European Review of Agricultural Economics Vol **34 (1)** (2007) pp. 1–20
doi:10.1093/erae/jbm002

Reallocating sugar beet contracts: can sugar production survive in Denmark?

Peter Bogetoft, Kristoffer Boye, Henrik Neergaard-Petersen and Kurt Nielsen

University of Copenhagen, Denmark

Received October 2006; final version received January 2007

Summary

The reform of the EU sugar regime involves significant price reductions for sugar and sugar beet. We examine whether the Danish sugar industry can maintain production and profit levels by reallocating production from less to more efficient farmers. The impact of alternative reallocation mechanisms is estimated using a DEA model of sugar beet production, together with information about processing capacity at the three Danish plants, beet transportation costs and alternative crop options. The analysis shows that the present allocation is far from efficient. With the new reform fully implemented and the quota efficiently reallocated, actual production will fall by only 25 per cent, although profit will be substantially lower.

Keywords: structural inefficiency, reallocation, data envelopment analysis, double auction, price tatonnement

JEL classification: L52, Q13, Q18

1. Introduction

The EU Common Market Organisation (CMO) for sugar has been under pressure for reform for several years. By a mixture of production quotas, subsidies and levies, the price of refined (white) sugar within the EU was maintained at 2–3 times above the world market price for over two decades (see, for example, Frandsen *et al.*, 2003). In November 2005, a reform of the CMO for sugar was finally agreed. The new sugar regime will lead to dramatic price reductions: 36 per cent for white sugar and 40 per cent for sugar beet over a four-year period starting in 2006. To compensate growers, a decoupled subsidy of 64.2 per cent of the price reduction was introduced. Furthermore, the EU has offered to buy back quota, with the revenue from quota buy-back being shared between processors and farmers (Commission, 2005). However, these are intermediate measures. The main challenge in the longer run is to deal with the lower guaranteed prices. In this paper, we discuss how this can be done in Denmark, where a single processor, Danisco, operates three processing plants, to which approximately 4,000 producers deliver sugar beet.

In Denmark, as in some other EU countries, sugar production is based on non-transferable sugar beet contracts. The initial contract allocation is based on historical production levels, and over the years Danisco and the growers' association have agreed on minor reallocations away from farmers who failed to comply with their contract towards, in particular, new young farmers. Also, when a fourth processing plant in Gørløv closed in 1999, Danisco introduced a special incentive programme to transfer some quota from suppliers to Gørløv to growers living closer to the Assens plant. Since 2004, it has also been possible to lease quota. The general principle, however, has been that quota is linked to the land.[1] The lack of general transferability may be surprising from a purely economic perspective, since both theory and conventional wisdom suggest that quota transfer leads to more efficient production. One explanation may be the 'political costs' associated with transferability and the resulting structural development (see, for example, Sieper, 1982). Either way, reallocation has become more attractive now that profitability is under pressure. Therefore, bilateral trading with contracts among farmers has been allowed as from 2006.

In this paper, we study the potential gains from reallocating sugar production among existing producers. We develop a data envelopment analysis (DEA) model based on a representative sample of professional Danish sugar beet producers (full-time farmers) in 2003. We combine individual farm models with information on transportation costs and processing capacities in a sectoral reallocation model in order to determine the gains from reallocating quota. Alternative restrictions on reallocation are investigated to monitor the structural impact at the farm and processing levels. We also investigate the role of alternative trading mechanisms, in particular the use of three independent double auctions, one for each of the processing plants, as opposed to one combined mechanism with interrelated auction markets and endogenous choice of processing plant. The industry profits are estimated before and after the implementation of the new sugar reform under each of the two auction markets.

We find that Danish producers have forgone about 53 per cent of their potential aggregate profit by not having an efficient allocation of the quota in 2003. We also show that if reallocation is used under a fully implemented sugar reform, the production level will 'only' fall to 75 per cent of the present national sugar quota. If the processing plant in Assens is closed down, total production will be reduced to 64 per cent of the pre-reform level. Excess profit, i.e. profit in excess of that earned by the best alternative crop, will fall to approximately 30 per cent of pre-reform levels. In total, therefore, sugar production will become considerably less attractive in Denmark – but will nevertheless have a good chance of surviving on a large scale if quota is reallocated.

1 For details of the sugar contract, see Bogetoft and Olesen (2004).

The remainder of this paper is organised as follows. Section 2 discusses possible reallocation mechanisms and associated auction theory. Section 3 describes the DEA-based reallocation models. Section 4 presents the empirical results and Section 5 concludes the paper.

2. Reallocation mechanisms

In this section, we first sketch the strategic possibilities for the sugar industry in a situation with lower final product prices. Next, we focus on one alternative, namely to lower costs by reallocating production. Different reallocation mechanisms are discussed, namely bilateral trade, single auction and multiple auctions.

2.1 Strategic alternatives

Growers and processor have several alternatives for improving profitability. To illustrate, let us consider the profitability of a unit of white sugar (and the corresponding quantity of sugar beet). The growers' and the processor's per unit *integrated profit* is the price of refined sugar ($P^{\text{white sugar}}$) minus the upstream cost of producing and delivering the sugar beet and the downstream cost of processing the sugar beet (as per unit of white sugar output). The price of sugar beet, $P^{\text{sugar beet}}$, splits the integrated profit as illustrated in Figure 1. The price of white sugar has effectively been set by the EU. The EU also plays a role in the setting of $P^{\text{sugar beet}}$, since it is set as an EU regulated share of $P^{\text{white sugar}}$ plus nationally determined side payments for good quality, flexible delivery, clean beets and so on.

With final price $P^{\text{white sugar}}$ given, and keeping quantities fixed, integrated profit can be improved by reducing processing or production costs. In practice, processing costs can be cut by improving efficiency at the various plants and by closing less efficient ones. Likewise, production costs can be reduced by improving farm level efficiency and by reallocating production from less to more efficient farmers. In addition, quantities can be changed to exploit possible economies of scale.

