European Review of Agricultural Economics Vol **33 (2)** (2006) pp. 223–247
doi:10.1093/erae/jbl006

Modelling the EU sugar supply to assess sectoral policy reforms

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Received May 2005; final version received March 2006

Summary

We investigate the possible linkages between the EU sugar production under quota and the supply of C sugar. We calibrate the implicit cross-subsidy between in-quota sugar and out-of-quota sugar. The resulting supply specification is included in a computable general equilibrium model of the EU economy detailing the agricultural sector. We simulate the effects of the 2006 reform of the EU sugar regime and the effects of a ban on sugar export subsidies. Results suggest that the reform makes it possible to fill the requirements of the 2005 World Trade Organisation panel but that further adjustment will be needed to eliminate all export subsidies as is scheduled for 2013.

Keywords: common agricultural policy, sugar, export subsidies, general equilibrium model, WTO

JEL classification: Q17, Q18

1. Introduction

Sugar remains one of the most heavily subsidised sectors in many developed countries. The sugar sector is protected by high tariffs in the US, Japan and the EU, and it is estimated that 80 per cent of world sugar production benefits from some form of support (Mitchell, 2005). However, the sector has recently been subject to intense pressure. Multilateral negotiations under the World Trade Organisation (WTO) should result in significant tariff cuts in the sugar sector, as it has been agreed that the most protected products will face higher cuts (WTO, 2004; 2005a). The conclusion of the WTO panel challenging part of the EU's sugar exports requires *de facto* that the EU cuts its production (WTO, 2005b). The agreement to ban export subsidies by 2013 adds some longer-term constraints on the EU sugar regime (WTO, 2005a). Pressures for reforms also come from bilateral or non-reciprocal trade agreements. The US must grant duty-free access to Mexican sugar by 2008 under the North American Free Trade Agreement. Access to the US market for Dominican Republic and central American sugar is also bound to increase owing to the commitments under the Central America Free Trade Agreement. EU imports of sugar originating from least developed countries (LDCs) will enter duty-free and quota-free in 2009 under the 'everything but arms' (EBA) initiative.

These pressures have already led to major changes in sugar policies. The EU agreed a reform of the sugar sector on 20 February 2006, to begin in July 2006, involving a large cut in intervention price. It is a sweeping change in a common market organisation (CMO) that has resisted reform for 40 years. Because of the domestic support provisions under the 2004 WTO Framework Agreement, US sugar price support levels face the prospect of being capped at lower levels than the present ones.

Several authors have recently investigated the effects of changes in sugar policies. Studies have focused on multilateral trade liberalisation, either on the effect of an extension of preferential regimes (such as the EBA) or on the effect of domestic reforms. Perplexingly, the different studies provide results that are largely inconsistent, even for rather similar scenarios. Some authors find that market liberalisation will result in large welfare gains and significant changes in international trade. Others believe that the overall gains will actually be limited due to inelastic demand (i.e. small initial Harberger triangles on the consumer side), persistence of supply control (production quotas) and large rents that need to be reduced before reforms actually become binding and affect output. The inconsistencies exceed what is normally observed between different modelling approaches in the agricultural sector. Here, the effects of trade liberalisation are sometimes contradictory and the magnitude of the differences in, say, world price changes or changes in welfare is striking. Although there are several explanations for the diverging results regarding the effects of reforms on the world market, the changes in the EU sugar net trade appear to be of particular importance. There is a large degree of uncertainty as to the level of the EU sugar supply under different policy conditions. Because producers have been largely insulated from world market signals for decades, there is little statistical variability to exploit. 'Guesstimates' of supply elasticities and production costs rely on thin evidence.

A first objective of this paper is to model the EU sugar supply, accounting for specific aspects such as a potential cross-subsidy between production quota sugar and C sugar and the existence of rents in both the farm and processing sectors. Another objective is to provide estimates of the effects of the 2006 EU sugar reform and the elimination of EU export subsidies by 2013, a decision adopted (with some side conditions) in the framework of the WTO.

We first provide a brief survey of the various studies assessing the impact of liberalisation of the sugar sector. We then investigate some specific aspects of the EU sugar production, in particular, those that might result in a cross-subsidy between in-quota sugar and C sugar. We propose a way of modelling the sugar market that includes these specific aspects of the EU producer and processor behaviour. We estimate econometrically the parameters that allow us to account for this cross-subsidisation and to calibrate production costs. Finally, we integrate this representation of the sugar sector in a general equilibrium (GE) model of the EU economy in order to assess the effect of the 2006 sugar reform and the effect of future international discipline under the WTO.

2. Effects of liberalising sugar markets

2.1. Some ambiguous results

Recent studies have provided some information on the effects of sugar market liberalisation. Clearly, the scenarios vary according to authors, but the discrepancy in the findings can hardly be explained by differences in the policy changes that are modelled. Some authors have found that even a partial liberalisation in the sugar market will generate a very large increase in world prices (El Obeid and Beghin, 2005). One explanation is the decrease in the production of sugar in the EU, i.e. a fall of 61 per cent under multilateral liberalisation. As a result, the EU becomes a net importer of some 8 million tonnes of sugar.

Other partial equilibrium models that rely on a relatively similar structure lead to different results. For a similar increase in the world price, Wohlgenant (1999) found that EU production increases by 2 per cent and that the EU remains a net exporter of 2.5 million tonnes. Poonyth *et al.* (2000) also found that EU production is barely affected by the reduction in the intervention price required to export without subsidies and that, overall, EU exports would remain relatively stable. In contrast, OECD (2005) reported that EU production would decrease by some 60 per cent under their trade liberalisation scenario and according to Adenäuer *et al.* (2004), exports would decrease significantly if export subsidies were phased out. Witzke and Kuhn (2003) found a significant decrease in the production of C sugar for a 30 per cent decrease in sugar price.

The various GE approaches also lead to different, although perhaps less contrasting, results. Under a reform that liberalises the sugar market, Frandsen *et al.* (2003) showed mainly an erosion of rents, with production in France, Germany, Austria and the United Kingdom only marginally affected by a strong reduction in the intervention price. For Bouët *et al.* (2005), the reduction in the EU supply is significant if tariffs are cut by 60 per cent and export subsidies removed, but the resulting increase in the world market price is minimal. van der Mensbrugghe *et al.* (2003) found that the EU becomes a very large importer of sugar under a multilateral liberalisation of the world market.

2.2. Why do the results differ so much?

There are many explanations for these discrepancies across studies. Some refer to the model specification.[1] Different assumptions about some key factors such as the supply response in LDCs and Brazil also have a significant impact on the world price. The way some upstream, downstream and side-sectors (energy) are treated also plays a role because of the linkage with the ethanol market. However, a major explanation of the differences across models lies in the different response of EU supply to a particular policy shock. The EU is the second largest exporter of sugar, principally owing to its support policy, and the fourth largest importer, mainly because of its development aid policy. Changes in the EU net trade position have a significant impact on the world market equilibrium.

