WHEN MODERN AGRICULTURAL (BIO)TECHNOLOGIES MEET OBSOLETE TRADE POLICIES: THE CASE OF THE EUROPEAN UNION'S SUGAR INDUSTRY

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Abstract
We develop a theoretical 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 and the Rest of the World.

Keywords: welfare, agricultural biotechnology, sugar beets

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The EUWAB-project (European Union Welfare Effects of Agricultural Biotechnology)

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 AgBiotech 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

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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 (Falck-Zepeda, Traxler, and Nelson, 2000, Moschini, Lapan, and Sobolevsky, 2000). 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 three carefully selected case studies: (1) herbicide tolerant (HT) sugar beets, (2) insect resistant (IR) corn and (3) HT oilseed rape.

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 theoretical partial equilibrium welfare framework, which explicitly recognizes that research protected by intellectual property rights generates monopoly profits. 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, in future work[1], to assess the size and distribution of the 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, Traxler, and Nelson, 2000) and soybeans (Moschini, Lapan, and Sobolevsky, 2000). 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 yield increases, cost reductions and technology fees. 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 70 % of global sugar production, with beet sugar accounting for 30 % of global output (Duff, 1999). The EU is the world's largest beet sugar producer and third largest sugar exporter (Koo and Taylor, 2000). 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 bear little relationship to production costs. For long periods of time, the world sugar price cycle has been characterized by depressed prices at which not even the world's most efficient producers would survive. 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 (Roningen and Dixit, 1989). 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, Norton, and Pardey, 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, Sturgiss, and Borrell, 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 a small effect on the volume of EU production, since 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[2]. 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. GM sugar beet is already approved to be grown in the USA, and will shortly be grown in China. It cannot be long before South Africa and Australia follow 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, May, and Pidgeon, 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.

In the food processing and retail sectors, attitudes to GM crops are coloured by consumer opinion. For this reason, European sugar producers have for the most part adopted a position of neutrality towards GM beet. However, it is possible that new labeling laws in the EU may encourage sugar processors to express greater interest in GM beet. Under these laws, all foods containing GM crops or their derivatives are required to be labeled, *except* when neither protein nor DNA resulting from the genetic modification is present. For the EU sugar industry, this suggests that if GM beet were to be approved for use in the EU at some point in the future, the sugar produced from such beets would *not* have to be labeled as a GM food (Duff, 1999). The extraction and purification processes used in sugar production should ensure the purity of the final product. However, the pulp by-product is not pure and can contain traces of modified genes. Since Europe and Japan are reluctant to accept GM pulp[3], 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).

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, May, and Pidgeon, 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, May, and Pidgeon, 2000). Two commercial herbicide tolerant (HT) sugar beet varieties resulted from these genetic insertion techniques: (1) a Roundup Ready ™ (RR) variety, tolerant to glyphosate and developed by Monsanto, and (2) a Liberty Link ™ (LL) 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 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).

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, Zimmermann and Zeddies, 2000). 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 (ROR) 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 their internal rate of return (IRR) to producers. 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.

Measuring Surplus Generated by IPR-Protected Innovations

Conventionally, research benefits were estimated assuming that the research is publicly funded and innovated inputs competitively sold in the input market. Figure 1 represents the output (a) and input (b) markets surrounding the farm sector. Let $S_0(p)$ be the upward sloping supply curve and $D(p)$ the downward sloping demand curve in the output market for the conventional agricultural commodity being modeled (Figure 1a). The innovation is assumed to be cost reducing, resulting in a shift of the supply curve from $S_0(p)$ to $S_c(p)$ on the condition that the innovated input is competitively supplied. This supply shift leads to an increase in economic welfare, equal to the area *ABDE*, the so-called *gross annual research benefits* (GARB). The model presented in Figure 1a, has been used for numerous agricultural research evaluation and research priority studies (Alston, Norton, and Pardey, 1995).

However, 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 correct evaluation of the benefits from R&D aimed at agriculture needs to account for the relevant institutional and industry structures responsible for the actual development of technological innovations.