In this paper, we focus on gains from reallocation. For most of the analysis, we do not assume efficiency improvements for individual farms or processing plants. Thus, we deviate markedly from the traditional approach taken in

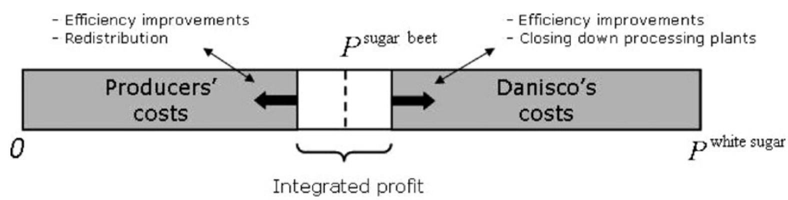

Figure 1. The integrated profit per unit of white sugar.

DEA-based studies, where local inefficiencies are eliminated before possible gains from reallocations and scale changes are considered.[2]

Redistribution could range from local collaborations among neighbouring farmers to a full scale nation-wide quota market. The potential gain from local collaboration, along the lines of Bogetoft and Wang (2005), cannot be estimated here because of the low geographical density in the sample.

The producers have private information about the values of their sugar contracts. This information is needed, directly or indirectly, to determine an optimal reallocation. On the other hand, producers cannot be trusted to reveal this information unless they are given the right incentives to do so. The choice of trading institution is therefore critical in terms of reaching the efficient allocation, where sugar contracts are reallocated to those that value them the most. To emphasise this, we consider three types of mechanism: (i) central planning, (ii) bilateral trade, (iii) auction markets.

2.2 Central planning

One possibility is to have a central planner that decides how much each farmer shall produce and where he shall deliver his beet. The reallocations that we formulate below as mathematical programs can be interpreted as those of a central planner. They determine a reallocation among the sample farmers based on a central approximation of local production possibilities and with the aim of maximising the profitability of the whole sector.

In reality, a central planner is not feasible in the Danish context, since a central dictate conflicts with the property and decision rights of individual farmers. We need a decentralised implementation with voluntary participation. Fortunately, a well-organised quota market will be able to implement the same solution, i.e. the mathematical programs can proxy the outcomes of market solutions (Andersen and Bogetoft, 2007).

Moreover, a central dictate will typically be inefficient since the central planner lacks the information about local production possibilities that is needed to determine the optimal reallocation. It is therefore important to consider more decentralised solutions that involve individual farmers and that the can depend on information from them about production possibilities.

Of course, the lack of perfect information also affects our approximation of the likely gains from reallocation. Effectively, the reallocation estimates we derive are based on the assumption that production possibilities can be approximated from historical production levels using a DEA model. Therefore, our estimates are uncertain. If our approximation of best practice production, i.e. the underlying DEA model, is very imprecise, the estimated reallocation gains may also be misleading.

2 See also Andersen and Bogetoft (2007) and Bogetoft *et al.* (2006)

2.3 Bilateral trade

In a bilateral trade regime, individual producers search the market and negotiate price on a bilateral basis. This allows for some attractive transfers but suffers from several problems.

The first problem is that of finding the right trading partners and quantities. The direct search costs (time, advertising and so on) may be considerable. Likewise, the indirect costs of, for example, ending up with a suboptimal quantity in relation to machine capacity may be significant.

The second problem is that of imperfect information. Bilateral trade has to be settled among farmers with private information about the value of quota. Simple Bayesian bargaining models have demonstrated how sellers will overstate and buyers understate values, often to the extent that no trade is realised, even when in reality the buyer values quota more than the seller. As emphasised by Myerson and Satterthwaite (1983), delays and failures are inevitable in private bargaining.

The third problem is that of possible uneven bargaining power. Experimental studies show that bilateral trade in a market with many buyers and sellers tends to empower the sellers and result in prices that are higher than the competitive prices. This result was first shown in Ketcham *et al.* (1984). Non-competitive prices will result in inefficiency and most likely lower traded quantities.[3]

In conclusion, it is unlikely that bilateral trade will suffice to realise the potential gains from reallocation. Empirically, the possibility of leasing contracts in Denmark points in the same direction. The leasing market has run for three years starting in 2004, but the traded quantity in 2004 was only 28 per cent of the optimal trade volume based on 2003 data as shown in Section 4 below.[4] Of course, part of the unrealised potential may reflect other factors, including the difference between a time-limited and a permanent transfer of delivery rights.

2.4 Auction markets

An auction is basically a set of trading rules that can improve the allocation of goods and services. This is done via a price setting mechanism that generates more efficient trades or makes the market more transparent.[5]

In the case of two-sided markets with multiple sellers and buyers, auctions are commonly called *double auctions or exchanges*. With many buyers and sellers, the double auction works to diminish the search costs, to lower the importance of private information and to diminish the market power of the individuals by aggregating demand and supply. Double auctions have been

3 If high (low) value producers generally trade with high (low) value producers, then the quantity traded may be inefficiently high and may exceed the competitive quantity.

4 Leasing volumes for 2005 and 2006 are not available but the general impression in the industry is that they are similar to the 2004 level.

5 For a survey of auction theory, see Klemperer (1999) and Krishna (2002).

used in agriculture (for example, to exchange milk quota in Denmark, Germany and Canada).

The literature on double auctions focuses in particular on three problems: (i) incentive compatibility (it must be optimal to submit reservation prices), (ii) *ex post* efficiency (all attractive trades must be realised), (iii) budget balancing (total volume bought must equal total volume sold). Attempts to solve the first two problems are typically at the cost of the third problem. Fortunately, the magnitude of the three problems diminishes as the number of participants grows. Satterthwaite and Williams (1989) showed analytically that a double auction modelled as a Bayesian game converges rapidly towards *ex post* efficiency as the market grows. Other contributions along this line are Satterthwaite and Williams (2002), Cripps and Swinkels (2005) and Nautz (1995). In addition, experimental studies have found double auctions surprisingly robust against strategic behaviour. Test auctions with as few as 2–3 buyers and 2–3 sellers have generated almost efficient outcomes (Friedman, 1984 and Friedman and Ostroy, 1995).