Inferring the effect of the 2006 sugar reform (to be implemented in July 2006), and the effect of multilateral trade liberalisation on EU supply is cumbersome. The present EU sugar policy is complex and it is understandable that modellers have taken different routes to cope with the difficulty of representing adequately all the components of the CMO for sugar: two types of production quotas ('A' and 'B') facing different supported prices, high specific tariffs, preferential access under import quotas, a safeguard clause, the possibility of producing out-of-quota sugar for the world market, levies for funding exports of in-quota sugar, etc. (see van der Linde *et al.*, 2000 for a complete description of the sector before the reform). It is difficult to assess EU production costs and rents. Producers expect significant changes in prices and quota allocation and some hope for some compensation, which means that information on costs is often subject to strategic behaviour and can hardly be trusted. Production quotas have been in place for more than 30 years and the administrative price has shown little variability. This makes it difficult to infer the effect of changes that would induce large shifts away from the present equilibrium. Because of the two-tier production quotas, it is unclear how the quantity produced would respond to price changes. The problem is made worse by the interaction between the agricultural and processing sectors. Indeed, there is evidence that part of the support to the sector is retained by the processing sector, which will also be affected by reforms. Because of fixed costs, the need to find suppliers of beet within limited distances, strategies of processing firms are likely to interact with those of the farm sector and affect the overall EU supply response in a way largely unknown to modellers.

Two issues appear particularly important: the level of costs and rents under production quotas, and the modelling of the supply of C sugar. As they drive the EU supply response, assumptions regarding these two issues play a large

1 The sensitivity of the assumption of a homogeneous good versus a differentiated good (à la Armington) was shown by van der Mensbrugghe *et al.* (2003). Models that include an endogenous supply of land in Brazil (such as van der Mensbrugghe *et al.* 2003 or Bouët *et al.* 2005) tend to show a smaller increase in the world price. Partial equilibrium models often provide larger price effects than general equilibrium model effects.

role in the results obtained by the different authors working on market liberalisation and policy reform.

2.3. EU production costs

A major problem in modelling the EU sugar supply is to assess which prices and costs actually drive production. The EU CMO sets an intervention price for sugar, from which a base price for beets is derived, but market prices may be different from regulated prices (Swedish Competition Authority, 2002). van der Linde *et al.* (2000), Eurocare (2003) and LMC (2004) compiled some information on costs of production. Estimates relying on budget generators and engineering data suggest that costs of production are close to the intervention price for sugar and the administrative ('base') price for beet (i.e. roughly €47 per ton of beet until the implementation of the 2006 reform). However, econometric or linear programming-based estimates of marginal costs or 'opportunity costs' (i.e. the cost of producing one unit of beet instead of alternative crops) are much lower (Bureau *et al.*, 1997). Recent estimates for France suggest that they were below €18 per ton of beet before implementation of the June 2003 reform of the common Agricultural Policy (CAP) (Rozakis and Sourie, 2005).

EU production of C sugar has been significant over the last decade, representing 4–13 per cent of the 18–20 million tons of sugar now produced in the EU25, depending on the year. It is therefore tempting to believe that, at least in the most efficient regions, producers respond to the world price. However, an indirect implication of this assumption is that the resulting EU supply curve is such that a fall in the intervention price would mainly erode rents, but not affect the production. Even though this seems consistent with the existence of the production of C sugar for the world market, the assumption that the aggregate EU production responds to the marginal costs of the most efficient producers might lead to an underestimation of the impact of reform on the EU output.

3. Microeconomics of the EU sugar supply behaviour

3.1 What drives C sugar production?

Cross-subsidisation of out-of-quota C sugar by A and B sugar is sometimes seen as driving C sugar production. Three possible effects can be identified.

- Some authors, and obviously the members of the 2005 WTO panel, have considered that the high supported price for the output under A and B quotas covers fixed costs. This would allow the production of C sugar at low prices, given the need to recover only variable costs. If this is the case, it is not only marginal (variable) costs that drive the EU sugar production. A change in the in-quota price will affect the possibility of recovering fixed costs (Chau and de Gorter, 2005).

- During recent periods of low world prices, it appears that the world price hardly covered the cost of even variable inputs (Rozakis and Sourie, 2005). A possible explanation for the C sugar production at such low prices is that some producers grow C sugar beet as an insurance strategy against revenues foregone when there are poor harvests. Again, if this is the case, one cannot model the EU supply as a function of marginal cost only. It is necessary to work out more carefully the interaction between the supply of C sugar and the level of the rent drawn from the production of in-quota sugar.
- Finally, another possibility is that C sugar was produced so as to build 'reference' quantities when producers expected that the ongoing reform would involve a particular allocation of future production rights, premium rights or compensation on the basis of past output levels. Again, if this is the case, this feature must be included in the modelling of the EU sugar supply.

These points may result in interactions between in-quota sugar and C sugar and could play a role in the response of the EU sugar production to price changes. This may occur both at the beet production level and at the refined sugar production level. In the following section, we address these three possible cases in a more analytical way.

3.2. Cross-subsidisation through fixed costs

The potential cross-subsidisation between in-quota and C sugar can be modelled using a simple short-run comparative static framework. The short-run profit-maximising problem of the beet producer in the presence of quasi-fixed factors can be written as:

$$\max_{y_1, y_2} \pi = p_1 y_1 + p_2 y_2 - C^{SR}(y_1 + y_2; w; z) - p_z z, \quad \text{subject to } y_1 \leq \text{quota}, \tag{1}$$

where z denotes an aggregate of quasi-fixed primary factors (capital, self-employed labour and land owned or subject to long-term leases) whose (exogenous) price is p_z. The variable w denotes the price of variable inputs; p_1 the price of in-quota sugar beet; p_2 the price of out-of-quota beet; y_1 the quantity produced within the quota; and y_2 the quantity produced out of the quota (beet quantities are expressed in sugar equivalent so as to adjust for the sugar content), and C^{SR} the restricted or short-run cost function.

For certain levels of the marginal cost function, the quota and the price of C beet, the existence of quasi-fixed inputs may result in a cross-subsidy between in-quota and C beet outputs (a similar pattern applies to sugar production, so we will use 'sugar' to describe both). This happens when p_2 and y_1 are such that the production of C sugar induces a lower average cost owing to a larger production scale. In such a situation, profit maximisation may result in a larger output than if the quantity y_1 was not subsidised, i.e. if there was only one sugar price p_2. This situation is well described by Kopp and de Gorter (2005), who provided a graphical illustration of two possible cases where the in-quota price results in some cross-subsidisation. They showed that the quota rent may push the revenue over the break-even point (cost savings due to returns to scale exceed the losses on the out-of-quota market; see Chau and de Gorter (2005) for a more easily accessible reference).

The analytical derivation of the optimal conditions is cumbersome because of the discontinuity in the supply response introduced by the quota regime. The maximisation programme is such that one cannot assume the equality between marginal cost and the out-of-quota price drives production in the general case. The level of quota must be high enough to ensure that the short-run profit (profit less fixed costs) is positive. Supply is then determined by the combination of two conditions: (a) that p_2 equals marginal cost, and (b) that $p_1y_1 + p_2y_2 - C^{SR}\ (y_1 + y_2; w; z) > 0$ (break-even point).

