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Global Welfare Effects of GM Sugar Beet under Changing EU Sugar Policies

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Ex-post impact studies of genetically modified crops indicate that society is capturing sizeable gains in agricultural biotechnology. In Europe, in contrast, due to limited adoption, research has been largely restricted to ex-ante technology and policy impact assessment of GM crop cultivation. In this study we assess the impact of a hypothetical introduction of herbicide tolerant sugar beet in the global sugar sector under both the former and the actual European Common Market Organization for sugar. The model starts from a farm-level analysis, introducing a perfect corporate pricing strategy under restricted monopoly power, which is expanded to a partial equilibrium model of the world sugar trade. We show that even under the given condition of private market power, significant gains accrue to farmers and consumers, while a smaller part goes to the seed sector (gene developers and seed suppliers). The global value of HT sugar beet for society in the period 1996-2014 is estimated at €15.4 billion, of which 29% is captured by EU farmers, 31% by farmers and consumers in the rest of the world, and 39% by the seed sector. However, the global sugar sector is foregoing most of this value, as the technology is currently only accepted by the US sugar industry.

Key words: ex-ante impact assessment, partial equilibrium, policy distortion, market power, welfare distribution.

Introduction

In the literature, the debate on the economic impact of genetically modified (GM) crops has been characterized by polar viewpoints.[1] In contrast with public research, in the case of proprietary GM seed innovations societal interest is typically not focused on the rate of return of biotechnology research, but on its welfare distribution among the private upstream seed sector (gene developers and seed suppliers) and downstream stakeholders (farmers, processors, distributors, and consumers) in the supply chain. The published ex-post impact assessments indicate that farmers clearly capture sizable gains despite the proprietary nature of the innovation (Demont, Dillen, Mathijs, & Tollens, 2007). According to Dillen, Demont, & Tollens (2008b), heterogeneity among farmers drives value sharing of proprietary seed technologies by restricting monopoly power as described by Weaver (2004).

In the European Union (EU), only a limited number of member states have been growing GM crops so far and only a few ex-post impact assessments have been published, i.e., on Bt maize in Spain (Demont & Tollens, 2004b; Gomez-Barbero, Berbel, & Rodriguez-Cerezo, 2008) and the Czech Republic (Demont et al., 2008), and herbicide-tolerant (HT) soybeans in Romania (Brookes, 2005). Some ex-ante EU distributional impact studies on GM sugar beet are documented as well (Demont, 2006; Demont et al., 2008; Demont & Tollens, 2004a; Demont, Wesseler, & Tollens, 2004), reporting a global welfare increase of €1.1 billion during the five-year period of 1996-2000, shared among EU producers (26%), the global seed industry (24%), and farmers and consumers in the rest of the world (50%).

Despite the official end of the moratorium and new approvals of GM crops, adoption of national guidelines on coexistence has been relatively slow in the EU, and, due to regulatory uncertainty and consumer hostility, the adoption of GM crops is still limited. This means that the EU is still in a state of *quasi*-moratorium regarding the introduction of GM crops (Devos, Demont, & Sanvido, 2008), foregoing important benefits of these technologies. However, with upwards price pressure in world food markets, shortages in the non-GM feed market and development of a significant bio-energy market,

1. *For example, despite the vast literature on the positive welfare effects of GM crops (e.g., see review by Demont et al., 2007), in several public debates and some recent papers the relation between adoption of GM cotton in India and increased farmer suicides is investigated (e.g., Herring, 2008).*

it seems the tide could be changing and the demand for the introduction of GM crops might increase in the EU in the near future. In this study we therefore assess the potential global welfare implications of HT sugar beet for upstream and downstream stakeholders in the global sugar beet sector under perfect corporate pricing strategies. Since our analysis covers both the future and the past, results both include the welfare forgone and the potential future benefits of the technology. Furthermore, this study also takes into account the change in the Common Market Organization (CMO) for sugar that Europe underwent in 2006. In the first section, we describe the partial equilibrium model, EUWABSIM, and highlight some of its major upgrades and new features introduced for this study. A second section describes the calibration and data used. The third and the last section present the results and conclude.

