects the land sharing between these two regions (respectively 31 % and 69 % of total land allocated to sugar beet, Table 2). The depressing effect on world prices, engendered by innovating world price responsive regions, is profitable for ROW consumers, who gain 323 million €, but is completely offset by the loss of ROW cane growers, accounting for 316 million €. The net effect is that roughly half of the benefits spills over to the ROW.

Since we assumed no technology-induced export expansion in the ROW, due to high government interventions, these spillovers do not affect the EU through depressing world prices. Instead, the world price responsive part of EU sugar supply will have a negative effect on world and EU domestic prices and producers' welfare, but this effect is small. The model suggests that a minor world price decline of 0.29 % is expected to occur after 5 years of adoption, given the assumed adoption pattern. This price decline is only partially (27.6 %) transmitted to domestic B sugar prices, declining by only 0.08 % during the same period. The EU sugar industry captures the next largest share of the benefits (345 million €, i.e. 30 %).

Since EU intervention prices are exogenously fixed each year, no domestic price declines are engendered by the introduction of the technology. As a result, EU consumers do not take part in the distribution of the gains from the innovation. Therefore when modern (bio)technologies are introduced in commodity markets subject to obsolete trade policies, the natural flow of domestic benefits from the input industry, via farmers, to consumers is hampered and biased towards the producing sector (input industry and farmers), leaving domestic consumers unaffected. Remarkably, consumers outside the EU gain while EU citizens continue to subsidize EU sugar production trough high sugar prices, despite the innovation. Therefore, trade policies should at least endogenize the effects of technologies that have an important impact on societal welfare, such as agricultural biotechnology.

The smallest share of the benefits (194 million €, i.e. 17 %) finally, accrues to the monopolistic input industry (seed suppliers and gene developers). The limited ability of the input industry to extract a large part of the benefits can be explained by the fact that in a quota system, producers not responding to world prices will decrease their land supply to the sugar industry, rather than increase it. This negatively affects demand for the new technology. The aggregated global welfare increase after five years of adoption amount to roughly one billion €.

Extensions of the Model

A first interesting extension to the model has been the inclusion of social costs due to environmental externalities, elaborated in Demont et al. (2002). Detailed information is needed about the current externalities, occurring in conventional sugar beet growing, as well as a methodology to valorize these externalities and translate them into social costs. These costs can be included into the welfare framework. They cause a negative shift of the supply curve, enabling to partition the benefits and costs between producers and environment (Alston et al., 1995).

Secondly, as a first pass we assumed an exogenous adoption curve and a distribution of possible price markups while in reality these parameters are endogenous variables of the model. Adoption will depend on profit, which depends, in its turn, on the price of the innovation. Reversely, the price markup depends on demand (adoption), which depends on profit. An extension could be to endogenize these variables in the model.

However, actual consumer and political resistance towards GMO's, especially in the European Union, has shown that the simplified scheme of adoption we just outlined, does not hold any longer. Especially in the case of the sugar sector, sugar and sugar beet demand is very concentrated. If one of the major clients (e.g. Coca Cola) refuses sugar produced with GM sugar beets, processors will change their contracts towards producers and force them to produce GM-free. Hence, the adoption decisions of the latter are no longer autonomous as in the past with previous agricultural innovations. Thus, the combination of uncertainty and a strongly concentrated sugar industry will complicate the endogenization of adoption and biotechnology pricing policies in the model.

Finally, an extension could be to re-run the model for different scenarios of liberalization of the EU's sugar CMO. These studies would illustrate the distortions that occur in the interaction between policies and modern agricultural innovations and that would prevent the benefits from R&D to flow from beet growers to consumers.

Conclusions

We showed that the EU's sugar market could serve as a relevant case study for the calculation of the *ex ante* welfare effects of agricultural biotechnology in the EU. Therefore, we developed a theoretical welfare framework shaped to the characteristics of the EU's Common Market Organization (CMO) for sugar. The result is the simulation model 'EUWABSIM', which enables to assess the size and distribution of the benefits of transgenic sugar beet adoption in the European Union and the Rest of the World.