These considerations suggest that the coverage of fixed costs by the rent provided to the in-quota production is a possible determinant of C sugar supply. This idea was central in the decision of the WTO panel that EU exports of C sugar should be considered as subsidised. However, such a cross-subsidisation cannot hold in the long run. If quasi-fixed factors can adjust to their optimal level for production y_1, then there is no point in producing C sugar at loss. The simple expression of the long-run producer's profit-maximisation problem (2) and Hotelling's lemma shows that such a cross-subsidy is not optimal.

$$\begin{aligned}\underset{Y}{\text{Max}}\ \pi &= p_1y_1 + p_2y_2 - C^{LR}(y_1 + y_2; w; p_z) \\ &= p_1y_1 + p_2y_2 - CV(y_1 + y_2; w; z^*) - p_z z^*, \end{aligned} \tag{2}$$

with

$$z^* \equiv\ z^*(y_1 + y_2) = \text{Arg}\frac{\partial \pi}{\partial p_z}$$

Because z can adjust freely in the long run, there will be no production of y_2. The reason is that there is no cost saving due to increasing returns to scale (caused by a non-optimal level of fixed cost at y_1 in the short run) that can offset a loss in the out-of-quota market. Obviously, there might be production of C sugar in efficient firms where the long-run marginal cost is lower than p_2 at the production level y_1, however, in such cases, the difference between p_1 and p_2 is a simple rent, and there is arguably no cross-subsidy.

As pointed out by Witzke and Kuhn (2003), the quota regime has been in place for many decades almost without modification, and it is difficult to believe that the situation that has been taking place during the past years is merely a short-run equilibrium. Major non-convexities (indivisible inputs) could prevent firms from adjusting their production structure to the optimal input level corresponding to the quota as in equation (2). However, in the beet sector, there are many opportunities to share machinery, to buy second-hand equipment and to purchase contract work. Contract harvesting or planting costs are only slightly decreasing with the size of operation. The fixed component in the cost of contract work is not large enough to provide a significant incentive for producing C beet so as to spread this fixed cost on a larger output. Overall, the argument that the fixed costs of C sugar are covered by the quota, and that this explains the production of C sugar in the EU, is not fully compelling. However, a recurrent problem in production economics is to define how long the 'long run' is. In Europe, there is evidence that some equipment has a long service life (Ball *et al.*, 1993). In addition, in the processing sector, some equipment might be less divisible or less easily adjustable than in agriculture, and fixed costs in refineries could be a reason for sugar processors to encourage farmers to produce C sugar.[2] For this reason, we keep open the possibility, when we model the EU sugar sector, that the production of C sugar benefits from the high price of in-quota sugar, i.e. that there is some form of cross-subsidy.

3.3. C sugar as insurance

Because of the high price received for in-quota sugar beet, producers may overshoot so as to make sure that they will capture the rent in the case of poor harvests. A rational beet producer will accept losses on C sugar, or on a share of the C sugar, in order to maximise expected profit. The non-linearity in prices caused by the quota and the asymmetry between gains and losses caused by the dual price system result in kinked marginal returns, showing similarities with the classical concavity of the expected utility function. In such a case, even a risk-neutral producer will overshoot as a preventive measure.[3] A defendable assumption is that all costs are incurred by the time of harvesting.[4] In such a case, if the output harvested is one unit lower than the target quantity y_1, the loss is p_1. If it is one unit larger, the extra profit is p_2. Let us call q the subjective

2 At least one anecdotal case in France suggests that some sugar factories require some of their beet suppliers to produce beet beyond their individual quota, even though it is not necessarily profitable for the farmers (the refinery accepts in-quota beet only if supplemented by a certain percentage of C beet). More generally, it seems that the cooperative processing sector modulates the actual price paid for beet to the farmers (who are also shareholders of the cooperative). If there is significant unused capacity, processors may also pay above the nominal price for C sugar beet (the exact nature of contracts between beet producers and processors is a grey area).

3 Similar behaviour can be observed for B sugar in some regions where farmers aim at filling their A quotas only. Given the risk of poor yields that would lead them not to fill their A quota, some take the chance of overshooting, as pointed out to us by H. G. Jensen.

4 When the actual yield (i.e. quantity of beet per hectare and the sugar content) becomes apparent to the farmer, the cost of variable inputs (including fertiliser) has already been incurred. It is also reasonable to assume that most remaining (post-harvest) costs are not a function of the quantity produced. A large share of the yield variability depends on the sugar content, a function of sun exposure during the pre-harvest period, when fertiliser and pesticides have already been applied. It is true, however, that the level of some inputs (pesticides, herbicides) affects the degree of yield variability caused by pests and weeds.

probability that actual yield exceeds target yield by one unit. For the sake of simplicity, assume that the discrete distribution as only two outcomes (as pointed out by an anonymous referee, the situation would be more complex if there were more outcomes, i.e. $y_1 + 1,\ y_1 + 2,\ \ldots$). The expected profit of the producer targeting a production level, y_1, is $p_1 y_1 - C(y_1) - qp_1 + (1-q)p_2$. Here, C denotes the long-run cost function (rather similar behaviour can be derived with a restricted cost function) and MC denotes the marginal cost. The expected profit of a producer targeting one unit of production above y_1 (i.e. overshooting) is $p_1 y_1 + p_2 - C(y_1 + 1) + (1 - \text{q})p_2 - qp_2$, with $C(y_1 + 1) -$ *$(y_1 1)C(y_1) \approx MC(y_1)$, that is, overshooting is rational provided that $MC(y_1)p_2 q(p_1 p_2)$. The higher the difference between the two prices, the more likely the overshooting.*

More formally, the introduction of an 'insurance' behaviour modifies the standard marginal conditions that characterise optimal production. Following Roumasset (1977), the producer's expected profit-maximisation problem involves a discontinuous function as in equation (3), where δ denotes the Kronecker symbol and μ_r is the expected yield (unit sugar content times quantity of beets per hectare) under the assumption that variable costs are experienced before climatic conditions affect the final yields. L denotes the quantity of land used, r the actual yield and the bar over y_1 the quantity under quota.

$$\underset{L}{\text{Max}} E\big(p_2(rL - \overline{y_1}) + p_1\overline{y_1} - C(\mu_r L; w) - \delta_{rL \le \overline{Y_1}}(p_2 - p_1)(rL - \overline{y_1})\big) \tag{3}$$

or

$$\underset{L}{\text{Max}}\, p_2(\mu_r L - \overline{y_1}) + p_1\overline{y_1} - C(\mu_r L; w) - (p_2 - p_1)\cdot \text{Prob}[rL \le \overline{y_1}]\cdot\ E(rL - \overline{y_1};\, rL - \overline{y_1} \le 0).$$