Model

Weed control is crucial to economic beet production, which makes the HT trait very attractive to farmers (Demont, 2006). The case of HT sugar beet is very timely. It seems that the sugar industry opened its doors towards HT sugar beet, which has been commercialized in the United States since 2008. Furthermore, sugar beet is a potential input commodity for the growing bioenergy sector and the bio-based chemistry sector. The reduction of internal sugar prices following the reform of the CMO for sugar might also increase the demand for efficiency increasing innovations. Dillen et al. (2008b) develop a framework to model heterogeneity among potential adopters in ex-ante welfare assessments of innovations protected by intellectual property rights. Their farm-level approach allows determining the marginal adopter, i.e., the farmer in a population of heterogeneous farmers who is indifferent between adopting and not adopting the technology (Lapan & Moschini, 2004), and the anticipated adoption ceiling. Moreover, it allows endogenizing the technology fee in the case of perfect corporate price setting under intellectual property rights and estimating farmer profits and the revenue for the seed sector as a result of the hypothetical adoption of the technology.

Frisvold, Sullivan, and Raneses (2003) argue that distributional effects cannot be assessed adequately without aggregating results and incorporating market effects. Therefore we incorporate the farm-level model into the EUWABSIM[2] model (Demont, 2006; Demont & Tollens, 2004a; Demont, Wesseler, & Tollens, 2004; Dillen, Demont, & Tollens, 2008a) to assess the distributional effects of the technology in the global sugar market, assuming a counterfactual adoption scenario. The adoption scenario considered covers 19 agricultural seasons (1996-2014) and, hence, captures the accession of new member states in 2004 and 2007 and the reform of the EU sugar policy in 2006 (see below). EUWABSIM is based on the large open-economy framework of Alston, Norton, and Pardey (1995), but explicitly recognizes that research protected by intellectual property rights generates some monopoly profits (Moschini & Lapan, 1997). It is framed in the policy and market features of the EU CMO for sugar over time. The model starts from non-linear constant-elasticity (NLCE) supply functions, analogous to Moschini, Lapan, and Sobolevsky (2000), which incorporate technology-specific parameters that enable the detailed parameterization of the herbicide tolerance technology. The trade model incorporates three regional aggregates, i.e., the EU, the Rest of the World (ROW) sugar beet region, and the ROW sugar cane region. To allow for a realistic representation of EU sugar supply response (Gohin & Bureau, 2006), we capture heterogeneity among member states by disaggregating EU sugar supply (analogous to Frandsen, Jensen, Yu, & Walter-Jørgensen, 2003) into 14 EU regions before 2004 and 17 thereafter, representing, respectively, the EU-15 and the EU-27 (covering 92% of EU-27 sugar production). This specification allows technology spillovers to be included for the ROW sugar beet region. The 17 EU and two ROW supply functions are aggregated, respectively, into an EU and a ROW aggregate supply function. The model is non-spatial and since intra-EU trade flows are not modeled, only aggregate EU and ROW demand for sugar are taken into account. The differentials between aggregate supply and demand functions result in an EU export supply function and a ROW export demand function. By imputing a hypothetical adoption curve for HT sugar beet into the model, calibrated through our estimated adoption ceilings, the technology-specific parameters engender a pivotal shift of the regional NLCE supply functions and, hence, of the export supply and demand functions. The world price is modeled as the intersection of both functions on the world market. Finally, the welfare changes (producer and consumer surplus) are calculated via standard procedures (Just, Hueth, & Smith, 2004). The EUWABSIM model is further extended to

2. *European Union Welfare effects of Agricultural Biotechnology SIMulation model (EUWABSIM).*

explicitly incorporate two distinct EU sugar policies, the features of which are highlighted in the next paragraphs.

Former Common Market Organization (CMO) for Sugar (1968-2006)

The EU's former CMO for sugar came into full effect in 1968. The key features of this policy included a minimum price and the creation of a two-tiered production quota system (A and B). Anticipating an increase in consumption, the quotas were set at a higher level than internal consumption. This overproduction, although receiving a guaranteed B sugar price, was exported on the world market and hence subsidized. This export subsidy system was completely auto-financed by levies on A and B quota production. Consumers, who paid high internal intervention prices, subsidized the internal within-quota production. Both the levies on A and B quota served to satisfy the auto-financing constraint, which was a function of the world price (Combette, Giraud-Heraud, & Réquillart, 1997). The levies had to fill the gap between the world price and the high internal price for quota production, which was in excess of consumption and exported on the world market. For each member state, A and B quota prices were derived from the institutional price by deducting the levies. Thus, under the former CMO the producer price was endogenous since it depended on sugar production, internal demand, and the gap between the intervention and the world price. All out-of-quota production was called 'C sugar' and either: (1) stocked to be carried over to the following marketing year, enabling a smoothing out of annual production variations, or (2) exported on the world market at the world price.