Since only two gene developers (Monsanto and Aventis) and three seed companies (KWS, Advanta and Novartis) dominate the market for GM sugar beet seeds, seed prices will be higher compared with a competitive market. As a result, some benefits will accrue to input suppliers in the form of 'oligopolistic rents'. However, due to the presence of alternative non-GM technologies, the input sector pricing decisions are bounded by the producers' adoption incentive. Consequently, producers will be able to extract a part of the benefits, in most cases a within-quota benefit that is more or less protected from price depreciation. Low cost producers will gain some additional benefits on the world market. However, declining word prices, since the EU is an important player in international sugar trade, will dampen these producer surplus increases. The outcome for producers in the rest of the world will depend on technology adoption and on structural parameters of the world sugar trade. Since the ROW Cane region is lagging behind the EU, due to our *ceteris paribus* focus, competition on the world market between the two players will adversely affect ROW cane producers and reversely. Given that quota prices for both growers and processors are fixed, there is no rent in this model that accrues to processors. Due to fixed internal sugar prices, EU consumers will not see any price change or welfare increase in the short run. ROW consumers will gain, due to the depressing effect of the technology on world prices. In literature there is widespread belief that positive environmental externalities of HT sugar beets (declining herbicide use and toxicity) exceed negative ones (gene flow risks, weed resistance, etc.). Hence, net benefits, or more correct a reduction in current negative externalities (social costs), are expected to flow to the environment. Finally, since the CMO for sugar is largely self-financing from a public financing perspective, neither public expenditures – except for public biotechnology R&D in the sugar sector – nor benefits will accrue to EU governments.

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[1] This is actually the only way benefits of technological progress end up being passed on to consumers in the European Union (Thirtle, 1999).

[2] However, since Europe and Japan are reluctant to accept GM pulp, up to now, the marketing concerns of US sugar processors have been a significant roadblock to the introduction of GM sugar beets in the US (Lilleboe, 2000).

[3] In this paper we will not distinguish between these two technologies and assume that their cost advantages will quickly converge after their introduction. While most data is available for Roundup Ready™ varieties, in the remainder of the paper, the term 'herbicide tolerant sugar beets' will refer to both technologies.

[4] Belgium and Luxembourg are united in one block.

[5] We are grateful to Brent Borrell for pointing this out.

[6] In the short run, these surpluses will be added to the carry-over and 'precautionary' production (cfr. infra). In the medium and long run, farmers will adapt their land allocated to sugar beet production.

[7] We convert all quantities and prices to their white sugar equivalent. Since we assume constant unit extraction rates and costs per member country, there is no rent in this model that accrues to processors. Given that for within-quota production, prices for both growers and processors are fixed, this is a realistic assumption.

[8] This is only true to a certain extent, since the auto-financing constraint relates world prices to domestic prices (equations 18 to 23). Increases in EU's C sugar exports, due to technological change, engender a decline of the world price which is reflected on A and B sugar prices and finally of the research benefits of within-quota sugar production (see below).

[9] In our model, only regions responding to world prices are able to contribute to the technology-induced export expansion.

[10] However, intervention is hardly used in the European sugar sector as surpluses are exported to the world market. The costs of keeping sugar (storage, financing, etc.) are reimbursed to manufacturers.

[11] Producers may carry over a quantity of C sugar to the following marketing year equal to a maximum of 20 % of their A quota (European Commission, 1996).

[12] It can be argued that even C sugar is implicitly subsidized since fixed costs of exporting producers are already covered by the high within-quota prices (Harris and Tangermann, 1993).

[13] Ivan Roberts correctly points out that this is so as long as the aid is maintained. But if it were to be discontinued, it would raise world prices, influencing C-sugar and B-sugar returns. In our framework however, initial returns are modelled as scaling parameters that are inconsequential to the calculated changes in profits due to the adoption of the technology (Moschini et al., 2000).

[14] In the short run, producers could stock and carry over surpluses generated by the innovation, but this 'hold-up' of R&D benefits can only be temporal, since these stocks are limited to 20 % of the A quota.

[15] In Figure 2, this error seems to be large, but this is due to visibility-enhancing effects. In reality, this error is probably small, compared to the large quota rents.

[16] In contrast, world price changes are endogenous to producer prices through the auto-financing constraint (equation 18).