To formalise, assume that I sellers have well-defined supply schedules given by a set of L quantity–price bids $\{(s^i_1,p_1),(s^i_2,p_2),\ldots,(s^i_L,p_L)\}$. Here, s^i_l is the quantity seller i offers for sale at p_l. Likewise, let J buyers have well-defined demand schedules represented by a set of quantity–price bids $\{(d_1$ $^{dj}{}_1,p_1),(d^j_2,p_2),\ldots,(d^j_L,p_L)\}$. The demand and supply schedules are assumed to be monotonic: for any two prices p_h and p_l where $p_h \leq p_l$, we have $s^i_h \leq s^i_l$ for any seller i and $d^j_h \geq d^j_l$ for any buyer j. Bids to buy above and sell below the market clearing price are accepted; the remaining bids are rejected. Aggregate demand and supply are found by summing demand and supply for each feasible market clearing price. For any price p_l, $l = 1, 2, \ , L$, aggregate demand is given by $\mathrm{AD}_l = \sum_{j=1}^{J} d^j_l$ and aggregate supply is $\mathrm{AS}_l = \sum_{i=1}^{I} s^i_l$. Excess demand is defined as $Z_l = \mathrm{AD}_l - AS_l, \forall l = 1, 2, \ , L$. We will typically say that an (approximate) equilibrium is where Z_l is closest to zero.

In the Danish context, farmers deliver the sugar beet to three processing plants, called for simplicity A, B and C. They cover their own transportation costs.[6] Moreover, quotas are plant specific delivery rights. To model reallocation via double auctions, we would therefore need *three double auctions*, one for delivery rights to each of the plants.

Of course, the three double auctions would be closely related. If the price on one auction changes, demand and possibly supply on the other auctions would also change. For example, if the price of delivery to plant A increases, farmers would find it relatively more attractive to buy delivery rights to plants B and C.

To take the interactions into account, we would ideally need a so-called combinatorial auction. A *combinatorial auction* allows the bidders to bid on any combination of items. In principle, a bidding strategy is now a set of combined bids, each of which has three prices and three quantities; i.e. the (demand) bids are of the form $(d^j_{\mathrm{A}l_\mathrm{A}}, d^j_{\mathrm{B}l_\mathrm{B}}, d^j_{\mathrm{C}l_\mathrm{C}}, p_{\mathrm{A}l_\mathrm{A}}, p_{\mathrm{B}l_\mathrm{B}}, p_{\mathrm{C}l_\mathrm{C}})$ with the

6 They do get a transportation allowance, but it is independent of actual transportation and therefore basically an add-on to the sugar beet price.

interpretation that farmer *j* is demanding ($d_{Al_A}{}^j, d_{Bl_B}{}^j, d_{Cl_C}{}^j$) of the three types of quota when the prices of the three types are ($p_{Al_A}, p_{Bl_B}, p_{Cl_C}$). A buyer's bidding strategy therefore requires him to specify three demand quantities for each of L^3 such price combinations (if we use the same price grid with *L* price levels in each market as before).

Defining one's strategy is therefore an overwhelming task. Also, the auctioneer's task of selecting winners and setting the prices is complex. In general, the problem of solving a combinatorial auction is so-called NP-hard.[7] This means that the calculation burden required for solving the problem increases very fast as the number of bidders increases. The number of 'elementary operations' (such as addition, subtraction, etc.) increases faster than any polynomial function of the number of bidders, the number of points in the price grid and so on. For practical purposes, this means that there is no guarantee that a solution will be found. Fortunately, most combinatorial problems can be solved by restricting the permissible combinations or by applying heuristics that find 'reasonable' solutions.[8]

In general, a Walrasian tatonnement guarantees convergence towards equilibrium if the traded goods are mutual substitutes, i.e. if the prices increase weakly on all goods but one, there will be a weakly increasing demand for the remaining goods. This is a reasonable assumption when the goods are sugar contracts. The higher the price on delivery rights for plant B and C, for example, the more an individual farmer would be interested to buy delivery contracts to plant A.

Unfortunately, the price development in a Walrasian tatonnement with three substitute goods is not monotonic over iterations, and the process is not guaranteed to end in a finite number of steps (Milgrom, 2004). If we close one plant, say plant C, as has in fact been decided by Danisco in our case study (see below), the tatonnement can be simplified, and finite, monotonic convergence ensured. Starting with low prices and positive excess demand, one can increase the price one step at the time in market A as long as its excess demand Z_A (p_{Al_A}, p_{Bl_B}) is positive. Once, it becomes negative, the price on market B should increase to lower Z_B (p_{Al_A}, p_{Bl_B}) and possibly increase Z_A (p_{Al_A}, p_{Bl_B}). If the excess demand for A, Z_A (p_{Al_A}, p_{Bl_B}), becomes positive, we can again increase the price on A etc. At each step, we either come closer to an approximate equilibrium–or we learn that it has been reached (when excess demand has just become negative).

To implement the auction, it is necessary to collect supply and demand schedules and to use these to clear the markets using one or another tatonnement principle. Since the demand and supply schedules contain potentially confidential information, the collection of information and the calculation of equilibria would ideally be handled by a trusted third party, typically an

7 *NP-hard* (Non-deterministic polynomial-time hard) denotes a problem whose solution algorithm can be translated into one for solving any NP problem. An NP-hard problem is at least as hard as, but may be harder than, any NP problem (Weisstein, 1999).

8 For a survey of combinatorial auctions, see Vries and Vohra (2003). The use of combinatorial auctions is still very limited, for more see, for example, Pekec and Rothkof (2003) and Cramton *et al.* (2006).

auction house or a professional exchange. In the specific case, however, the problem can be further simplified to limit the burden on bidders and the auctioneer. In particular, and as an interesting aside, the necessary calculation with only two interrelated markets is sufficiently simple to be undertaken by the so-called secure multiparty computation (Bogetoft *et al.*, 2005). Secure multiparty computation is based on recent advances in computer science that allow calculations to be done on encrypted information. The trusted and potentially expensive third party can hereby be avoided and substituted by general multiparty computations in a network of computers (for example, one located at the growers' association and one at the processing plant) without risking information misuse.