To calculate the producer surplus induced by the innovation, member states are classified into categories (Dillen et al., 2008a). The categories group countries with different incentive prices, depending on the competitiveness of the sugar sector and whether they are filling their assigned quota. The calculation of the welfare effects in EUWABSIM is a function of the category, but the category is assumed independent of the technological innovation (see Demont, 2006, for detailed formulas).

Finally, the EU's CMO for sugar contained some additional features, such as the African, Caribbean, and Pacific (ACP) import arrangements, conferring free access to the EU market for ACP countries, up to a certain limit. These arrangements were 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, at least in the medium- and long-run.

New Common Market Organization (CMO) for Sugar (2006-2014)

On the first of July 2006 a new CMO for sugar was introduced. The key features of the reform were (1) a progressive cut of the EU institutional price (the reference price) up to 36% over four marketing years, (2) direct compensatory payments of 64.2% of the estimated revenue loss over three marketing years, and (3) a single quota arrangement for the term 2006/07-2014/15 (European Parliament, 2006). The goal of this reform was to reduce domestic EU sugar production in order to comply with the WTO, the Everything But Arms agreement and the commitment of the EU to make agriculture more competitive under the Lisbon Treaty. In order to facilitate this reduction in production, a buy-out scheme was established. Sugar producers giving up production volume due to the lower internal prices could sell their quota to the EU for an annually decreasing amount (from €730/ton to €520/ton). This had to stimulate less competitive producers to reduce or abandon production in the early years of the reform. Furthermore, the incentive for selling quota is greater than the buy-out scheme solely, since the possession of quota is taxed, leading to fixed costs of owning quota even if not filled. If the reduction in production is insufficient in 2010, the EU can decide on a linear quota cut for all European producers in order to reach the goals of the reform.

For the model, this drastic policy change has several structural effects. The older differentiated quotas are replaced by one quota with a price independent from the world market price, i.e., the reference price. In the short run, internal sugar prices can deviate from the reference price, but in the long run the price is stabilized by the European authorities. Furthermore, the new quota arrangement affects the differentiation of member states into the categories defined earlier. Producers that before did not fill their assigned quota will sell the excess quota and fill their new quota. Producers filling their quota under the old CMO will keep on supplying filled quota, although some selling of quota can occur due to reduced sugar prices. Countries which were able to profitably supply sugar at world market prices before are affected the most. Due to a complaint by the WTO, export of out-of-quota sugar (former C sugar) is severely constrained. Total export from the EU is limited by the WTO to 1.4 million tons of white sugar per year. Since this allocation is first filled with excess quota sugar (as long as the budget is sufficient) and can only be used for out-of-quota sugar in special cases, producing for the world market is impeded. However, under the new CMO for sugar, the possibility exists to produce industrial sugar outside quota production. Competitive producers will produce sugar for industrial use, which means European industrial users will import less sugar off the world market. This decrease in demand on the world market implies that the EU is still able to influence the world market (through, e.g., technological innovation) to some extent. In 2009 the Everything But Arms agreement will grant free access to the European sugar market for the least-developed countries (LDC). However, the combination of lower prices for ACP countries with the free access for LDC will marginally affect European imports (Nolte, 2008); hence, it is assumed exogenous in EUWABSIM.