The discontinuity represented by the Kronecker symbol results from the fact that if yields are low this particular year and that production does not reach the quota, the expression of the profit function is different from the one when the quota is reached. The first-order conditions involve

$$p_2\mu_r - \mu_r \text{MC}(\mu_r L; w) = (p_2 - p_1)\cdot \left\{ \begin{array}{l} \dfrac{\partial \text{Prob}[rL \le \overline{y_1}]}{\partial L} \cdot\ E(rL - \overline{y_1};\, rL - \overline{y_1} \le 0) \\ + \text{Prob}[rL \le \overline{y_1}] \cdot \dfrac{\partial E(rL - \overline{y_1};\, rL - \overline{y_1} \le 0)}{\partial L} \end{array} \right\}. \tag{4}$$

Three conclusions can be drawn from equation (4) and from the fact that the bracketed term is positive, and therefore the right-hand side of equation (4) is negative. First, producers will overshoot and produce C sugar, as the determination of the optimal supply behaviour responds to the condition that marginal costs equals the price p_2 plus a positive term. Second, this term depends positively on the probability of a bad harvest. Third, this positive term depends positively on the difference $(p_1 - p_2)$. This point is important because it shows that in the presence of 'insurance' behaviour, there is a cross-subsidy between in-quota and C sugar even in the long run, without the fixed cost effect described previously. Indeed, the higher p_1, the more it becomes profitable to produce C sugar for insurance.

This relationship does not prove that C sugar is formally cross-subsidised in the EU. The incentive to overshoot is mitigated by the possibility of carrying over sugar quota rights from one year to another, a feature of the EU CMO even before the 2006 reform. This possibility reduces significantly the cross-subsidy resulting from equation (4). Some sugar processors also have private arrangements giving flexibility to beet suppliers to smooth the supply over several years so as to prevent overshooting. In addition, empirical evidence suggests that insurance behaviour is unlikely to explain all the C sugar production in EU15 (Adenäuer *et al.*, 2004). Indeed, the level of EU15 production is only consistent with unrealistic levels of yield expectations. However, the 'overshooting' factor may explain a share of C sugar production, and we believe that the resulting implicit cross-subsidy needs to be included in the modelling of the EU supply response behaviour.

3.4. Expectations

Projects for a reform of the EU CMO circulated for decades before 2006. It is possible that farmers have produced beyond the (static) optimum level, expecting that historical reference levels would be used in the future. Indeed, in past reforms of the CAP, many quota allocations, premium rights or compensation payments have been given on the basis of historical references. Precautionary behaviour involving the building up of potential reference levels would be rational under particular expectations by producers and/or processors regarding future reforms. Assume that producers expect that future quota mobility across the EU will result in closing sugar factories in some regions. This assumption is realistic, as some sugar processors closed profitable plants in anticipation of the reform in 2005 (e.g. Greencore's Carlow plant in Ireland) and others announced such closures in early 2006 (Greencore in Ireland, Ebro in Spain, Danisco in Finland and Sweden). Consider an efficient producer who expects that, in his area, local processors will manage to increase their sugar quota and that the current level of C sugar output will be used as a variable in allocating the new quota between individual beet producers. (Other patterns of expectation are possible, but it is likely that farmers will end up with the idea that the more C sugar beet they produce, the more eligible they will be for extra compensation or future reference values.) Let us use a subscript $t + 1$ to denote expected prices and quantities in the future period, a subscript t for the present period and the variable τ

to represent a discount factor. The profit-maximisation problem of a producer, similar to the one described previously is then

$$\begin{aligned}\text{Max } \pi = {} & p_{1,t}y_{1,t} + p_{2,t}y_{2,t} - C(y_{1,t} + y_{2,t}; w_t; z) \\ & + \tau(p_{1,t+1}y_{1,t+1} + p_{2,t+1}y_{2,t+1} \\ & - C(y_{1,t+1} + y_{2,t+1}; w_{t+1}; z)),\end{aligned} \tag{5}$$

subject to $y_{1,t} < \bar{y}_{1,t}$ and $y_{1,t+1} < \bar{y}_{1,t} + \lambda y_{2,t}$, where λ represents the degree to which the producer estimates that future quotas will be based on the present production of C sugar. Maximisation with respect to y_{2t} leads to a first-order condition stating that $\mathrm{MC}_t = p_{2t} + \tau\lambda(p_{1,t+1} - \mathrm{MC}(y_{t+1}))$, that is, the optimal production of C sugar satisfies the condition that $\mathrm{MC} = p_2$ plus a positive term. This term depends on future rents, i.e. on future in-quota prices. Although it is likely that producers expect future in-quota prices to be lower than the present prices, the prospect that these prices will remain higher than the world price may explain current production of C sugar.

Does this show that C sugar is cross-subsidised? Formally, there is no direct linkage between the in-quota sugar price and the supply of out-of-quota sugar, as the production of C sugar depends on future in-quota prices but not on present in-quota prices. However, even if the 'reference building' behaviour does not introduce a formal cross-subsidy, it may be one of the explanations for the relatively high levels of C sugar produced in the EU15 in recent years, despite low world prices.

4. Econometric identification of production costs

4.1. Rents and production costs

The three cases presented previously suggest that modelling the EU production under the usual assumption, namely that producers maximise profit so that marginal revenue equals marginal costs, may represent the EU supply response incorrectly. In this article, we consider aggregate supply curves as did Frandsen *et al.* (2003). A common feature of the three effects described earlier (fixed costs, uncertainty regarding future yields and the asymmetry of gains/losses, expectation regarding future reference levels) is that the producer's behaviour leads to conditions between the marginal cost, MC, and the out-of-quota price, p_2, of the type $\mathrm{MC} = p_2 + \theta$, where θ is a positive function of p_1, a negative function of p_2 and a positive function of the quota.

We have little information about the value of θ. In order to characterise θ, we estimate econometrically the linkage between the decision to plant L hectares with sugar beet, on the one hand, and sugar prices and quotas, on the other hand. We assume that MC is a linear (increasing) function of L and we include a trend t to account for technical change, i.e. $\mathrm{MC} = W(\alpha + \beta rL + \gamma t)$, where α, β and γ are coefficients to be estimated and W is a price index of inputs. The variable θ is also assumed to depend linearly on the in-quota and out-of-quota sugar prices, i.e. $\theta = \delta + \varepsilon Q + \phi(\mathrm{p}_1 - \mathrm{p}_2)$, with Q being the level of quota, δ, ε and ϕ being coefficients to be estimated. Combining the expressions for MC and θ, a synthetic representation of the land area-planting decision is therefore:

$$L = \frac{1}{Wr}\left(\frac{\delta}{\beta} - \frac{\alpha}{\beta}W - \frac{\gamma}{\beta}Wt + \frac{1}{\beta}p_2 + \frac{\phi}{\beta}(p_1 - p_2) + \frac{\varepsilon}{\beta}Q\right) \qquad (6)$$

Econometric estimation of the coefficients of equation (6) makes it possible to estimate the cross-subsidy between in-quota sugar and C sugar, and the production costs and the supply elasticities. In order to do so, we add an error term to equation (6), reflecting all other variables omitted in this specification.[5] We use the generalised maximum entropy (GME) estimation technique. This technique is robust for small samples. It is also useful for integrating inequality constraints that are consistent with the theory (such as $\beta > 0$; $\theta \geq 0$, see the appendix). In addition, GME allows estimation of non-linear functions, which makes it possible to perform specification tests on a larger range of functional forms. The method used is described in Golan *et al.* (2001). We test the significance of estimates by the ratio of entropy (Golan *et al.*, 1999).