3. Modelling production and reallocation

To estimate the potential gains from reallocating quota through auctions, we developed models of sugar beet production at the farm level and combined the individual farm models into a sector model, taking into account the capacities of the different plants. Specifically, the procedure involves four steps:

1. Develop a DEA model of sugar beet production at the farm level.
2. Calculate individual farmer efficiency levels.
3. Combine all the farm models into a (large) linear programming-based sector model.
4. Evaluate aggregate profit under different scenarios about farm level learning and permissible reallocations.

This approach is essentially an application of Andersen and Bogetoft (2007). They developed a general framework to model reallocation of production rights among individual firms and illustrated the approach by estimating gains from introducing individually transferable quota in Danish fishery. In the case of sugar production in Denmark, there is only one type of output, sugar beet, but since it can be delivered to three different processing plants, one can think of plant-specific deliveries as three possible outputs, much like the different fish species in Andersen and Bogetoft (2007). This approach to modelling gains from reallocation is also closely related to studies by Brännlund *et al.* (1995, 1998), who investigated the Swedish pulp and paper industry and estimated the gains from reallocating pollution quota.

A crucial question in these studies is how technical inefficiency is affected by reallocation. Technical inefficiency is the ability to produce the same outputs with lower input levels. Allocative efficiency is the ability to choose the right mix of inputs to produce the right mix of outputs. In earlier reallocation studies and in the general productivity analysis literature on allocative efficiency, it is always assumed that technical inefficiency on individual firms is eliminated *before* reallocation. We consider this to be a naïve assumption. It is not obvious why a sugar beet grower should learn how to be fully technically efficient simply because he sells or buys quota, or as a prerequisite to quota trading. More recent studies (Andersen and Bogetoft, 2007; Bogetoft *et al.*, 2006; and Kerstens *et al.*, 2006) have relaxed this assumption, and we do so here as well. Moreover, technical inefficiencies in DEA models are basically residuals, which may reflect model misspecifications as well as inefficiency. If this is the case, the assumption of fixed efficiency levels is a way of acknowledging these possible model-misspecifications in the calculation of reallocation gains. It does not matter for the gains we calculate if the so-called technical inefficiency reflects insufficient learning or an over-simplified model of farm-level production conditions.

3.1 Sugar production at the farm level

We applied data envelopment analysis (DEA) to model sugar beet production in Denmark. Since it was first proposed by Charnes *et al.* (1978, 1979), DEA has become a tremendously popular relative performance evaluation tool for researchers and theorists alike. The basics of DEA modelling are described in various text books, such as Charnes *et al.* (1994), Coelli *et al.* (1999) and Cooper *et al.* (2000). Since the agricultural economics literature already contains many applications of this technique,[9] we shall not give an in-depth introduction to DEA here. We simply recall that DEA is a non-parametric, deterministic estimation technique, which treats outputs as separate 'activities'.

Consider the case of B farmers, $b = 1, \ldots, B$, who transform N inputs into M outputs. Let $x^b = (x_1^b, \ldots x_N^b) \in \Re_0^N$ be the inputs consumed and $y^b = (y_1^b, \ldots, y_M^b) \in \Re_0^M$ the outputs produced by farmer b. The actual input and output levels are denoted by superscript 'obs' and T is the underlying production possibility set:

$$T = \{(x, y) \in \Re_0^{N+M} |\ x \text{ can produce } y\}. \tag{1}$$

For a given technology, inefficiency implies the ability to reduce inputs without affecting outputs or to increase outputs without requiring more inputs. We take the input perspective here and assume that inputs can be divided into two types, the controllable (discretionary, variable) inputs $n = 1, \ldots, \tilde{N}$ and the non-controllable (non-discretionary, fixed) inputs $n = \tilde{N} + 1, \ldots, N$. Let the corresponding vectors be $x^b = (x_V^b, x_F^b)$. The efficiency of farmer b can now be calculated as:

$$E^{\text{obs},b} = \min\{E \in \Re_0 | (Ex_V^{\text{obs},b}, x_F^{\text{obs},b}, y^{\text{obs},b}) \in T\}, \tag{2}$$

where $E^{\text{obs},b}$ is the maximal radial contraction of all controllable inputs $x_V^{\text{obs},\,b}$.

The estimate of T, the empirical reference technology T^*, is constructed according to the *minimal extrapolation principle*. T^* is the smallest subset of $\Re_0^{N+M}$ that contains (envelops) the actual production plans $(x_b^{\text{obs}}, y_b^{\text{obs}})$, $b = 1, \ldots, B$, and satisfies certain technological assumptions specific to the given approach. In the present analysis, we shall make use of the traditional

9 See, for example, Thiele and Brodersen (1999), Brümmer (2001), and Oude Lansink *et al.* (2002).

assumptions of free disposability ($(x',y') \in T$ and $x'' \geq x'$ and $y'' \leq y' \Rightarrow (x'',y'') \in T$), convexity ($T$ is convex) and constant return to scale ($(x',y') \in T$ and $k \geq 0 \Rightarrow (kx,ky) \in T$). These assumptions lead to the empirical reference technology:

$$T^* = \left\{ (x,y) \in \Re_0^{N+M} \middle| \exists \lambda \in \Re_0^B : x \geq \sum_{b=1}^{B} \lambda^b \, x^{\,\text{obs},b}, y \leq \sum_{b=1}^{B} \lambda^b \, y^{\,\text{obs},b} \right\} \quad (3)$$

We used this approximation of the production possibility set with one modification. The constant returns to scale assumption is sensible only as long as sugar beet production does not take up the full farm capacity. Since Danish contracts generally restrict the area used for beet to a maximum of 35 per cent of the grower's agricultural area, the constant return to scale assumption is reasonable.

Initially, we assumed as explained above that the efficiency level of a given farmer is unaffected by changes in the scale of operation. This means that a farmer with efficiency level $E^{\text{obs},\,b}$ needs $1/E^{\text{obs},\,b}$ times the fully efficient input level. In other words, if he is only 50 per cent efficient, he needs twice the amount of input. In a supplementary analysis, we investigated the effects of varying the efficiency levels.