Data and Model Calibration

In our simulation model, our counterfactual scenario assumes hypothetically that both the EU's beet sugar industry and the ROW beet region have embraced the technology since the marketing year 1996/97, and progressively adopt it up to 2014/15. Our model is calibrated on the observed production data from the past period 1996-2006. Observed yields, 'incentive prices' (see below), London n°5 world sugar prices, quantities, and quota are taken from various sources (European Commission, 1999; F.O. Licht, 2001, 2005; Food and Agricultural Organisation [FAO], 2006; USDA FAS, 2006).[3] Forecasted data are borrowed from the Food and Agricultural Policy Research Institute (FAPRI, 2006) model, linear extrapolations of historical yield trends, and from decision 290/2007 from the EU (European Parliament, 2007). We assume that only low-cost producers will supply industrial sugar and will do so up to an amount of 1.5 million ton (SUBEL, 2007, personal communication), shared according to their quota. The other member states are assumed to just fill their new quota. All cost and price data are first deflated and actualized to the agricultural season 2006/07 using the GDP country deflators form the world development indicators and then converted to the Euro using the exchange rate of 2006. Institutional prices are deflated using both agricultural and financial exchange rates. Because HT sugar beet is not yet adopted, the characteristics of the adoption pattern are not yet known. Therefore, for each member state we construct a counterfactual logistic adoption curve (Griliches, 1957) calibrated on the adoption ceilings estimated by Dillen et al. (2008b), which take into account heterogeneity of weed control expenditures in the different member states. We further complete the parameterization of the adoption curve through analogy. More specifically, we impute adoption pattern (speed and shape) parameters of a comparable technology in the United States, i.e., HT soybeans (USDA, 2006).[4] The inclusion of regional adoption ceilings allows for a more realistic representation of the adoption of the technology and, hence, consists in a major upgrade of the former EUWABSIM model (Demont, 2006; Demont & Tollens, 2004a; Demont, Wesseler, & Tollens, 2004; Dillen et al., 2008a).

We assume a uniform pricing strategy in which the innovating firm monopolistically prices the technology in two stages, i.e., in 1996 upon introduction and in 2004 upon the introduction of new member states. The adoption ceilings then represent the maximal adoption of the technology under the restricted monopoly held by the seed sector. Heterogeneity of weed control expenditures is based on estimated herbicide and application costs (Dillen et al., 2008b; Hermann, 1997, 2006) (Table 1). Since we are only focusing on a single technology in a single sector, in our model the technology cannot 'spillover' to the ROW cane region. Therefore, we allow technology spillovers to the ROW beet region, subject to a similar adoption pattern, but assume a ceteris paribus in the ROW cane region.

As we carry out the analysis from an ex-ante perspective, i.e., before adoption has taken place, the relevant adoption data (yield increases and cost reductions) are not yet available. Moreover, the estimation of certain parameters, such as elasticities, is surrounded by uncertainty. Therefore, using the computer program @Risk from Palisade Corporation, we incorporate subjective distributions for these parameters into the model, using all prior information available. Through Monte Carlo simulations, stochastic distributions are generated for the outcomes of the model.

Technology-induced cost reduction estimates are crucial to economic surplus calculations. We reproduced

3. *We assume complete market clearance, i.e., stock decisions are not affected by the technology.*

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

Table 1. Heterogeneity of herbicide expenditures and predicted technology fee and adoption ceilings in herbicide tolerant sugar beet adoption in the EU-27.

	Mean herbicide expenditures (€/ha)[a]		Technology fee (€/ha)		Adoption ceiling	
	1996	2004	1996	2004	1996	2004
Belgium	167.6 (37.3)	226.9 (110.2)	98	88	89%	91%
Denmark	180.5 (83.4)	180.8 (84.8)	98	88	88%	92%
Germany	216.0 (85.4)	178.7 (95.3)	98	88	90%	69%
Greece	228.1 (46.8)	122.9 (21.6)	98	88	99%	63%
Spain	280.3 (98.7)	233.1 (73.5)	98	88	100%	100%
France	134.1 (55.5)	138.2 (26.4)	98	88	43%	89%
Ireland	199.8 (37.1)	85.9 (16.5)	98	88	93%	1%
Italy	194.3 (64.9)	151.4 (45.4)	98	88	74%	53%
The Netherlands	144.8 (101.2)	165.8 (22.6)	98	88	69%	100%
Austria	246.9 (104.3)	275.9 (99.1)	98	88	87%	96%
Portugal	280.3 (98.7)	280.3 (98.7)	98	88	99%	100%
Finland	276.8 (81.0)	204.0 (37.6)	98	88	99%	100%
Sweden	159.6 (100.6)	162.7 (77.7)	98	88	47%	60%
United Kingdom	130.1 (42.2)	130.1 (42.2)	98	88	66%	73%
Czech Republic	n.a.	183.1 (34.0)	n.a.	88	n.a.	92%
Hungary	n.a.	166.7 (162.1)	n.a.	88	n.a.	46%
Poland	n.a.	192.6 (57.4)	n.a.	88	n.a.	87%

[a] standard deviation between brackets

n.a.=not applicable as these countries were not part of the EU-27 in 1996.