There is hardly any literature on the properties of GME estimators under inequality constraints, but there is little reason to believe the GME method solves the spurious regression problem if series are non-stationary and non-cointegrated. We thus test for stationarity using common tests. Because the EU sugar market organisation has not changed over recent years, there is only limited variability in some of the series. Even though the goodness of fit looks satisfactory, the different stationarity tests are often inconsistent (see the appendix). The risk of spurious regression is a limitation of the study, as the parameters δ, ε and ϕ play a role in the computation of production costs and rents. In each of the six countries producing C sugar where equation (6) was estimated, at least one parameter entering the expression of θ is significantly different from zero. This suggests that there is indeed some form of cross-subsidy between the C sugar production and the quota rent. The costs of production presented in Table 1 are derived from the parameter estimates of equation (6). The estimates suggest low production costs in Belgium, Germany and France, and high production costs in Italy and Spain. This is in line with the findings of the EC Commission (2004). The low costs in the Netherlands and the UK are perhaps more surprising. But they are in line with van der Linde *et al.* (2000) and could be explained by the scale of the plants in the processing sector (van der Linde *et al.*, 2000; Figure 14.2). We also estimate the elasticity of supply with respect to a change in the net in-quota price. These estimates are rather low for northern

5 The specification given in equation (6) performs poorly in the case of Italy. An alternative specification used is $\theta = \delta + \varepsilon Q + \phi(p_1 - p_2)Q$. In that case, ε and ϕ are not constrained.

Table 1. Production costs and aggregate supply response estimates

	Costs (€/ton)	Supply elasticity estimate with respect to p_1	R^2 of equation (6)
The Netherlands	355	0.33	0.83
UK	388	0.11	0.60
Belgium	407	0.06	0.82
France	397	0.14	0.78
Germany	424	0.22	0.96
Spain	527	0.14	0.87
Italy	551	0.90	0.45

EU countries and larger for southern countries. The weighted average elasticity is 0.23.

5. Simulation framework

5.1. GE model

The modelling of the EU sugar sector is included in a larger GE framework in order to assess the effect of trade liberalisation and policy reforms on the EU economy. The GE framework is appropriate for modelling multi-output production, consistent with the fact that sugar is always produced in combination with other crops. Welfare effects are also more easily addressed within a GE framework in the case of second best equilibria (Gohin and Moschini, 2006). In addition, GE approaches impose an internal consistency because of accounting equalities. This, for example, makes production costs at the different levels more consistent than in many partial equilibrium approaches (Hertel, 2002). Because production costs play a significant role in the characterisation of sugar supply, a proper endogenisation of returns to primary factors accounting for intersectoral linkages is an asset.

The GE model focuses on the agricultural and food processing sectors of the EU15. Other countries and sectors are treated in a much less detailed way. The model used in this study is static, with perfect competition in most sectors and a neo-classical closure. Investment is savings-driven and balance of payment equilibrium is ensured by financial flows. A social accounting matrix (SAM) was constructed for the EU, using data for 1995. The calibration of the model for the year 1995 requires a caveat, especially because of the high price of sugar that particular year. However, we introduced the changes in policy and macroeconomic environment that took place until 2005 in our pre-experiment simulation, as well as expected changes (demography, technical change, etc.) after 2005 in order to construct a 2010 baseline (see Section 6.1). This limits the consequences of using 1995 data for the SAM, even though it would be preferable to calibrate production and demand functions on more recent data and to consider the EU25.

The sectoral coverage distinguishes 75 products, including 18 and 29 agricultural commodities in the arable crop and livestock sectors, respectively. There are three primary factors (capital, labour and land) whose total quantities remain constant, but which are mobile across sectors. The EU is a large country whose trade affects other regions' exports prices through a series of export supply and demand functions. The model has four main original features: (i) the use of flexible forms that globally satisfy regularity conditions for production technology, household preferences and factor mobility, (ii) a detailed disaggregation of the agricultural sector, (iii) a detailed representation of all instruments of the CAP and (iv) the use of mixed complementarity programming (MCP) methods in order to represent changes in regimes such as production shifts under a quota. The specification used to represent preferences, technologies and factor mobility makes use of latent separability. The model is described in Gohin and Latruffe (2006).

5.2 Modelling the sugar sector

The sugar sector includes the sugar beet activity, which supplies 'A&B beet', i.e. in-quota beet, 'C beet' and the sugar processing sector which supplies 'A&B sugar', 'C sugar', 'pulp' and 'molasses'. In-quota and out-of-quota beet (respectively, sugar) are distinct products, but perfect substitutes. They differ in terms of prices, levies and constraints. Isoglucose is modelled as a substitute for sugar. Sugar beet is assumed to be non-tradable. Sugar is modelled as a homogeneous product. Accordingly, a net trade (rather than an Armington) specification is used so that the difference between EU sugar exports (A&B and C sugar) minus preferential imports meets a net export demand function from non-EU countries. EU imports are limited by tariff quotas, which generate rents, assumed to be retained by the exporting countries. The processing sector is represented in the model. Raw sugar is the only type of sugar imported, whereas only white sugar is exported. The difference in price between raw and refined sugar is kept constant so that the products behave like perfect substitutes. The modelling of the beet and processing sectors allows for a cross-subsidy between A&B and C outputs at both stages. The A&B beet and sugar are linked through a Leontieff technology, and assumptions must be made regarding the share of the rent passed to the farm sector and retained by the processing sector. The convention that is adopted here is the one used by Frandsen *et al.* (2003), with a constant proportion of price decrease between the two sectors as long as there remains some positive rent at both stages.

The production cost estimates presented in Table 1 characterise supply response at the national (country) level, and as mentioned before, we rely only on the average in the EU model. Here, a fully articulated model of each EU country would be required in order to take into account the differences in domestic production costs. However, one may always argue that the heterogeneous sugar production conditions in the EU require a region-specific model, or even a farm-level model (Mahler, 1994; Revoredo *et al.*, 2005). We need to combine country-specific information on supply and an EU-wide GE model. In order to do so, the GE model was first used to simulate the 2010 baseline, using average figures obtained from our econometric estimation.[6] National supply curves were then used to calculate country-level supply and production costs under the baseline and the reform scenarios. The fall in domestic production caused by the reform was then introduced into the GE model, which was used for simulating the overall impact of the corresponding scenario. This iterative technique allowed us to include the information on supply in the different EU countries while taking advantage of the GE model.