[17] As we mentioned earlier, this strategy reveals the *benefits foregone* or costs of the current moratorium on GMO's in the EU, and more specifically on transgenic sugar beets. This implies that the relevant counterfactual is a situation with GMO adoption, in contrast to an *ex- post* setting, where the counterfactual is a situation without GMO adoption. Our scenario of adoption during the period 1996/97-2000/01 is completely hypothetical, since effective adoption is not expected to occur before 2002-2005 (Table 3).

[18] In an *ex post* setting, the model would be calibrated on observed production data reflecting adoption, like in the model of Moschini, Lapan, and Sobolevski (2000).

[19] After an extensive sensitivity analysis it appears that this is just an inconsequential scaling parameter, which is in line with the observations of Moschini, Lapan, and Sobolevski (2000).

[20] For simplicity we only consider the case of glyphosate tolerant Roundup Ready™ sugar beets. We assume that the overall profitability (including the price premium) of glyphosate and glufosinate ammonium tolerant Liberty Link™ sugar beet seeds would converge after the introduction of both products on the market and that possible differences would be outweighed by the more important uncertainty regarding the price premium of both products.

[21] In a future version of this paper, all uncertainties are analysed, including structural modelling uncertainties regarding elasticities and calibration parameters which are difficult to estimate. In this paper however we want to focus on the two main uncertainties regarding the new technology.

[22] Note that an important part of the world is not able to adopt the new technology, since we are only focusing on one technology, i.e. herbicide tolerance in the sugar beet sector. As a result, in our model the technology cannot 'spillover' to the ROW cane region. This *ceteris paribus* point of view implies that the ROW cane region is 'lagging behind' the EU in adopting the new technology. In reality, the opposite may happen if herbicide tolerant sugar cane varieties are timely introduced in the ROW and if adoption in the EU continues to be very slow. But again, we have set up our framework to estimate 'what could have been if', rather than 'what will be'. Although influencing the size of the benefits substantially, the assumption of an exogenous adoption curve does not influence the distribution of the benefits as long as the same adoption patterns are assumed. Since it is difficult to obtain information on potential adoption rates in all regions, the estimated welfare effects should be interpreted as functions, conditional on adoption rates.

Table 1: Sugar Production and Utilization, Five-Year Average (1996/97-2000/01)

Raw Sugar	Beet Sugar (10^3 ton)	Cane Sugar (10^3 ton)	Total (10^3 ton)	%	Export (10^3 ton)	%	Net Export (10^3 ton)	Δ in Stocks (10^3 ton)	Cons. (10^3 ton)
EU (15)	18.406	9	18.415	14%	8.398	20%	3.790	-10.475	14.261
Eastern Europe	7.984	0	7.984	6%	1.611	4%	-6.385	193	14.177
Other Western Europe	3.137	0	3.137	2%	425	1%	-151	10.997	3.112
USA	4.056	3.126	7.181	6%	226	1%	-1.747	169	9.081
Japan	662	180	841	1%	6	0%	-1.588	-76	2.506
Canada	121	0	121	0%	19	0%	-1.108	-1	1.230
Australia	0	5.311	5.311	4%	3.975	10%	3.972	44	1.103
Brazil	0	17.517	17.517	13%	8.356	20%	8.356	189	9.293
India	0	16.959	16.959	13%	457	1%	-46	475	16.525
Indonesia	0	1.913	1.913	1%	7	0%	-1.507	110	3.243
Mexico	0	5.102	5.102	4%	645	2%	583	23	4.501
South Africa	0	2.628	2.628	2%	1.249	3%	1.152	78	4.070
Thailand	0	5.391	5.391	4%	3.457	8%	3.457	122	1.813
Other Central America	0	8.600	8.600	7%	5.728	14%	5.220	127	2.954
Other South America	483	6.270	6.753	5%	1.687	4%	592	152	6.012
Other Africa	623	5.901	6.524	5%	2.487	6%	-3.603	356	7.215
Other Asia	1.962	13.418	15.380	12%	2.687	6%	-8.955	192	24.151
Other Oceania	0	414	414	0%	348	1%	76	21	309
World	**37.433**	**92.738**	**130.171**	**100%**	**41.767**	**100%**	**2.107**	**2.696**	**125.556**
Share	29%	71%	100%						

F.O.Licht (2000, 2001)

Table 2: Area and Production of Sugar Beets and Beet Sugar in the World, Five-Year Average (1996/97-2000/01)