The technology is assumed to be cost reducing and this can be visualized in the input market (Figure 1b) by representing input prices in efficiency units, resulting from a one-factor-augmentation model (Moschini and Lapan, 1997). This allows the new, more productive, factor to be measured in the same physical units as the pre-innovation input. Farmers will adopt the new variety if the price in efficiency units of the new input is less than that of the old input: $w_1/a \le c$. In other words, farmers will adopt a biotechnology variety when the value of the cost reduction plus the increase in yield is greater than the price differential between these varieties. It is reasonable to assume that both types of seeds are produced at a constant marginal cost c. We also assume that the conventional technology is produced in a perfectly competitive input market, so that its price approximates this marginal cost c. However, in the case of the new technology, the IPR's allow the firm to hold a temporary monopoly position, bounded of course by some limit pointed out by Lapan and Moschini (2000). Let $X(w)$ be the downward sloping demand curve of the farm sector for genetically engineered seed in the input market (Figure 1b). The higher the price w, the lower demand x will be for the improved variety due to the existence of alternative conventional technologies such as chemicals. If the firm is the only player in the market, it faces the demand curve $X(w)$. The marginal return curve MR, or return of an additional unit seed sold on the market, can be easily derived from this demand curve (Figure 1b). The firm will maximize profits by producing an amount GM seed equal to $a x_1$, where marginal cost c/a in efficiency units is equal to marginal return MR. Since it is the only player in the market facing demand curve $X(w)$, the firm is able to raise its price above the marginal cost c/a . Even at a price w_1/a , the farm sector is willing to buy $a x_1$ units of the GM seed variety. This *monopoly price* w_1/a will maximize firm profits and will allow the firm to regain the high R&D costs via a so-called *monopoly rent*, represented by rectangle $w_1/aHIc/a$. Because of the fact that the monopolistic seed price w_1/a is higher than the marginal cost c/a, i.e. the seed price that would emerge in a perfectly competitive market, farm-level benefits are lower and the corresponding supply shift is smaller. The effects of a departure from the assumption of perfect competition towards monopoly are visualized in Figure 1 by a shift of the supply curve from $S_c(p)$ to $S_m(p)$. Hence, the Marshallian surplus increase equals area $ABCF$ instead of simply area $ABDE$ as in the conventional framework of Alston, Norton and Pardey (1995). However, according to Moschini and Lapan (1997), welfare effects of IPR-protected innovated inputs have to be estimated in the input market, with area $cGHw_1/a$ representing the change in Marshallian surplus. Thus, the correct estimation of total welfare increase is equal to the sum of the shaded areas $cGHw_1/a$ and $w_1/aHIc/a$.

However, equivalent with what Alston, Sexton and Zhang (1997) pointed out in their study about imperfect competition in the downstream processing sector, extreme assumptions of monopoly or monopsony seem at least as inappropriate as one of perfect competition. Indeed, different patents exist for the same phenotypic trait, e.g. RR® (Monsanto) and LL® (Aventis) for herbicide resistance. Thus, the ML-model, which focuses on the extreme setting of pure monopoly, might need to be adapted to account for a departure from monopoly to different oligopolistic settings. This can be visually done in Figure 1b by rotating the marginal return (*MR*) curve towards the demand curve *X(w)* in the input market (Fulton and Keyowski, 2000). If the *MR* curve in Figure 1b corresponds to the extreme position of monopoly in the input market, in the case of pure competition this curve would coincide with the *X(w)* curve. An oligopolistic input market would then be an intermediary situation between these two extremes, with a marginal return curve situated somewhere between *MR* and *X(w)*. In Figure 1a, a departure from a monopolistic towards an oligopolistic input market can be visualized by shifting the supply curve from $S_m(p)$ to somewhere between $S_m(p)$ and $S_c(p)$.

The Model

Equivalently to what Falck-Zepeda, Traxler, and Nelson (2000) 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 (Figure 1b) 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 RR® soybeans. They develop an aggregate supply function incorporating four technology-specific parameters enabling to parameterize the herbicide resistance innovation in detail:

$$q = \underbrace{l\left[\underbrace{A + ra + \frac{(1+rb)G}{1+h}p^{1+h} - dw(1+rm)}_{\text{average profit per hectare } \bar{p}}\right]^{q}}_{\text{aggregate supply of land to sugar beet production}} \underbrace{(1+rb)Ap^{h}}_{\text{(optimal) yield function}} \qquad (1)$$

$$L = l\bar{p}^{q}$$

General Parameters:	Technology-Specific Parameters:
l = scale parameter;	*a* = coefficient of unit profit increase due to the HT technology;
A, *G* = parameters subsuming all other input prices, presumed constant;	*b* = coefficient of yield change due to the HT technology;
h = elasticity of yield with respect to sugar beet price;	*r* ∈ [0,1] = adoption rate;
d = constant optimal density of seeds;	*m* = markup on HT seed price (reflecting technology fee).
w = price of seed;	
q = elasticity of land supply with respect to sugar beet profit per hectare.	