6. Policy changes simulations

6.1. Baseline

We first defined a reference scenario or baseline which corresponds to the situation in 2010, assuming the full implementation of Agenda 2000, the June 2003 CAP reform and the enlargement of the EU, i.e. without the 2006 reform of the sugar sector. The definition of this baseline is of particular importance, as the 2003 reform might have, in the absence of other policy development, favoured the production of C sugar in the most efficient regions. We thus constructed this baseline scenario as a pre-experiment simulation, updating the relevant data. Some variables describing the macroeconomic environment are set exogenously, using data from different institutions, including the Food and Agricultural Policy Research Institute. Assumptions were also made on technical change in different sectors. We assumed, for example, that the Hicks neutral technical change results in a 1 per cent reduction in unit costs in the sugar sector, on the basis of estimates for France (Sourie *et al.*, 2005).

Regarding external trade, we assumed that imports from the ACP, India, the Balkans and the LDCs are subject to the following quantity constraints. In 2010, the EBA will be fully implemented, but there are very few studies that give a reliable picture of what the resulting imports of sugar will be. The EU Commission has suggested that EBA imports would reach 3.5 million tonnes without EU sugar policy reform and 2.2 million tons with the reform (EU Commission, 2005). This is in the upper range of

6 In order to calibrate the sugar sector in our GE model, we first determined the gross margin of both in-quota and C beet outputs. We used input/output coefficients for a vector of intermediate inputs, and returns to land from various sources, including Eurostat SPEL and the Farm Accountancy Data Network. We assumed that the sum of the margins for A&B and C beet is fully allocated to the returns to labour, the capital bundle and quota rent. The econometric estimates of (6) were used to calibrate the cross-subsidies between in-quota beet and C beet, assuming that the unitary implicit subsidy on C beet adjusts to satisfy budget neutrality (i.e. the total implicit tax on in-quota beet equals total implicit subsidy on C beet). This made it possible to measure the value of the rent and the value of the returns to the capital and labour aggregate. For the refining sector, a similar calibration procedure was done, imposing that only A&B sugar beet is used to produce A&B sugar. The processing of both A&B and C sugar produces molasses and pulp. Unit labour costs cannot adjust in the processing sector. Profit is exhausted by returns to capital and in-quota rent. Econometric estimates of (6) were used to calculate the rent.

various estimates. There is no reliable estimate of production costs in Sudan, which is thought to have large export potential. Among other LDCs, only Zambia and Malawi seem to have low production costs, most of the LDCs being net importers of sugar (Garside *et al.*, 2004). For the definition of our baseline, we took a conservative approach on the basis of Cernat *et al.* (2003), suggesting that the EBA will mainly displace exports from ACP countries to LDC countries. It is uncertain that whether LDC exports will actually go beyond the 2008 level after 2009, still subject to a quota, and there is the possibility that extra import flows will be prevented through the activation of the safeguard clause (Talks, 2005). We assume in our baseline that, overall, duty-free imports (including from ACP countries) will be 2.2 million tonnes and that additional imports will be subject to prohibitive tariffs.

Table 2 presents the baseline, given our assumptions and the calibration of the cross-subsidisation presented earlier. In this baseline, the EU produces and exports some 1.3 million tons of C sugar in addition to the 3.0 million tons of in-quota sugar exported. Note that production costs account for cumulative technical change up to 2010, which explains the ability of the EU to produce C sugar at a price of €225 per ton. The quota rents amount to €2.5 billion after deducting a €798 million levy for the funding of B sugar exports. Production costs amount to €20 per ton of beet and €391 per ton of sugar particularly because of the flexibility brought by the 2003 CAP reform.

6.2. Policy scenarios

The model is used to simulate two scenarios:

- Scenario 1: the 2006 reform of the sugar sector is implemented, with no other adjustment coming from international pressures.
- Scenario 2: no reform, but the ending of all export subsidies in the sugar sector (including ending of exports of C sugar).

6.2.1. EU sugar reform

The 2006 sugar reform includes a 36 per cent price cut over 4 years beginning in 2006/07 and compensation to farmers averaging 64.2 per cent of the price cut as part of the CAP single farm payment. The ‘A’ and ‘B’ quotas will be merged into a single production quota, with no quota cuts, unless the market situation demands such a measure. The reform offers the possibility for member states to reduce production quotas. However, the reform allows coupled payments when production falls in excess of 50 per cent of the historical quotas, at least on a temporary basis. In addition, some 1.1 million tons of sugar will be made available for countries that produced C sugar in the past (firms that overshot internal production quotas will be able to access extra quotas against a one-off payment of €730 per ton). Finally, some national aids continue.

In Table 2, the Scenario 1 column presents the outcome of the EU reform of the sugar sector. The figures between parentheses are percentage changes relative to the baseline. Here, we assume that the compensation for the reform

Table 2. EU15 sugar markets under the baseline after the proposed reform and with a ban on export subsidies

	Baseline 2010	2006 reform relative to baseline (Scenario 1)	Total ban on export subsidies relative to baseline without reform (Scenario 2)
EU15 production of in-quota beet (million tons)	100.494	90.163 (−10 per cent)	80.605 (−20 per cent)
EU15 production of C beet (million tons)	8.928	0 (−100 per cent)	0 (−100 per cent)
EU15 production of in-quota sugar (million tons)	14.288	12.820 (−10 per cent)	11.461 (−20 per cent)
EU15 production of C sugar (million tons)	1.310	0 (−100 per cent)	0 (−100 per cent)
EU 15 imports of sugar[a] (million tons)	2.160	2.160 (0 per cent)	2.160 (0 per cent)
EU15 exports of in-quota sugar[a] (million tons)	3.052	1.402 (−54 per cent)	0 (−100 per cent)
EU 15 consumption of sugar (million tons)	12.987	13.171 (+1 per cent)	13.216 (+1 per cent)
Domestic price of in-quota beet (€/ton)	46	22 (−52 per cent)	16 (−65 per cent)
Domestic price of C beet (€/ton)	11	—	—
Domestic price of in-quota sugar (€/ton)	632	404 (−36 per cent)	357 (−43 per cent)
Export price (white sugar) (€/ton)	225	264 (+17 per cent)	283 (+26 per cent)
Export subsidies (€ million)	1243	196 (−84 per cent)	0 (−100 per cent)
Rents (sector) (€ million)	2185 (beet) 307 (sugar)	480 (beet) 0 (sugar)	0 (−100 per cent)
Cross-subsidy (€ million)	71 (beet) 138 (sugar)	—	—

[a]EU15 exports to EU10 are not included. Source: simulations by the authors.

provided to beet producers is a decoupled payment and has no impact on output (an assumption that we also use for the single farm payments in the baseline).

Our econometric estimates of national supply curves for seven countries suggest that several countries will not be able to produce all their quota economically at a price of €405 per ton. For example, in the case of Italy, our calibration of supply elasticities leads to a 20 per cent reduction in production at the national level after the cut in intervention price.[7] Summing over our seven

7 Recall that the country-specific elasticities were calibrated by taking into account the interaction between quota level, in-quota prices and the supply of C sugar.

national supply curves and assuming that sugar production will cease in some least efficient (but small) producers such as Finland, Portugal and Ireland, introducing the resulting EU supply changes in the GE model, and accounting for the linkages between markets in a GE framework, we found that aggregate EU sugar production decreased by 17.8 per cent. This estimated average change at EU15 level is below the estimates found in other studies (EU Commission, 2005). It is consistent with the idea that because some efficient producers are able to expand their quota and some national aids will persist, the fall in EU production will be less than what was originally expected (House of Lords, 2006).