Country	Area (10^3 ha)	%	Beet Production (10^3 ton)	%	Beet Yield (ton/ha)	Sugar Yield (% white sugar)	Sugar Production (10^3 ton white sugar)	%
Austria	47	1%	2.969	1%	63	16%	476	1%
Belgium-Luxembourg	96	1%	5.927	2%	62	16%	960	3%
Danmark	63	1%	3.369	1%	54	16%	532	2%
Finland	33	1%	1.108	0%	33	14%	153	0%
France	440	7%	31.259	12%	71	14%	4.410	13%
Germany	480	7%	26.480	10%	55	16%	4.211	12%
Greece	45	1%	2.663	1%	59	11%	286	1%
Ireland	33	1%	1.708	1%	52	13%	217	1%
Italy	270	4%	12.958	5%	48	12%	1.606	5%
the Netherlands	114	2%	6.531	3%	58	15%	1.012	3%
Portugal	6	0%	361	0%	58	15%	53	0%
Spain	137	2%	8.110	3%	59	14%	1.136	3%
Sweden	58	1%	2.592	1%	45	16%	407	1%
UK	184	3%	9.786	4%	53	15%	1.475	4%
EU(15)	**2.005**	**31%**	**115.819**	**46%**	**58**	**15%**	**16.934**	**49%**
Hungary	69	1%	2.973	1%	43	15%	432	1%
Czech Rep.	74	1%	3.244	1%	44	15%	488	1%
Poland	368	6%	13.951	5%	38	15%	2.044	6%
Russia	761	12%	13.697	5%	18	11%	1.500	4%
Ukraine	879	14%	15.188	6%	17	13%	1.975	6%
Turkey	434	7%	17.939	7%	41	13%	2.289	7%
Other	443	7%	12.580	5%	29	12%	1.503	4%
Europe	**5.034**	**78%**	**195.391**	**77%**	**39**	**14%**	**27.165**	**79%**
US	568	9%	27.959	11%	49	13%	3.731	11%
China	406	6%	11.410	4%	28	10%	1.103	3%
Iran	178	3%	4.784	2%	27	12%	564	2%
Other	292	5%	14.718	6%	37	13%	1.875	5%
ROW	**4.474**	**69%**	**138.443**	**54%**	**31**	**13%**	**17.505**	**51%**
World	**6.479**	**100%**	**254.263**	**100%**	**39**	**14%**	**34.438**	**100%**

FAO (2002), F.O.Licht (2000, 2001)

Table 3: Situation and Research Regarding Transgenic Sugar beets by Country

Country	Are any GM beet varieties currently being tested?	For what characteristic(s)?	When can the first GM beet variety authorisation be expected?	When can one expect a GM beet variety to be actually grown?	What strategy is to be adopted with the sugar industry regarding processing of GM beet?
B	yes (1989)	RR & LL	not before 2005	not before 2005; use will depend on acceptance by consumers and the interprofession	no strategy adopted yet no GM beet in sugar factories nor in the animal feed market
DK	yes (1996)	RR	not before 2002-2003	very uncertain	as long as authorisation of GM beet is not expected, the question of processing is not relevant; there will be no GM beet in sugar factories until industry is sure that consumers accept sugar from GM beet
D	yes (1998)	RR & LL	impossible to assess	impossible to assess	no GM beet in sugar factories before 2001; only GM varieties of cultural value (better than conventional ones) will be authorised
GR	not yet; Novartis and Agrevo have filed applications for trials of GM beet varieties	RR & LL	trials may start in a few years	not foreseeable at present	the sugar industry has reservations, but will consider the issue if other countries grow GM beet
E	yes (1997)	RR & LL	unknown	unknown	continue work with close collaboration between the administration, beet growers, sugar industry, seed producers and research institute (AIMCRA)
F	yes (1995)	RR & LL, resistance to nematodes and various diseases	not foreseeable	not before 2003-2005	market and consumer acceptance of sugar from GM beet is a precondition; no double sector (GM and non GM); GM beet on negative lists (exempt from labelling).
IRL	yes research trials	RR	not before 2005	not before 2005	no strategy adopted yet
I	no, not even for research trials				no strategy adopted yet
NL	yes (1997)	RR LL	not before 2003	not before 2003	any acceptance of GM beet for processing will be decided on a case by case basis; a strict surveillance of the production chain is indispensable
A	no; growing of GMO's, even just for pure research, is forbidden		unlikely even in the medium term	difficult to foresee	no strategy
P	no		-	-	-
FIN	yes (1998)	RR & LL	2002	not before 2003	no strategy adopted yet
S	yes (1998)	RR & LL	not before 2002-2003	not before 2002-2003	no gm sugar beet to be grown unless there is full consumer confidence
UK	yes	RR	not before 2003	unknown	continue work with close collaboration between the administration, beet growers, sugar industry, seed producers and research institutes; market and consumer acceptance of sugar from GM beet is a precondition
CH	no		unknown	unknown	no strategy; sugar industry does not want GM beet
H	no	-	-	-	-
PL	no	-	-	-	-
CZ	yes	RR & LL	2002	not before 2003	no strategy adopted yet
SK	yes	RR & LL	2002	2002	no strategy adopted yet