Source: Estimated and calculated through the framework of Dillen, Demont, and Tollens (2008b), with data from Hermann (1997, 2006).

the 2004 farm-level profit estimates of Dillen et al. (2008b) for the agricultural season 1996 upon the hypothetical introduction of HT sugar beet. Furthermore we assume that the ROW beet area is able to achieve a cost reduction similar to the EU-27 and use the area-weighted average for this region.

To calibrate the model, we need to define regional 'incentive prices' for all regions depending on the category introduced earlier. For the ROW, the world price is used. For EU regions, the incentive price depends on the region's production efficiency and the national pricing system applied to pay beet growers and processors. The incentive prices for the former CMO for sugar are modeled in a dynamic way and depend on the world price, which, on its turn, depends on world-wide adoption rates. Incentive prices can be either A or B sugar prices, a region-specific mixed price, or the world price. For the new CMO for sugar, the incentive price for in-quota sugar is fixed (although decreasing in time) and the out-of-quota incentive price is the world price (Table 2). Dillen et al. (2008a) introduce a multi-criteria decision tool to assign the right incentive price to different member states. Since our model features disaggregated area and yield response to prices, we need to find elasticities that correctly represent farmer behavior and incentives in the global sugar beet industry. In a quota system with fixed prices, annual within-quota price variation is too small to obtain reliable estimates of supply response. World price responsive (WPR) regions significantly affect world prices and global welfare through technological innovation. Therefore, for these regions in particular, i.e., Germany, Belgium, France, Austria, and the UK, precise estimates of supply response to world prices are needed. Poonyth, Westhoff, Womack, and Adams (2000) report short- and long-run area elasticity estimates for all EU-15 member states, except for Portugal and Greece. As Poonyth et al. (2000) do not report any standard deviations, we construct symmetric triangular distributions with the short-run elasticity as minimum value, the long-run as maximum value, and the medium-run, i.e., the average of both, as most likely value. For the remaining elasticities based on a single observation from the literature, we construct symmetric triangular distributions, centered on the base value and ranging from zero to twice the base value. The export supply flexibilities are borrowed from Poonyth et al. (2000). Devadoss and Kropf (1996) report supply elasticities for all major sugar producers in the world. For

Table 2. Regional specification of incentive prices and elasticities in EUWABSIM.

Region	Incentive price		Area elasticity	Yield elasticity
	Former CMO	New CMO		
ROW cane	World price	World price	0.290	0
ROW beet	World price	World price	0.202	0
Belgium	World price (C)	World price (industrial)	0.055	0.08
Denmark	B sugar price	Institutional price	0.034	0.08
Germany	World price (C)	World price (industrial)	0.074	0.08
Greece	A sugar price	Institutional price	0.228	0
Spain	B sugar price	Institutional price	0.226	0.08
France	World price (C)	World price (industrial)	0.172	0.08
Ireland	Mixed price (A, B and C sugar)	Institutional price	0.034	0.08
Italy	A sugar price	Institutional price	0.712	0.08
The Netherlands	Mixed price (A, B and a fixed quantity of C sugar)	Institutional price	0.041	0.08
Austria	World price (C)	World price (industrial)	0.154	0.08
Portugal	A sugar price	Institutional price	0.228	0
Finland	A sugar price	Institutional price	0.064	0.08
Sweden	B sugar price	Institutional price	0.030	0.08
United Kingdom	World price (C)	World price (industrial)	0.176	0.08
Czech Republic	World price (C)	Institutional price	0.569	0.08
Hungary	B sugar price	Institutional price	0.569	0.08
Poland	B sugar price	Institutional price	0.567	0.08

Sources: Banse, et al. (2005), Confédération des Betteraviers Belges (2002, personal communication), Devadoss and Kropf (1996), Frandsen et al. (2003), and Poonyth et al. (2000).