Clearly, these results depend strongly on our assumptions regarding foreign trade. It is likely that ACP imports will go down given the lower EU price. Some Caribbean islands and Guyana will certainly be unable to export sugar to the EU at the new domestic price (Garside *et al.*, 2004; LMC 2004). Part of the production of Fiji and Mauritius would also become unprofitable. However, as we lack accurate information, and so as to make the comparison *ceteris paribus*, we assume that import quotas will remain unchanged. We consider that a country benefiting from a duty-free tariff quota will export sugar (possibly purchased from other more competitive ACP countries such as Southern African ones) to the EU market as long as the EU domestic price for raw sugar is higher than the world market price.[8] We assume that in-quota imports with a positive tariff (i.e. imports under the traditional supply needs and special preferential sugar provisions) will continue as long as the gap between the EU domestic price for raw sugar and the world market price exceeds the tariff. Compared with a 2010 benchmark without a reform, EBA imports would also expand less because of the lower EU price. Again, we are unable to assess by how much. Costs of production seem lower in Zambia and Malawi than in Brazil and Australia (Garside *et al.*, 2004). We assume that the current exports from the least efficient LDCs will be compensated by extra imports from Sudan, Zambia and Malawi, as a crude approximation, and that the overall level of imports from LDCs will remain constant.

After the reform, the EU15 no longer produces C sugar. The decrease in intervention price reduces the incentive to 'overshoot'. Indeed, the asymmetric loss described in equation (3) between one unit below or over the targeted quantity is now reduced to a few euros per ton, an amount too small to justify overshooting. The overall simulation of the reform with the GE model suggests that with the combination of the decrease in in-quota sugar and C sugar, the EU production will fall by 2.8 million tons of white sugar. Our figures are consistent with an average EU production cost of

8 A referee pointed out that the assumption that re-exportation of sugar was possible would imply that the Brazilian harvest would be shipped to the EU through the LDC channel. However, we did not consider that large expansion of LDC exports could take place, as rules of origin requirements are more restrictive under the EBA than under the Cotonou Agreement, where diagonal cumulation is possible. In addition, we believe that the safeguard clauses in the EBA limit considerably the possibility of re-exportation of Brazilian sugar, since the EU will probably activate such clauses as soon as there is evidence of triangular trade (House of Lords, 2006, Section 91).

€370 per ton, a reference price of €404 per ton for white sugar and a world price of €264 per ton.

Figures in Table 2 show that, in terms of percentage, the beet price falls more than the sugar price. Our figures are therefore inconsistent with the February 2006 regulation that specifies that the minimum price for sugar beet will be reduced by 39.5 per cent only. However, we find that the reform exhausts the rents to the processing sector. At some point, the adjustment will need to be borne by beet growers. Our finding is obviously linked to our assumption that some of the unit costs of the processing sector are difficult to reduce, such as energy and labour costs. We believe that even under alternative assumptions on the sharing of the rents, processors are likely to put pressure on the farm sector and that it is unlikely that the 36 per cent decrease in final product price can be compatible with a 39.5 per cent decrease in the price of the beet input, given the low elasticity in the demand of other inputs.

The price falls result in only a slight expansion of consumption. The EU demand for sugar is very inelastic in our GE model. Such a low elasticity is questionable, but opportunities for substituting sugar for sweeteners are limited in the EU: unlike in the US, the EU soft drink sector does not use large quantities of isoglucose that could be replaced by beet sugar even if the latter become much cheaper.

The reform provides a considerable opportunity for lowering the EU tariff protection. Indeed, without the reform, we estimate that the minimal protection necessary to prevent sugar (outside tariff quotas) from flowing into the EU in 2010 will be €407 per ton of white sugar. The non-preferential tariff is presently €339 per ton for raw sugar and €419 per ton for white sugar. After the reform, the gap between the domestic and world prices for EU sugar would fall to €140 per ton of white sugar, that is, the EU community preference can be maintained with a significant decrease in MFN tariff. Clearly, the reform would be a major step towards compatibility with a WTO agreement under the Doha Round.

Our simulations for Scenario 1 suggest that the sugar reform will result in minor changes outside the sugar sector. In the EU15, 360,000 hectares will be reallocated to other enterprises, mainly grains and, in particular, soft wheat. This will result in a limited decrease in the cost of feedstuffs, with a small impact on livestock producers. The reform should also result in a limited increase in vegetable production and should lead to welfare gains estimated at €680 million. However, this results from conflicting effects, as the loss for sugar beet producers is significant (€1.7 billion). Given the estimated compensation paid to producers, their net losses should amount to some €550 million. The fall in production of refined sugar means a decrease in value added for the processing sector of €1.2 billion. The fall in farm sector employment in the EU15 (a decrease of 3,000 jobs) is limited because of the reallocation of resources to other farm enterprises, but is larger in the processing sector (5,500 jobs). The EU saves roughly €1 billion in export subsidies.

Overall, the reform offers the EU some room for manoeuvre relative to its WTO commitments on market access, domestic support or export competition. The reform brings export subsidies down to a level in conformity with the 2005 WTO ruling. Nevertheless, according to our estimates of domestic supply curves, the sugar reform alone hardly addresses longer-term constraints imposed by the WTO provisions on export competition.

6.2.2. Elimination of export refunds

Following the WTO panel adjudication requested by Brazil, Australia and Thailand, the 2005 ruling of the appellate body found that EU subsidised exports (including the re-exportation of ACP/India preferential imports and the sale of C sugar on the world market) were in violation of the maximum subsidised export commitments and must be reduced. In the longer run, all subsidised exports must be eliminated by 2013, following the ministerial meeting of the WTO in December 2005.

Scenario 2 imposes the elimination of all subsidised exports, including the C sugar relative to the baseline, assuming that the 2006 sugar reform does not take place. The ending of export subsidies might be obtained by reducing the level of the sugar quota. Here, we assume that quotas are unchanged but that the EU domestic price adjusts to clear the market. Results are presented under Scenario 2 in Table 2. The figures in parentheses indicate the change relative to the baseline.

With no possibility of using subsidies to dispose of excess supply on the world market, a considerable decrease in sugar prices is needed to clear the EU market (43 per cent relative to the baseline, i.e. a further 11 per cent decrease after the implementation of the 2006 reform). The required fall in the price of sugar beet would be even larger because we assumed that wages and some input prices could not decrease in the processing sector. Even though the domestic price would still be 26 per cent higher than the world price, all rents would disappear in the EU sector. Such a fall in EU domestic prices would make larger cuts in tariffs possible, that is, the WTO discipline on export competition (ban on export subsidies) seems more constraining than the WTO discipline on market access in the sugar sector.