Krick (2000)

Table 4: Spatial Dimension of the Model

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Region	ROW Cane	ROW Beet	BL	DK	D	G	E	F	IRL	I	NL	A	P	FIN	S	UK

Table 5: Temporal Dimension of the Model

j	0	1	2	3	4	5	6
Year	1996-1997 Benchmark	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002 Evaluation

Table 6: Average Price and Welfare Effects (in ∈) due to the Introduction of Herbicide Tolerant Sugar Beets in the EU and the ROW

Year	1996/97 Benchm.	1996/97	1997/98	1998/99	1999/00	2000/01	2001/2002 Aggregated
World Price	100,00%	99,88%	99,88%	99,81%	99,76%	99,71%	0
A Beet Price	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	0
B Beet Price	100,00%	99,95%	99,96%	99,95%	99,96%	99,92%	0
ROW Cane	0	-38.587.121	-36.757.489	-39.709.121	-43.782.468	-85.764.328	-316.131.971
ROW Beet	0	50.929.644	70.779.275	86.912.966	104.519.112	160.899.907	604.789.820
Belgium + Lux.	0	1.076.162	1.584.756	2.544.091	2.715.700	3.858.315	14.969.738
Danmark	0	786.710	1.158.030	1.478.211	1.967.714	2.751.737	10.337.818
Germany	0	6.062.648	8.786.850	11.173.670	15.059.855	21.585.928	79.467.881
Greece	0	832.805	1.061.482	1.362.588	2.129.391	2.678.090	10.231.423
Spain	0	2.597.248	3.623.578	4.622.465	5.835.492	8.608.548	32.171.024
France	0	4.808.968	7.602.577	8.555.833	11.298.548	17.550.909	63.240.882
Ireland	0	271.502	380.273	491.602	643.701	971.626	3.496.003
Italy	0	6.373.004	7.149.535	7.389.823	9.975.570	25.788.252	71.004.792
Netherlands	0	871.902	1.272.878	2.146.741	2.107.419	3.208.061	12.203.983
Austria	0	863.869	1.263.049	1.582.026	2.086.615	2.825.450	10.978.974
Portugal	0	11.700	292.158	380.715	572.580	677.430	2.391.317
Finland	0	591.105	802.680	1.233.718	1.479.269	2.032.431	7.794.853
Sweden	0	602.088	882.777	1.120.640	1.526.689	2.168.782	7.986.668
UK	0	1.437.253	2.209.844	2.498.791	3.323.735	4.983.694	18.379.815
$\Delta PS_{EU,j}$	0	27.186.963	38.070.464	46.580.912	60.722.279	99.689.252	344.655.172
$\Delta CS_{EU,j}$	0	0	0	0	0	0	0
$\Delta PS_{ROW,j}$	0	12.342.524	34.021.786	47.203.845	60.736.644	75.135.580	288.657.849
$\Delta CS_{ROW,j}$	0	39.321.066	37.310.643	41.589.491	47.306.907	84.256.010	323.232.065
Π_j	0	15.718.542	21.080.066	28.912.352	39.083.184	47.644.288	194.359.903
Total	0	94.569.095	130.482.959	164.286.600	207.849.014	306.725.130	1.150.904.989
$\Delta PS_{EU,j}$ Share	.	29%	29%	28%	29%	33%	30%
$\Delta CS_{EU,j}$ Share	.	0%	0%	0%	0%	0%	0%
NetROWj Share	.	55%	55%	54%	52%	52%	53%
Π_j Share	.	17%	16%	18%	19%	16%	17%
Total	.	100%	100%	100%	100%	100%	100%