the ROW cane and ROW beet regions, we calculate a production-weighted average supply elasticity of 0.269 and 0.207, respectively, and a consumption-weighted average demand elasticity of -0.034. For Greece and Portugal we use Devadoss and Kropf's (1996) supply elasticity estimate of 0.228 for A quota sugar. As supply elasticities already incorporate yield response to prices, we set yield elasticities to zero for these regions. For the other EU-27 regions we set the yield elasticity to 0.08, borrowed from the ESIM-model (Banse, Grethe, & Nolte, 2005). The ESIM-model also supplies us with area elasticities for the new member states (elasticities are listed in Table 2). Despite the drastic change in the CMO for sugar, we keep the elasticities constant over time for several reasons. First, our sensitivity analysis (see below) demonstrates that elasticities only play a role for WPR regions. This is inherent to the binding quota and the small effect of world prices on production in the regions that are non-responsive to world prices (WPN). However, despite the wide distributions assumed, the outcomes of our stochastic model are only marginally affected by elasticities of WPR regions. Secondly, since WPR regions produce sugar at the margin under world price incentives, we believe that these elasticities do not change significantly with the reform as the incentive mechanism essentially remains the same. This is in line with Dillen et al. (2008a), who observed that WPR regions' incentives for innovation were unaffected by the reform. Finally, no new elasticity estimates are available since the transition phase is still ongoing and no reliable data are available.

Results and Discussion

We conduct a Monte Carlo simulation of 6,000 simulations to generate stochastic distributions for our welfare estimates using the software @Risk from Palisade Corporation. Table 3 reports the mean values. The downstream sector (global producers and consumers) captures the largest share (61%), while the seed sector extracts 39% of the total welfare created despite the perfect corporate pricing strategy. This result is in line with ex-post impact studies on first-generation GM crops where, on average, a value sharing of two thirds downstream and one third upstream is observed (Demont et al., 2007). 31% of the benefits accrue to the ROW if we assume that beet producers in these countries are able to

Table 3. Price and welfare effects of the global adoption of herbicide tolerant sugar beet during the adoption scenario 1996-2015.

Year	96/98	98/00	00/02	02/04	04/06	06/08	08/10	10/12	12/14	14/15	NPV	LSR
						Price effects (%)						
World sugar price	99.6	99.4	98.9	98.7	98.6	98.3	98.4	98.4	98.4	98.4	n.a.	n.a.
A sugar price	99.9	99.9	99.9	99.9	99.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
B sugar price	99.8	99.7	99.2	99.2	99.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
						Welfare effects (million €)						
Belgium	6	10	15	18	34	31	30	31	31	16	223	0.2
Denmark	5	11	17	21	25	20	16	16	16	8	178	-3.1
Germany	31	56	88	97	98	89	92	94	95	48	888	0.2
Greece	5	9	17	18	11	8	4	4	4	2	115	-2.8
Spain	25	52	83	96	90	49	42	41	41	20	691	-3.3
France	13	21	31	33	106	100	94	97	99	50	603	0.3
Ireland	3	8	11	14	1	0	0	0	0	0	64	-2.0
Italy	15	32	50	63	44	21	18	17	17	9	390	-2.2
The Netherlands	10	24	36	43	68	41	34	33	33	16	389	-3.2
Austria	4	6	9	10	19	17	17	17	17	9	127	0.6
Portugal	1	3	4	5	6	3	2	2	2	1	36	-3.6
Finland	3	6	9	11	10	8	5	5	5	2	79	-3.6
Sweden	2	4	6	8	10	10	8	8	8	4	74	-2.0
United Kingdom	7	11	16	18	30	27	26	27	27	14	210	0.3
Czech Republic	0	0	0	0	30	18	13	13	13	6	80	-4.3
Hungary	0	0	0	0	18	10	7	7	7	3	45	-2.2
Poland	0	0	0	0	114	73	60	59	59	29	331	-4.1
EU-27 producers	128	253	392	454	712	522	468	468	472	238	4,523	-1.2
EU-27 consumers	0	0	0	0	0	0	0	0	0	0	0	n.a.
ROW cane	-232	-313	-529	-596	-730	-999	-1,046	-1,110	-1,167	-606	-7,222	-0.4
ROW beet	107	205	316	369	383	391	398	399	405	205	3,461	-2.8
Net ROW producers	-125	-108	-213	-227	-347	-609	-649	-711	-762	-402	-3,761	-0.7
ROW consumers	296	387	637	685	865	1,171	1,226	1,306	1,384	723	8,610	n.a.
Net ROW	171	279	424	458	518	562	578	595	622	322	4,848	n.a.
Seed sector	189	403	585	716	715	628	601	588	585	292	6,069	n.a.
Total	489	935	1,401	1,628	1,945	1,712	1,646	1,651	1,680	851	15,440	-0.7
						Welfare distribution (%)						
EU-27 producers	26	27	28	28	37	30	28	28	28	28	29	n.a.
EU-27 consumers	0	0	0	0	0	0	0	0	0	0	0	n.a.
Net ROW	35	30	30	28	27	33	35	36	37	38	31	n.a.
Seed sector	39	43	42	44	37	37	36	36	35	34	39	n.a.
Total	100	100	100	100	100	100	100	100	100	100	100	n.a.