In an analogous way, we parameterize the introduction of HT sugar beets for each separate country *i* in the EU and calculate the aggregate EU sugar[4] supply function by adding up all[5] country-specific supply functions:

$$q(p) = \sum_{i=1}^{14} q_i(p_i) \qquad (2)$$

This aggregate sugar supply function is very detailed in that it contains 11 parameters per country, totaling 154 parameters, of which 56 are technology-specific.

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 3). 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, the Council fixes *intervention*[6] (p_i) 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 are set at a higher level than internal consumption C, the internal demand (D) at the intervention price p_i (Figure 3). This overproduction Q_d (= $Q_a + Q_b - C$), although receiving a guaranteed B sugar price p_b, is exported on the world market and hence subsidized. This export subsidy system is completely auto-financed by levies (t_a and t_b) on A and B quota production. Consumers, who pay a high internal intervention price p_i, subsidize the internal within-quota production. A and B quota production receive prices equal to respectively

$$p_a = p_i\,(1 - t_a), \text{ and} \qquad (3)$$

$$p_b = p_i\,(1 - t_a - t_b). \qquad (4)$$

A levy t_a 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 t_b 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 (Combette, Giraud-Heraud, and Réquillart, 1997):

$$p_i\, t_a(Q_a + Q_b) + p_i\, t_b\, Q_b = (Q_a + Q_b - C)(p_i - p_w) \qquad (5)$$

They have to fill the gap between the world price p_w and the high internal price p_i 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 (5) and (6), the system (5) and (7) is solved. Finally, when the latter neither yields a solution, a positive multiplicator a is defined solving the system (5) and (8).

$$\left| \begin{array}{l} t_a \in [0, 0.02] \\ \\ t_b = 0 \end{array} \right. \qquad (6)$$

$$\left| \begin{array}{l} t_a = 0.02 \\ \\ t_b \in [0, 0.375] \end{array} \right. \qquad (7)$$

$$\left| \begin{array}{l} t_a = (1 + a)\, 0.02 \\ \\ t_b = (1 + a)\, 0.375 \end{array} \right. \qquad (8)$$

This explains why B quota prices p_b 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. 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 p_a and p_b (Combette, Giraud-Heraud, and Réquillart, 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[7] 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[8] 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 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[9] and long run, it is omitted from our model.

For each country, the 4 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 substantially. In a two-tier price system, the marginal return (MR) curve is stepwise, following the three price levels p_a, p_b, and p_w (Figure 2a). In a mixed price system, the stepwise MR curve has only two levels: p_m and p_w (Figure 2b). Country A represents a high cost producer. $S_{A,0}$ and $S_{A,1}$ are respectively its pre-innovation and post-innovation marginal cost (or supply) curves. Country A is only able to supply high-priced A sugar, since its marginal cost curve intersects with the *MR* curve at levels below Q_a. In a two-tier price system, the research benefits, visualized by area *a*, are higher than in a system with a unique quota and mixed price (area *a* – area *d*). This can be explained by the fact that its marginal production increase, due to the innovation, is priced lower in a mixed price system.

The opposite holds for a lower cost producer *B*, which is able to supply lower-priced B sugar. Changing from a two-tier pricing to a mixed pricing system enables to capture a larger part (area *b* + area *e*) of the research benefits since its extra production is priced higher. Finally, for a low cost producer *C*, producing significant amounts of C sugar at the world price, the marginal return p_w and hence the research benefits (supply shift from $S_{C,0}$ to $S_{C,1}$) of its within-quota production are unaffected by the pricing system (area *c*). It is clear that in all three cases, countries extract a part of research benefits, which are protected from price depreciations[10] due to guaranteed EU intervention prices.