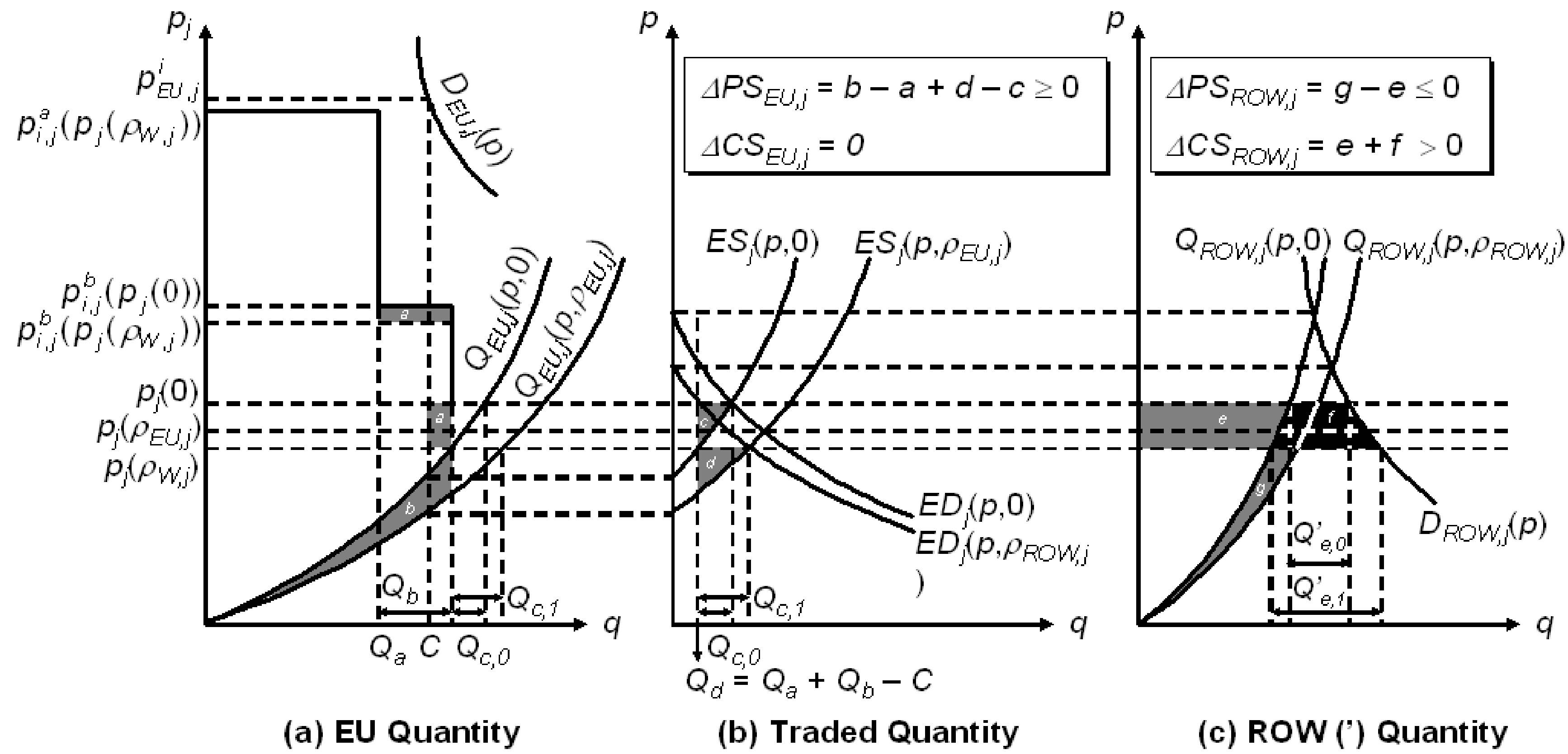

Figure 1 : Size and Distribution of Research Benefits in the Sugar Industry of a Large, Innovating Exporter (European Union), with Technology Spillovers to the Rest of the World (ROW)