The fall in domestic price required to eliminate export refunds would erode the rent for preferential imports of sugar under tariff rate quotas. The difference between domestic prices and world prices would be barely enough to sustain the present imports facing a positive tariff (the 'traditional supply needs' and the 'special preferential sugar', whose future after 2009 is, in any case, uncertain due to the full implementation of the EBA). Indeed, the rent associated with the tariff quota would fall to almost zero for these categories of imports under Scenario 2.

Overall, our results suggest that the 2006 reform does not decrease the EU production to allow the abolition of all export subsidies, at least not unless exogenous changes (for example, trade liberalisation in other countries such as the US or the development of ethanol production) result in a large increase in the world price. Further adjustments in the CMO are likely to be necessary to cope with WTO commitments, even though our assumptions on the level of EBA imports are quite conservative. Should LDC exports be higher, they would need to be offset by a corresponding reduction in the EU production. This would require a cut in quotas or forcing EU sugar prices much closer to the world market price.

7. Conclusion

The various assessments of the effects of liberalising world sugar markets differ a lot. We believe that a significant explanation of the observed differences concerns the specification of the EU supply response and, in particular, the modelling of C sugar production. The supply of C sugar can be affected by the in-quota sugar through three channels: the existence of fixed costs covered by in-quota sugar such that C sugar can be sold at prices covering marginal (variable) costs only, 'overshooting' behaviour as insurance against poor yields and the production of C sugar as 'reference building' in view of expected reforms. We show that these effects may make the supply of C sugar dependent on the level of the in-quota price and on the quota level itself. We introduce some interaction between the quota and the supply of marginal sugar in our model. We calibrate the supply of C beet and sugar, using econometric estimates. We then include our specification in a GE model that includes a detailed representation of the sugar sector.

Our results are conditional to our particular assumptions regarding sugar production in LDC and ACP countries. Our model also relies on an SAM calibrated for the year 1995. The evaluation of the reform is based on a baseline for 2010 that includes available information up to 2005 so that our results reflect recent policies and macroeconomic environment. However a model based on a more recent representation of the technology, including for the ten countries that joined the EU as full members in 2004 could modify some of the results.

Our simulations suggest that the 2006 reform of the EU sugar sector will mean the end of C sugar exports and that the price falls allow room for significantly reducing EU sugar tariffs. The reform should also make it possible to cope with short-run constraints imposed by the WTO disputes panel, that is, the requirement to cut subsidised exports by an amount corresponding to the sum of ACP sugar imports and C sugar. The losses for sugar beet producers and processors will be significant, although they are partly compensated under the 2006 reform. The reform should also result in savings for taxpayers and consumers. Overall, the reform should result in welfare gains for the EU15, although cheaper sugar might raise some public health issues that are not accounted for in the model. However, it is likely that the 2006 reform is not sufficient to address longer-term commitments such as a complete elimination of export subsidies. An additional cut in either the level of quotas or the domestic price could be necessary to accommodate the ending of export refunds, even under our rather conservative assumptions regarding the impact of the EBA.

Acknowledgements

The authors acknowledge financial support by the Agricultural Trade Agreements (TRADEAG) project, funded by the European Commission, DG Research (Specific Targeted Research Project, Contract no. 513666). The authors thank H. Jensen, P. Witzke, J. Beghin and A. Carpentier for their comments on earlier versions, as well as three anonymous referees for their thorough review and their constructive comments. The authors are solely responsible for the contents of this paper.

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Appendix: Econometric procedures and estimates

The equation that is estimated corresponds to equation (6) in the paper. The series are annual data from 1981 to 2004. Data sources include: Eurostat (for areas), annual report of the Confédération Générale de la Betterave (for p_2 (spot sugar prices, London)), van der Linde *et al.* (2000) and Confédération Générale de la Betterave (for p_1 and various taxes). All prices were deflated by the GNP price deflator using Eurostat data. Yields at time t were expressed as arithmetic averages of yields at $t-3$, $t-2$ and $t-1$. Expected prices are based on naïve expectations. Various specifications with trends and lagged variables were tested, but the naïve expectation specification fits the data best.

Stationarity tests

The time series used in the econometric estimation were tested for stationarity, using the augmented Dickey–Fuller (ADF) test as well as with the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests for stationarity (Kwiatkowski *et al.*, 1992). As is well known, these tests have low power with small samples. On the basis of the ADF test, we do not reject the hypothesis of nonstationarity at the 5 per cent significance level for a large number of series. However, for these series, we cannot reject the hypothesis of stationarity on the basis of the KPSS test. The two exceptions where both tests converge to conclude that the series are non-stationary are the variable L for Italy and the variable $(p_1 - p_2)$/Wr for Spain. In the case of inconsistencies, we opted for stationarity and estimated accordingly.

Econometric estimation

The GME method allows us to consistently and efficiently estimate equations with non-negativity constraints and relatively few degrees of freedom without imposing restrictions on the error process. The GME estimates are robust even if errors are not normal and the exogenous variables are correlated. Entropy is used to measure the uncertainty (state of knowledge) we have about the occurrence of a collection of events. The GME approach uses each observation by treating moment conditions as stochastic restrictions. The parameters to be estimated are expressed as probabilities using a support space (i.e. a set of discrete points) and a vector of corresponding unknown weights. The GME estimator maximises the joint entropy of all the probabilities representing the parameters to be estimated and the error terms subject to the data and the various constraints. The various desirable properties described by Golan *et al.* (2001) include the ability to impose non-linear and inequality constraints and the efficiency of the estimator with small samples.

In practice, we set support values for parameters and residuals as triplets $\{-\eta, 0, \eta\}$. An initial value of the parameters to be estimated is set, and entropy is maximised under the constraints that the data match equation (6) and the various constraints imposed: $\beta > 0$; $0 < \phi < 1$; $\theta \geq 0$; $p_1 \geq \theta + p_2$. Estimation results are provided in Table A1.

Table A1. Estimation results

	R^2	DW	β	ε	ϕ
The Netherlands	0.83	1.92	1.09[a]	0.57[b]	0.69[a]
UK	0.60	2.08	3.97[a]	0.76[a]	0.99[a]
Belgium	0.82	1.95	3.74[a]	0.61[b]	0.38[a]
France	0.78	1.80	0.32[a]	0.45[b]	0.34[b]
Germany	0.96	1.89	0.36[a]	0	0.56[b]
Spain	0.87	1.76	2.82[a]	0	0.65[a]
Italy	0.45	1.72	0.67[a]	2.64[a]	0.001[a]

It is noteworthy that most of the parameters of interest, i.e. parameters β, ϕ and ε, are significantly different from zero (with the exception of Italy). This suggests that in the specification adopted (where the usual marginal conditions are replaced by MC $= p_2 + \theta$), θ is indeed a positive function of p_1, a negative function of p_2 and a positive function of the quota.
[a]Coefficient significantly different from zero at the 10 per cent significance land.
[b]Coefficient significantly different from zero at the 5 per cent significance land.

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