In Figure 3, our welfare framework has been outlined. Primes designate the rest of the world (ROW). At the center of the analysis is the calculation of a counterfactual world price (after decline) 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, Traxler, and Nelson, 2000). The world price reduction (from p_0 to p_2) is a synergy of two forces. First, the EU technology-induced export expansion would cause the world price to decline from p_0 to p_1. 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 EU sugar net exports N_t:

$$\log(p_w) = -1.0 \log(N_t) + 0.46 \log(N_{t-1}) \qquad (9)$$

By taking the first differential, we obtain a formula in elasticity-form, relating relative world price changes to relative changes in net exports:

$$\partial[\log(p_w)] = -1.0\ \partial[\log(N_t)] + 0.46\ \partial[\log(N_{t-1})]$$

$$\frac{\partial p_w}{p_w} = -1.0\frac{\partial N_t}{N_t} + 0.46\frac{\partial N_{t-1}}{N_{t-1}} \qquad (10)$$

If we assume that imports are not affected by the innovation, due to fixed ACP import arrangements, and since $N_t = q_t - C_t - M_t$ (imports), we can transform equation 10 into an equation relating relative technology-induced supply (q_t) increases to relative world price changes:

$$\frac{\partial p_w}{p_w} = -1.0\frac{\partial q_t}{q_t} + 0.46\frac{\partial q_{t-1}}{q_{t-1}} \qquad (11)$$

The short-run flexibility is minus one and the long-run flexibility is approximately half that of the short-run, reflecting sugar export demand elasticities that are approximately twice as large in the long run as in the short run (Poonyth et al., 2000).

Secondly, the ROW technology-induced export expansion, which equals the reduction of the demand for EU exports, would further reduce the world price from p_1 to the counterfactual world price p_2. We assume a constant elasticity ROW demand function for sugar:

$$D'(p) = k'p^{-e'} \qquad (12)$$

The positive ROW supply shift (from S'_0 to S'_1) translates into a negative export demand shift (from ED'_0 to ED'_1):

$$ED'_0 = D' - S'_0 \qquad (13)$$

$$ED'_1 = D' - S'_1 \qquad (14)$$

Market clearing at equilibrium in the world market implies:

$$ED'_1 = ES_1 = S_1 - C \qquad (15)$$

Equation 15 finally yields an estimate of the counterfactual world price p_2. The corresponding surplus changes can now be computed using standard procedures (Just, Hueth, and Schmitz, 1982). If $L_i(p_i)$ denotes the optimal allocation of land to sugar beets in country i, the variation in producer surplus (relative to the benchmark where the unit profit is $p_{i,0}$) due to the innovation (which leads to a unit profit $p_{i,1}$) can be calculated according to an elegant methodology of Moschini, Lapan, and Sobolevski (2000), and adapted to the EU's CMO for sugar. The producer surplus change strongly depends on the competitiveness of the country in sugar production. The change in producer surplus of a high-cost country i that only produces A sugar in a two-tier price system, can be computed as:

$$\Delta PS_i = \int_{p_{a,0,i}}^{p_{a,1,i}} L_i(p)dp \qquad (16)$$

Parameter $p_{a,1,i}$ represents the unit profit for A quota sugar with price p_a, corrected for the A levy change (t_a) to satisfy the auto-financing constraint (equations 3 to 8). In a mixed price system, the research benefits can be calculated with the same formula after replacing $p_{a,0,i}$ and $p_{a,1,i}$ by the unit profits $p_{m,0,i}$ and $p_{m,1,i}$, occurring in a mixed price (p_m) system. The same formula is also valid for medium-cost countries that produce both A and B quota sugar under a mixed price system, without exporting on the world market. Again, these unit profits have to be corrected to satisfy the auto-financing constraint. In a two-tier price system, the innovation rents of these medium-cost countries can be calculated as follows:

$$\Delta PS_i = L_{a,i}(p_{a,1,i} - p_{a,0,i}) + \int_{p_{b,0,i}}^{p_{b,1,i}} \left[L_i(p) - L_{a,i}\right]dp \qquad (17)$$

For exporting low-cost countries operating in a two-tier price system, the change in producers' surplus is split up in two parts: (1) a within-quota part, and (2) an out-of-quota part, earned on the world market:

$$\Delta PS_i = L_{a,i}(p_{a,1,i} - p_{a,0,i}) + L_{b,i}(p_{b,1,i} - p_{b,0,i}) + \int_{p_0}^{p_1} \left[L_i(p) - L_{a,i} - L_{b,i}\right]dp \qquad (18)$$