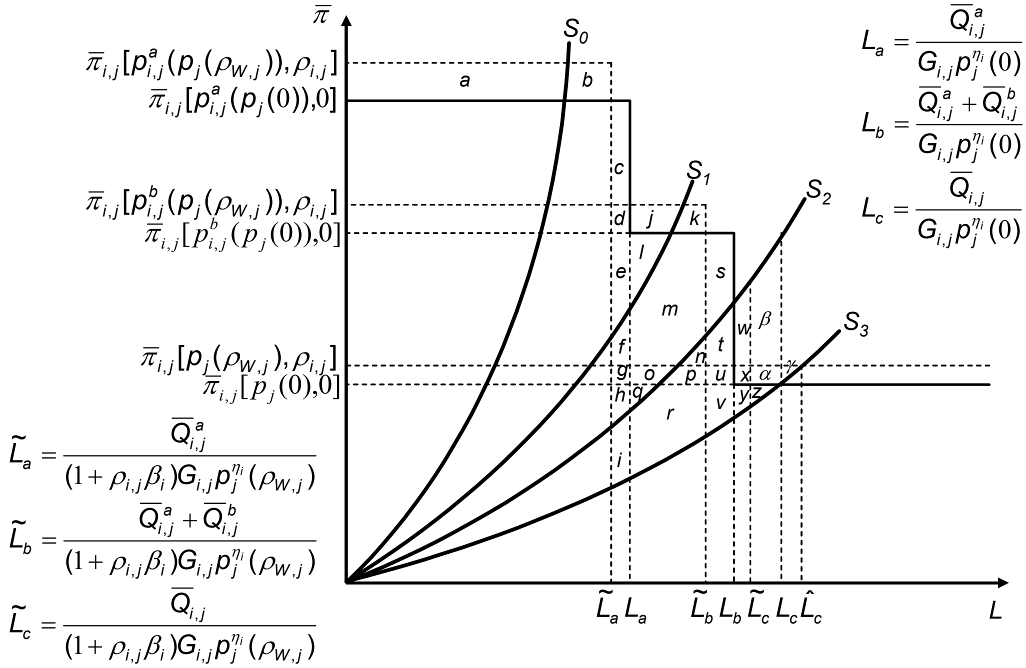

Figure 2: Innovation Rents Measured in the Land Market

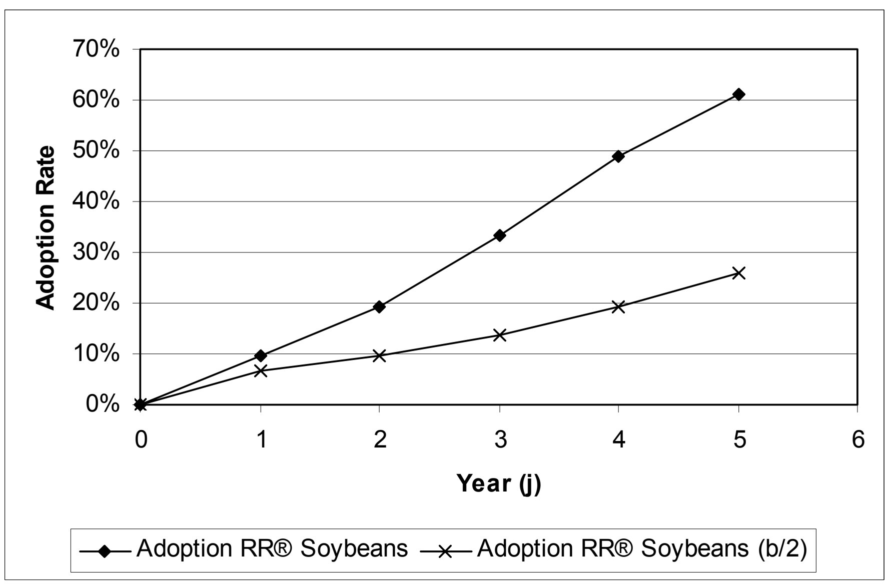

Figure 3: Estimated Logistic Adoption Curve of RR® Soybeans in the US and Hypothetic Half-Speed Adoption Curve of HT Sugar Beets in the EU

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