3.2 Data

The data source provided detailed accounting information for 234 sugar beet producing farms in 2003. The sample corresponds to 7 per cent of all full-time sugar beet producing farms in Denmark. The farms in the sample were chosen to be representative of the sector which allows us to scale up our analysis to give national estimates. The selection criteria were field size, location, age of the farmer and economic situation in general.[10]

Table 1 compares the actual number of hectares registered by Statistics Denmark with the number of hectares in the sample scaled up to the national level.

Data on all inputs used to produce sugar beet were available. Inputs were categorised into eight different groups, of which seven are variable costs and one is fixed cost.[11] The variable inputs are seed, fertiliser, chemicals, energy, labour, machine and transportation costs. The fixed costs cover property taxes, taxes on emission, insurance, maintenance, depreciations and interest on land and buildings. Production (sugar beet) is divided into three outputs, each of which corresponds to the specific processing plant to which the beet was delivered. Unit prices were derived from revenues and output quantities. The unit price may vary from one grower to another due to quality variations.

10 For more information about the creation of the dataset, see Institute of Food and Resource Economics (2003).

11 All inputs are measured in euros (average exchange rate in 2003: EUR 1 = DKK 7.44).

Table 1. Production in different counties (hectares, percentages in parentheses)

County	Statistics Denmark	Dataset
Vestsjælland	6,414 (12.9)	5,158 (10.6)
Storstrøm	29,538 (59.6)	29,099 (59.7)
Fyn	11,193 (22.6)	12,367 (25.4)
Sønderjylland. Vejle mv.	2,455 (4.9)	2,111 (4.3)
Total	49,600 (100)	48,736 (100)

Currently, and in 2003, individual farmers deliver to one processing plant only. Therefore, the transport cost per tonne of sugar was recorded for that processing plant only. Transport costs for the other processing plants were estimated based on distances to the processing plants, the need to pass toll bridges and the average cleanness and the sugar percentage for the given area. It is assumed that farmers within 15 km of the plant transport the beet themselves. Our transport estimates were validated using information from the Sugar Beet Growers Union (DKS), local advisory centres and sugar beet transportation cooperatives.

3.3 Reallocation modelling

To calculate the potential gains from reallocating quota, the individual DEA-based farm models can be combined with industry-wide constraints to reflect the available national quota; i.e. production of the so-called A and B beets that is not sold at the world market price. This leads to the following reallocation model:

$$\Pi = \max_{(\lambda^{b',b}, x_V^b, y^b)} \sum_{b=1}^{B} \left(\sum_{m=1}^{M} \left(P_m^b \cdot y_m^b\right) - \sum_{n=1}^{\tilde{N}} \frac{x_n^b}{E^{\text{obs},b}} - \sum_{m=1}^{M} \left(t_m^b \cdot y_m^b\right) \right) \tag{4}$$

$$\text{s.t.} \sum_{b=1}^{B} \lambda^{b',b} \cdot y_m^{\text{obs},b} \geq y_m^{b'} \qquad m = 1, 2, 3 \tag{5}$$

$$\sum_{b=1}^{B} \lambda^{b',b} \cdot x_n^{\text{obs},b} \leq x_n^{b'} \qquad n = 1, \ldots, \tilde{N} \tag{6}$$

$$\sum_{b=1}^{B} \lambda^{b',b} \cdot x_n^{\text{obs},b} \leq x_n^{\text{obs},b'} \qquad n = \tilde{N} + 1, \ldots, N \tag{7}$$

$$\lambda^{b',b} \geq 0 \qquad b = 1, \ldots, B \tag{8}$$

$$\sum_{m=1}^{M} y_m^{b'} \leq Q^{b'} \tag{9}$$

$\vdots$

Repeated for each $b' = 1, \ldots, B$

$\vdots$

$$\sum_{b=1}^{B} y_m^b \leq \sum_{b=1}^{B} y_m^{\text{obs},b} \qquad m = 1, 2, 3 \tag{10}$$

The objective function captures the producers' aggregate profit, measured as the revenue minus the variable production costs and the transportation cost. Here, P_m^b and t_m^b are, respectively, price and transportation cost per tonne when farmer b delivers to processor m. The fixed cost at the farm level is not changed by reallocation; therefore, it does not enter the objective function. Also, the profit measure does not allow for any improvements in the relative efficiency.

The first four restrictions ensure that the new production plan for farmer b is technically feasible. The fifth restriction ensures that the farmer does not grow beet on more than 35 per cent of the total land available.

These constraints are repeated for each farmer in the sample.

The last set of restrictions, equation (10), ensures deliveries within the capacity of each processing plant. It also ensures that national production does not increase.

The above formulation assumes that all farmers are allowed to deliver to all processing plants–and that the national quota can be transferred from one plant to another if this is attractive and is compatible with the processing facilities' capacities. This corresponds to the use of dependent double auctions or a combinatorial action as discussed above.

As explained in Section 2.4, it is easier to organise three independent double auctions than to handle interrelationships between the markets and endogenous choice of processing plant. At present, each individual farmer only delivers to one plant. We can therefore model the case of independent double auctions easily by restricting the new output vectors to be proportional to the old vectors; i.e., by adding constraints

$$y_m^{b'} = \beta^{b'} \cdot y_m^{\text{obs},b'} \qquad m = 1, 2, 3$$

for each of the farms $b' = 1, \ldots B$. We shall call the resulting model Model 1, and the more flexible model without these constraints Model 2.

Another variant of the model is to allow possible learning on individual farms. This can be done by replacing the observed efficiencies by $\delta \cdot 1 + (1 - \delta) \cdot E^{\text{obs},\, b}$ in the objective function. Here, δ can be interpreted as the degree of learning. Letting $\delta \in [0;1]$ vary from 0 (no learning) to 1 (full catch up), we can determine the profitability as a function of the learning possibilities.