$L_{a,i}$ and $L_{b,i}$ represent respectively the A and B sugar quota, expressed in land units (hectares). p_0 and p_1 are the pre- and post-innovation unit profits related to the world prices p_0 and p_2. Similarly, in a mixed price system, these research benefits equal:

$$\Delta PS_i = (L_{a,i} + L_{b,i})(p_{m,1,i} - p_{m,0,i}) + \int_{p_0}^{p_1} \left[L_i(p) - L_{a,i} - L_{b,i}\right]dp \qquad (19)$$

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

$$\Delta PS = \sum_{i=1}^{14} \Delta PS_i \qquad (20)$$

In Figure 3a, this aggregate benefit can be assessed by a pivotal shift of the aggregate EU supply function (from S_0 to S_1). 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 p_b, while it is exported at the world price p_w. Decline of the world price from p_0 to p_2, due to the technology-induced shift of EU aggregate supply, raises subsidy costs up to Q_d (p_0 – p_2). These extra costs have to be borne by the producers via increased levies on their within-quota production (equations 3 to 8). In most cases, adapting only the B quota levy t_b is sufficient, visualized in Figure 3a, where these costs are represented in two ways (two areas '*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 ROW producers' innovation rent (area *g* – area *e* in Figure 3c) equals:

$$\Delta PS'_i = \int_{p_0}^{p_1} L'_i\,(p\,)dp \qquad (21)$$

The ROW consumers' surplus change (area *e* + area *f* in Figure 3c) equals:

$$\Delta CS' = \int_{p_2}^{p_0} D'(p)dp \qquad (22)$$

Finally, the profit of the input suppliers is simply computed as:

$$\Pi = \sum_{j=EU,ROW} r_j\,L_j\,m_j dw_j\ , \qquad (23)$$

where L_j is the total amount of land allocated to sugar beet production in region j when the adoption rate is r_j, the price markup m_j, the seed cost per hectare dw_j, and the equilibrium price for sugar $p_{s,j}$.

To summarize, our strategy for estimating surpluses created by the introduction of herbicide tolerant sugar beets and accruing to innovators, domestic and international farmers and consumers is the following:

1. as a benchmark, we assume hypothetically[11] that the European Union's sugar industry, as a competitive player in the world market, embraced the new technology of herbicide tolerant sugar beets since the marketing year 1996-1997, and progressively adopted it up to 2000-2001;

2. we allow technology spillovers to the rest of the world (ROW), but assume that the ROW is lagging[12] behind the EU in the adoption of the new technology;
3. we parameterize the supply functions of the 14 production blocks (equation 1) and aggregate them up to the EU sugar supply function (equation 2);
4. we parameterize the aggregate ROW supply function (equation 1);
5. we calculate the counterfactual world price as a function of the shifts of aggregate EU supply, export demand, and aggregate ROW supply (equation 15);
6. to satisfy the auto-financing constraint (equation 5), we transmit the world price decline on domestic prices via a feedback system (equations 3 to 8);
7. for each country we calculate the change in producers' surplus using the corrected (step 6) domestic prices and counterfactual world price (equations 16 to 19);
8. we calculate the aggregate change in the EU producers' surplus by adding up the surplus change of each individual production block (equation 20);
9. we calculate the aggregate change in the ROW producers' surplus (equation 21) and ROW consumers' surplus (equation 22);
10. we calculate the rents accruing to input suppliers (equation 23);
11. according to an exogenously assumed adoption curve, the accumulated present value of the surpluses accrued during the five-year period 1996/1997-2000/2001 is calculated as well as the distribution of these surpluses among (1) EU member countries and (2) stakeholders in the sugar sector, such as input suppliers, producers and consumers;
12. using stochastic sensitivity analysis via @Risk, subjective prior distributions of non-deterministic parameters (elasticities, yield increases, cost reductions, technology markup price, etc.) are included to generate posterior distributions of the outcomes (counterfactual world price and research benefits) of the model (Davis and Espinoza, 1998).

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.