n.a.=not applicable
NPV=net present value in the agricultural season 2006/07 of the accumulated welfare effects
LSR=land supply response to the technology

achieve similar cost reductions from the technology as in the EU-27, and are not able to export the technology-induced surplus on the world market, which would further erode the world market price (i.e., they are assumed to be WPN). The results presented further include welfare effects foregone in the past and potential benefits in

Table 4. Descriptive statistics of the global 2006/07 net present value of herbicide tolerant sugar beet during 1996-2015.

	Minimum	2.5% confidence limit	Mean	97.5% confidence limit	Maximum
EU-27 producers	3,245	3,751	4,523	5,347	5,998
EU-27 consumers	0	0	0	0	0
Net ROW	2,563	3,366	4,848	6,333	7,415
Seed sector	4,310	4,777	6,069	7,355	7,838
Total	10,999	12,512	15,440	18,462	20,161

the future. Biennial price and welfare effects are reported in Table 3. Worldwide, sugar beet growers gain €8.0 billion almost equally shared between EU-27 producers (57%) and ROW producers (43%). The seed sector extracts €6.1 billion of the global welfare gains. If we do not take into account any market effects, 57% of the benefits would flow to the beet growers, while 43% would accrue to the seed sector.

The depressing effect on world prices engendered by innovating WPR regions causes ROW consumers to gain €8.6 billion, but this is in large part offset by the ROW cane growers' loss of €7.2 billion. Since we assume that the technology spillovers to the ROW beet sector do not depress the world price (WPN assumption), the EU is not affected by HT sugar beet adoption in the ROW. Instead, through the inclusion of WPR member states, our model implicitly allows for the EU eroding its own profitability through technological innovation, an ambiguity called 'immiserizing growth' (Bhagwati, 1958). However, our results show that the CMO for sugar largely protects domestic producers against this perverse side effect of innovation. The model suggests a world price decrease of 1.6% over a period of 19 years due to the progressive adoption of the innovation. This estimate is relatively small compared with the estimated annual price declines of 0.64% in the case of Bt cotton adoption in the United States (Falck-Zepeda, Traxler, & Nelson, 2000) and 0.88-0.97% in the case of Roundup Ready® soybean adoption in the United States and South America (Moschini et al., 2000; Qaim & Traxler, 2005).

Under the former CMO, EU institutional prices were exogenously fixed, i.e., no important price declines were possible. As a result, the benefits essentially accrued to farmers without affecting EU processors and consumers. However, if weed control based on GM HT technology increases the sugar beet's sucrose content (Kniss, Wilson, Martin, Burgener, & Feuz, 2004), processors will be expected to gain from the technology since the processing costs are approximately the same per ton of beets regardless of sugar content (DeVuyst & Wachenheim, 2005). Moreover, if the EU government endogenized public and private agricultural research expenditures (see, e.g., Swinnen & De Gorter, 1998) in the CMO for sugar, benefits would be shared among farmers and consumers. Under the new CMO, where no institutional prices for beets exist, created benefits can be shared between farmers and sugar processors through lower beet prices. The welfare increase for sugar processors could increase the pull by the sugar lobby to accept GM sugar beet in the EU. The global welfare gain over the entire 19-year period, finally, would accumulate to a 2006/07 net present value (NPV) of €15.4 billion. As we assume no supply response for the majority of beet producers, the enhanced yields of the technology engender important land contractions in the beet industry. Table 3 reports the average land supply response (LSR) to the technology. Our model predicts that due to the adoption of HT sugar beet, the EU-27 beet area will shrink by 1.2% on average. WPN member states' beet areas are expected to decline between 2.0% and 4.3%, whereas WPR regions are expected to allocate more land to sugar beet, i.e., between 0.2% and 0.6%, in response to increased profits. The ROW beet region will remove 2.8% of sugar beet area from cultivation, while the ROW cane area will shrink by about 0.4%. On a global scale, the sugar industry is expected to contract its area allocated to sugar beet and cane by 0.7%.