The next section explains how the different models were applied using both pre- and post-reform sugar prices.

4. Results

Here, we present the underlying DEA model, and the reallocation gains under the pre- and post-reform sugar regimes.

4.1 The underlying DEA Model

The primary DEA model consists of 8 inputs and 3 outputs as described above. We tested alternative plausible variable combinations to see which variables are best able to capture the production conditions. As one may expect from general DEA experience, the specific variables were not so important to the calculation of individual inefficiencies as long as the same types of inputs and outputs were covered. We also tested alternative returns to scale assumptions and found that the constant returns to scale assumption is reasonable given the imposed limit on maximum output.

In order to refine the traditional efficiency measures, bootstrapping was used to correct for bias and to determine 95 per cent confidence intervals for the bias-corrected efficiency scores (see Simar and Wilson, 2000). The resulting individual efficiencies with 95 per cent confidence intervals are depicted in Figure 2.

The bias-corrected scores can be used in the reallocation analysis as discussed in Andersen and Bogetoft (2007). Standard DEA estimates of production possibilities are biased downwards by the envelopment property, and the bias for a given farmer is larger when it is more difficult to find farmers who are comparable to him. Thus, for farms with special structures,

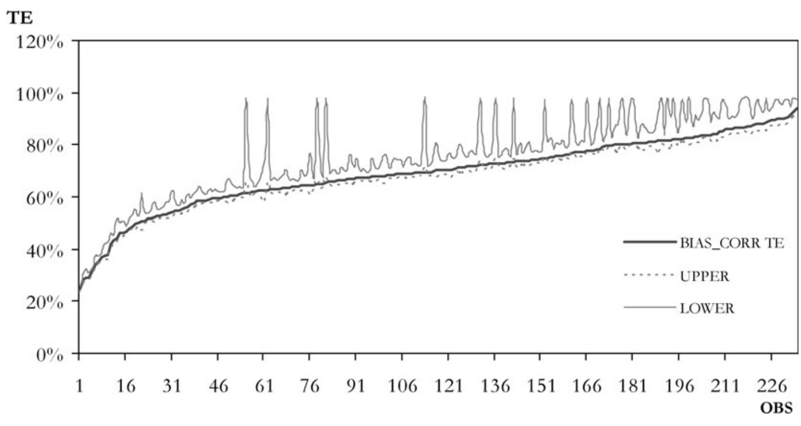

Figure 2. Bias-corrected efficiency scores.

we may expect to find larger biases and higher efficiencies than for other units. Still, from the point of view of the reallocation problem, there is no reason to expect that the bias problem will have a systematic impact on the relative gains from learning and reallocation. The learning potentials may be underestimated for unusual production profiles, but this also implies that the gains from allocating production to these units will be underestimated. We therefore used the normal efficiency scores in the estimation of reallocation gains. The confidence intervals are nevertheless useful in giving an idea about reasonable variations in the efficiency assumptions. We see that, for most units, the confidence intervals are quite narrow.

4.2 Reallocation gains with the present reform

Table 2 summarises the impact of changing the quota allocation in the sugar regime of 2003.

Farmers could have more than doubled their aggregate profit from sugar beet production (from EUR 19.0 million to EUR 40.4 million) if the quota had been optimally allocated.[12] The largest contribution to the increased profitability comes from lower variable costs. Transport costs drop only slightly, and by definition the fixed costs do not improve in the short run. We see also that estimated optimal revenue drops somewhat. This suggests that quota has been allocated to farmers with lower unit prices (P_m^b) on average. Lower prices can result from (for example) a lower sugar content or a dirtier beet crop, which in turn could explain part of the reductions in variable costs.

The extra gain from using Model 2 instead of Model 1 is only 2.8 per cent of the profit generated by Model 1. Model 1 uses the existing distribution of producers over the three processing plants, unlike Model 2 where the distribution is endogenous to the auction. Therefore, the result indicates that the initial allocation of growers to processing plants is relatively efficient.

Total production of sugar by full-time Danish farmers in 2003 was 417,000 tonnes, and the quota was 363,000 tonnes. The model reallocates 114,000 tonnes, indicating that approximately 25 per cent of the rights belonged to less productive farmers. Compared to actual quota rentals, the simulated quota trade is four times as large.

The LP problems determine all profitable reallocations, irrespectively of size. However, trades involving only very small quantities may not be carried out in practice, because transaction costs will exceed benefits. To see the impact of ‘small trades’, we considered the following two constraints: (i) any producer who sells has to sell at least 50 per cent of his quota and (ii) any producer who buys has to increase his production by at least 15 per cent. These two assumptions lower the total volume traded by no more than 3.5 per cent.

12 Moreover, if individual farmers could have eliminated technical efficiency, $\delta = 1$, profit would have been EUR 35.2 million in Model 1 and EUR 54.1 million in Model 2.

Table 2. The loss from inefficient allocation in 2003 (million EUR)

Model	Revenue	Variable cost	Fixed cost	Transportation cost	Aggregate profit
Initial	136.1	78.7	28.2	10.6	19.0
Model 1	132.2	54.1	28.2	9.5	40.4
Model 2	132.6	53.8	28.2	9.1	41.5

4.3. Efficient reallocation with the new reform

Consider now the new sugar regime. As a part of the reform, it will no longer be possible to sell excess production on the world market (C sugar). Therefore, the production available for reallocation is limited to 363,000 tonnes of sugar (former A and B sugar).[13] Clearly, this makes the balancing of the actual production and the quota more important. To meet the quota, farmers may transfer a limited quantity from one year to another. Also, unlike the prices in the present regime, the new reform may make it attractive to switch the production to a different crop. The cut-off threshold has been set to EUR 336 per hectare corresponding to the profit of best alternative crop, which is assumed to be wheat for all producers.