Data

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 a and b. At a first pass, an exogenously assumed adoption curve (r) is used, combined with a relatively wide distribution of potential markup prices (m) for herbicide tolerant sugar beets. The minimum, most likely and maximum value of the markup prices are assessed using expert opinions and analogies with other agricultural biotechnology innovations. 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 $y = (\partial L/\partial p)(p/L)$. Given these estimates, the parameter q is calibrated as $q = y p/py$ (Moschini, Lapan, and Sobolevsky, 2000). For yields (y), prices, quantities and quota, various sources (USDA, European Commission, etc.) are used. Given the assumed, estimated and retrieved parameters, structural parameters, such as l, A, G, and k' will be calibrated so as to retrieve acreage, quantity, yield and price data for the period 1996/1997-2000/2001.

Extensions of the Model

A first interesting extension to the model in future work could be the inclusion of social costs due to environmental externalities. 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, Norton, and Pardey, 1995).

Secondly, as a first pass we exogenously assumed an 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 markup price 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 – despite the fact that labeling will not be necessary – 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 and Expected Outcomes

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, in future work, 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 (1) *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, (2) *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 countries 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. If the ROW is lagging behind the EU, as we hypothetically assume, competition on the world market between the two players will adversely affect ROW producers and reversely. Given that quota prices for both growers and processors are fixed, there is no rent in this model that accrues to (3) *processors*. Due to fixed internal sugar prices, EU (4) *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 (5) *environment*. Finally, since the CMO for sugar is largely self-financing from a public financing perspective, neither public expenditures – except for public R&D in the sugar sector – nor benefits will accrue to (6) *governments* in the EU.

Not surprisingly, the first model results suggest that the monopolistic input industry (seed suppliers and gene developers) capture the largest share of the benefits, with the next largest share accruing to the already high rents of the highly protected EU sugar industry. 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. However, consumers outside the EU necessarily gain due to the depressing effect of the technology on world sugar prices. Assuming that the adoption process of HT sugar beets in the ROW is lagging behind that of the EU, producers in the ROW lose due to declining producer prices. Moreover, the adoption of the technology in the ROW harms the competitive position of the EU in the world market and erodes the gains from biotechnology research in the EU. The monopolistic input industry (seed suppliers and gene developers) additionally gains from any technology spillover to the ROW.

In conclusion, our results reveal an apparent contradiction. When modern (bio)technologies are introduced in commodity markets subject to obsolete trade policies, the natural flow of 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. Caricaturally, 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.

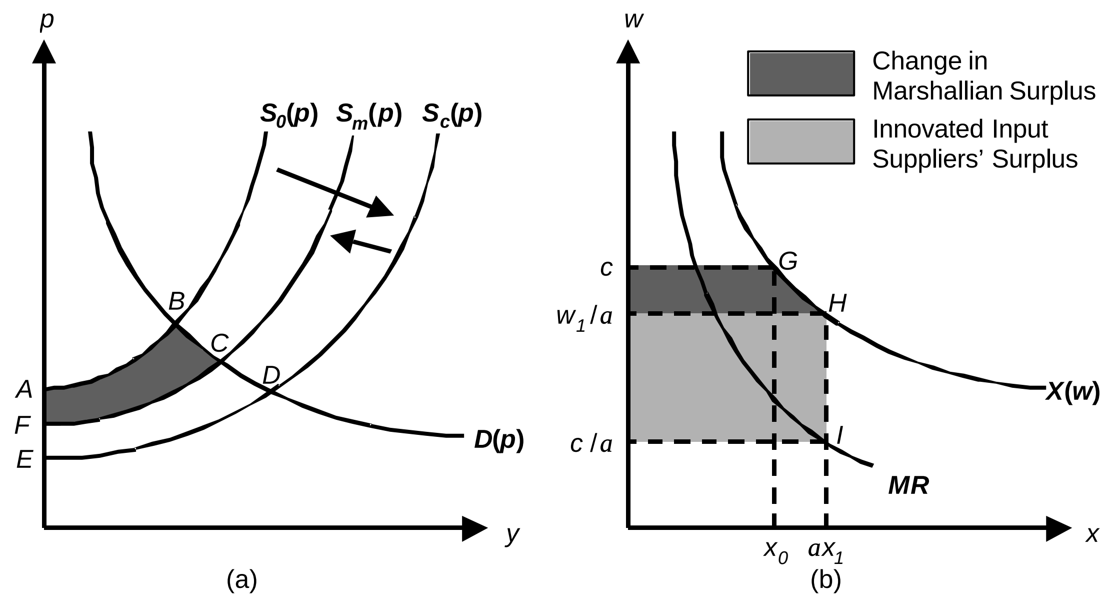

Figure 1: Change in Marshallian Surplus (area *ABCF* or $cGHw_1/a$) and Innovated Input Suppliers' Surplus (area $w_1/a\,HIc/a$) Resulting from an IPR-Protected Innovation in the Input Market (Moschini and Lapan, 1997)