In Table 4, we present some descriptive statistics of the global 2006/07 NPV of HT sugar beet during the period 1996-2015. Given the assumed subjective distributions, EU-27 producer surplus ranges from €3.8 billion to €5.3 billion in 95% of the cases. Total welfare increase is less robust, ranging with the same probability from €12.5 billion to €18.5 billion. Normalized regression coefficients in Table 5 reflect the robustness of the model to individual parameter values. The coefficient of determination R^2 is high in all regressions, which suggests that the linear response surface sufficiently explains the variation in the iterations. We investigate the coefficients for the most recent agricultural season (2006/07), with the sensitivity estimates for the other seasons being similar. The short-run flexibility (≤ 0), which can be interpreted as the inverse of the ROW

Table 5. Normalized regression coefficients of the estimated welfare effects in the agricultural season 2006/07 in function of the model parameters.

Model parameter	World price	EU-27 producers	ROW cane	ROW beet	ROW consumers	Net ROW	Seed sector	Total
Short-run flexibility	0.905	0.094	0.905	0.709	-0.905	-0.088	0.003	-0.020
Long-run flexibility	0.375	0.039	0.375	0.293	-0.375	-0.037	0.000	-0.008
Area elasticity ROW cane	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.009
Area elasticity ROW beet	-0.004	0.000	-0.004	-0.003	0.004	0.000	0.000	0.000
Yield change ROW	0.000	0.000	0.000	0.534	0.000	0.861	-0.052	0.444
Yield change EU[a]	-0.018	0.133	-0.018	-0.014	0.018	0.002	-0.001	0.038
R^2	0.982	0.997	0.982	0.989	0.982	0.998	1.000	0.999

[a] The normalized regression coefficients are averaged over all EU regions.

export demand elasticity, is the main driver of technology-induced world price movements. A higher short-run flexibility implies a more elastic export demand curve, engendering (1) a smaller technology-induced world price decline, (2) a smaller loss for all farmers (positive coefficient, columns 3, 4 and 5), and (3) a smaller gain for ROW consumers (negative coefficient, column 6). For the global welfare gains, the opposing effects largely cancel each other out. Sensitivities to the lagged sugar export supply expansion coefficient (long-run flexibility) are smaller because of two reasons. First, we assumed a more narrow distribution for this parameter. Second, as we assumed a monotonically increasing adoption curve, lagged technology-induced EU sugar export supply expansions are smaller than actual expansions such that it has a smaller effect on welfare gains, regardless of its stochastic distribution. All yield increases have an important effect on global welfare. As the EU model is disaggregated, each region features a separate stochastic yield boost, and the aggregate effect is partly cancelled out. However, for individual EU regions the coefficients are larger, ranging from 0.011 for Hungary to 0.216 for Germany. The ROW cane area benefits from all factors that prevent the EU (1) from achieving large cost reductions in adopting HT sugar beet, e.g., a small yield boost; and (2) from exporting its surplus on the world market, e.g., an elastic export demand and/or inelastic supply. As the ROW cane region does not innovate in our model, its welfare is essentially a function of the world sugar price. Therefore, the world price and the ROW cane region equations share the same regression coefficients. Table 5 reports a small but significantly negative effect of a yield increase on the seed sector's profits. In highly protected sectors, such as quota systems, yield-enhancing technologies negatively affect their own demand, as farmers who are WPN will decrease their land allocated to the crop, lowering the derived demand for enhanced seed. This phenomenon has long been observed in the EU market for sugar beet seed, which is gradually decreasing due to increasing productivity and to decreasing acreage (Bijman, 2001). Including the market for biofuels or modeling the introduction of GM technologies in sugar cane production could also be included in further updates of the EUWABSIM model.

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