4.3.1. The quantitative consequences of the new regime with three processing plants

The lower prices are gradually introduced in 4 steps corresponding to cumulated reductions of 25, 32, 39 and 40 per cent in farm prices faced by the farmer. The lower prices limit the beet production even with an efficient reallocation. The result in tonnes delivered to the three processing plants is shown in three histograms in Figure 3. The first column (grey) in each price scenario for each processing plant is the quantity delivered without any reallocation. The second column (black) is the quantity delivered with reallocation according to Model 1. The third column (white) is the quantity delivered with reallocation according to Model 2. Neither of the reallocation models allow for individual learning.

Figure 3 shows that a reallocation is necessary in the new regime. With no reallocation, the aggregate output delivered to the three processing plants with a fully implemented reform (year 4) is only 25 per cent of the national quota. Reallocation with Model 1 and 2 improves this percentage considerably. With the most efficient reallocation (Model 2), the overall delivered quantity is 75 per cent of the national quota under a fully implemented reform (year 4). The lower prices have the largest impact on the processing plant in Assens, where only half of the quota is used.

For quota to be fully utilised in year 4, individual growers must improve their efficiency. We have estimated that the quota limit is reached for

13 The sugar reform also allowed countries that used to export C sugar to buy some extra quota at a price equal to the amount of restructuring aid per tonne in the first year. The Danish processor Danisco has chosen not to make use of this option.

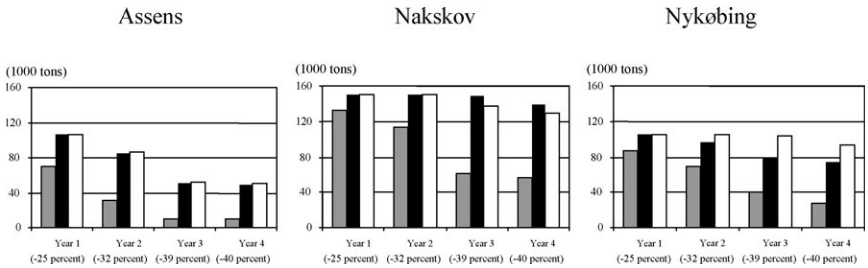

Figure 3. Deliveries to the three processing plants with each of the four price steps.

$\delta = 0.46$. This means that if all inefficient producers can halve their inefficiency losses, then the quantities delivered will meet the national quota (assuming Model 2). It requires more detailed analysis to investigate whether this is realistic. To the best of our knowledge, nothing is known about the speed with which inefficient beet producers can catch up with best practice. In an industry with heavy infrastructure like electricity distribution, estimates of 5–15 years for full catch up have been suggested (Agrell *et al.*, 2005). With such benchmarks, it should not be impossible to move individual sugar beet growers 50 per cent closer to the frontier in, say, four years. On the other hand, if the estimated technical inefficiencies are not reflecting insufficient learning but rather model specification, there is no reason to expect that this will be reduced over time.

4.3.2. Choice of auction institution

With Model 2, in which the choice of processing plant is endogenous, the sector is by definition more efficient than with Model 1. However, the transaction costs involved in setting up the interrelated auction markets are also higher than those involved in handling separate auctions. It is important, therefore, to have an idea of the potential gains. Table 3 compares the solutions.

In overall terms, the additional gains from using a more flexible solution (Model 2 instead of Model 1) are limited as it was the case in the old sugar regime as well. The greatest impact is on the total quantity delivered to the processing plants. It increases by 5.2 per cent with interrelated auction markets. Figure 3 also shows that the interrelated auction moves production from Nakskov to Nykøbing. This suggests that the present allocation across plants is quite efficient. There is no great difference between the profitability of the least productive suppliers to two different plants. In other words, the

Table 3. The impact of reallocating across plants

	Model 1	Model 2	Difference	% Increase
Quantity (tons)	2,611,886	2,748,356	136,470	5.2
Aggregate profit (EUR)	5,550,210	5,680,741	130,531	2.4

Table 4. The consequences of closing down Assens

	With Assens	Without Assens	Difference	% Decrease
Quantity	2,748,356	2,333,852	414,504	15.1
Aggregate profit (EUR)	5,680,741	4,933,010	747,730	13.2

inefficiencies of Danish sugar production allocation derive more from the quota allocation among individual farmers than from the allocation among plants. This is perhaps not surprising, given the reallocation across plants that took place in connection with the recent closing of the Gørløv plant.

4.3.3. The loss from closing down the processing plant in Assens

We finally examined the consequences of closing down the processing plant in Assens. In this scenario, it is important to use the interrelated auction approach so as to allow quota to be moved to the remaining plants. On the other hand, this is also rather easy to implement in the case of only two plants (see Section 2.3). The consequences of setting the capacity at Assens equal to zero in Model 2 are given in Table 4.

The closure of Assens lowers aggregate profit and consequentially increases the problems of reaching the national quota. With the most efficient reallocation (Model 2), the total delivered quantity is reduced from 75 to 64 per cent of the national quota with a fully implemented reform. The required individual catch-up in terms of δ is calculated as 0.89, that is if all inefficient producers shorten their distance to the best practice frontier by 89 per cent, then the delivered quantities will meet the national quota even if Assens is closed down. We also note that fixed costs may be reduced in the longer run by closing Assens. Therefore, the estimated profit loss in Table 4 is a pessimistic prediction. In reality and in the longer run, the losses may be less.

5. Conclusion

The new EU sugar price regime significantly lowers the price of white sugar and therefore that of sugar beet. This raises the question of whether sugar production can be sustained at a reasonable level in Denmark in the future.

We show that the present quota allocation is inefficient. In fact, by reallocating quota from less efficient growers to more efficient ones, aggregate grower profit is estimated to more than double the level in the old regime. Thus, with quota reallocation over producers, this profit potential can be used to offset the price reduction in the new regime. The impact of the reform will still be dramatic in terms of profit. Only about 10 per cent of the extraordinary profits from sugar are retained in the new regime. On the other hand, this is sufficient to maintain production equal to 75 per cent of the quota in Denmark. If growers at the same time become more efficient, moving closer to best practices, it is possible that full use of the historical quota would be profitable by individual learning.