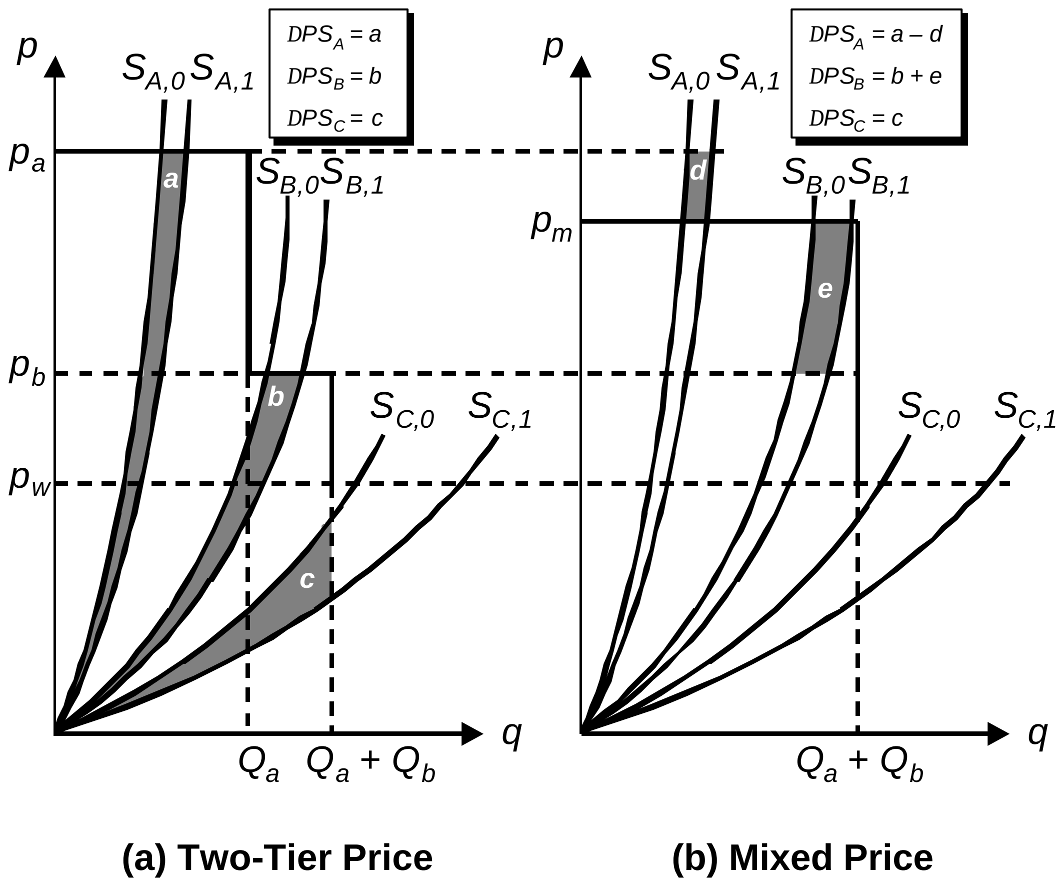

Figure 2: Influence of Pricing Systems Applied in the EU on Research Benefits

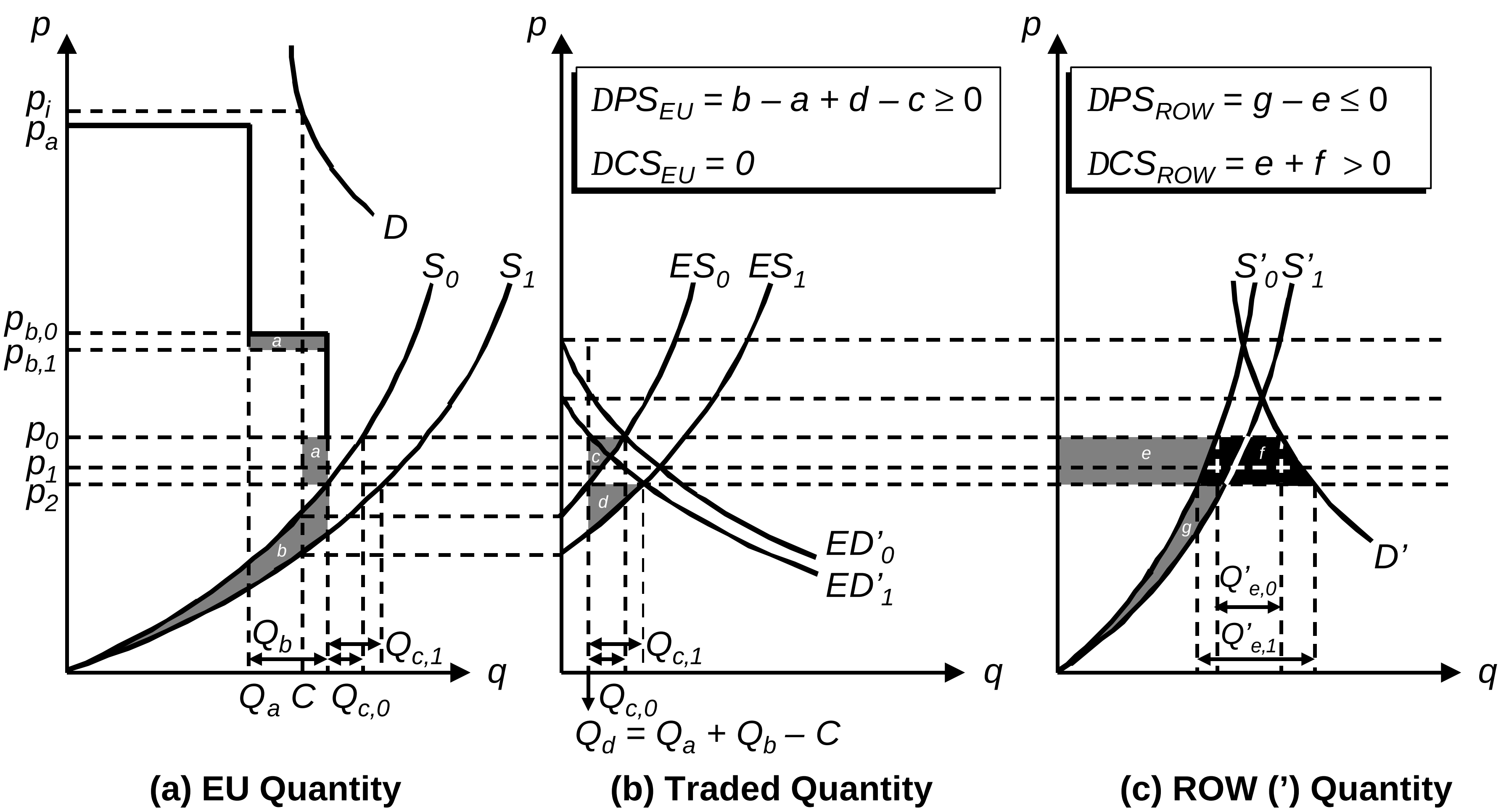

Figure 3 : Size and Distribution of Research Benefits in the Sugar Industry of a Large, Innovating Exporter (European Union), with Technology Spillovers to the Rest of the World (ROW)

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[11] In this paper, we only present the theoretical framework. The model is currently being tested and run but data collection is still not completed. Results will be reported in a future version of this paper.

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

[3] despite the fact that currently, an important share of imported animal feed in Europe is genetically modified

[4] 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.

[5] The model includes 14 sugar production blocks of 15 countries. Belgium and Luxembourg are united in one block.

[6] 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.

[7] 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).

[8] 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).

[9] 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.

[10] This is only true to a certain extent, since the auto-financing constraint relates world prices to domestic prices (equations 3 to 8). 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).

[11] 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.

[12] In reality, the opposite will probably happen due to the hesitant behaviour of the EU in taking regulatory decisions. But again, our framework aims at estimating 'what could have been', rather than 'what will be'.