In terms of policy implications, the results suggest that the establishment of organised and centralised markets for production quota would be very attractive. There are large potential gains and the decentralised leasing arrangements have been far from able to realise them. Our results also show that an improvement in best practice is a worthwhile complement to reallocation. This suggests more extension service support and perhaps the establishment of more local collaboration between growers.

The analyses also suggest that relatively simple auction designs would be adequate. The gains from solving dependent as opposed to independent auctions for the three plants may not justify the added complexity. The main problem for farmers is reallocating within plants rather than across plants. Of course, when the plant in Assens is closed in 2007, as is planned, some reallocation across areas will be needed, but in that case the auction mechanism is also relatively simple as it involves only two plants.

References

Agrell, P., Bogetoft, P. and Tind, J. (2005). DEA and dynamic yardstick competition in Scandinavian electricity distribution. *Journal of Productivity Analysis* 23: 173–201.

Andersen, J.L. and Bogetoft, P. (2007). Gains from quota trade: theoretical models and an application to the Danish fishery. *European Review of Agricultural Economics* (this issue).

Bogetoft, P. and Olesen, H.B. (2004). *Design of production contracts*. Copenhagen, DK: CBS-Press Copenhagen.

Bogetoft, P. and Wang, D. (2005). Estimating the potential gains from mergers. *Journal of Productivity Analysis* 23: 145–171.

Bogetoft, P., Damgaard, I.B., Jacobsen, T., Nielsen, K., Pagter, J.I. and Toft, T. (2005). *Secure Computation, Economy, and Trust – A Generic Solution for Secure Auctions with Real-world Applications*. Basic Research in Computer Science (BRICS) Report RS-05-18.

Bogetoft, P., Färe, R. and Obel, B. (2006). Allocative efficiency of technically inefficient production units. *European Journal of Operational Research* 168: 450–462.

Brännlund, R., Färe, R. and Grosskopf, S. (1995). Environmental regulation and profitability: an application to Swedish pulp and paper mills. *Environmental and Resource Economics* 6: 23–36.

Brännlund, R., Chung, Y., Färe, R. and Grosskopf, S. (1998). Emissions trading and profitability: the Swedish pulp and paper industry. *Environmental and Resource Economics* 12: 345–356.

Brümmer, B. (2001). Estimating confidence intervals for technical efficiency: the case of private farms in Slovenia. *European Review of Agricultural Economics* 28: 285–306.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978). Measuring efficiency of decision making units. *European Journal of Operational Research* 2: 429–444.

Charnes, A., Cooper, W.W. and Rhodes, E. (1979). Short communication: measuring efficiency of decision making units. *European Journal of Operational Research* 3: 339.

Charnes, A., Cooper, W.W., Levin, A.Y. and Seiford, L.M. (1994). *Data envelopment analysis: theory, methodology and application*. Norwell, MA, USA: Kluwer Academic Publishers.

Coelli, T., Rao, D.S.P. and Battese, G. (1999). *An introduction to efficiency and productivity analysis*. Norwell, MA, USA: Kluwer Academic Publishers.

Cooper, W.W., Seiford, L.M. and Tone, K. (2000). *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software*. Norwell, MA, USA: Kluwer Academic Publishers.

Cramton, P., Shoham Y. and Steinberg R. (2006). *Combinatorial auctions*. Cambridge, MA, USA: MIT Press.

Cripps, M.W. and Swinkels, J.M. (2005). Efficiency of large double auctions. *Econometrica* 74: 47–92.

Frandsen, S.E., Jensen, H.G., Yu, W. and Walter-Jørgensen, A. (2003). The EU sugar policy - An analysis of price versus quota reductions. *European Review of Agricultural Economics* 30: 1–26.

Friedman, D. (1984). On the efficiency of experimental double auction markets. *The American Economic Review* 74: 60–72.

Friedman, D. and Ostroy, J. (1995). Competitivity in auction markets: an experimental and theoretical investigation. *Economic Journal* 105: 22–53.

Institute of Food and Resource Economics (2003). Operating Account Statistics for Agricultural Enterprises, Series B, no. 88 (available in Danish only: Landbrugsstatistik 2003 – udvælgelse, beregninger og definitioner), www.foi.kvl.dk.

Kerstens, K., Vestergaard, N. and Squires, D. (2006). A short-run Johansen industry model for common-pool resources: planning a fishery's industrial capacity to curb overfishing. *European Review of Agricultural Economics* 33: 361–389.

Ketcham, J., Smith, V.L. and Williams, A.W. (1984). A comparison of posted-offer and double-auction pricing institutions. *Review of Economic Studies* 51: 595–614.

Klemperer, P. (1999). Auction theory: a guide to the literature. *Journal of Economic Surveys* 13: 227–286.

Krishna, V. (2002). *Auction theory*. San Diego, CA, USA: Academic Press.

Milgrom, P (2004). *Putting auction theory to work*. New York, NY, USA: Cambridge University Press.

Myerson, R.B. and Satterthwaite, M.A. (1983). Efficient mechanisms for bilateral trading. *Journal of Economic Theory* 29: 265–281.

Nautz, D. (1995). Optimal bidding in multi-unit auctions with many bidders. *Economics Letters* 48: 301–306.

Oude Lansink, A., Pietola, K. and Bäckman, S. (2002). Efficiency and productivity of conventional and organic farms in Finland 1994–1997. *European Review of Agricultural Economics* 29: 51–65.

Pekec, A. and Rothkopf, M.H. (2003). Combinatorial auction design. *Management science* 49: 1485–1503.

Satterthwaite, M.A. and Williams, S.R. (1989). The rate of convergence to efficiency in the buyer's bid double auction as the market becomes large. *Review of Economic Studies* 56: 477–498.

Satterthwaite, M.A. and Williams, S.R. (2002). The optimality of a simple market mechanism, *Econometrica* 70: 1841–1863.

Sieper, E. (1982). Rationalizing Rustic Regulation. The Centre for Independent Studies, St. Leonards, NSW, Australia.

Simar, L. and Wilson, P. (2000). Statistical inference in nonparametric frontier models: The state of the art. *Journal of Productivity Analysis* 13: 49–78.

Thiele, H. and Brodersen, C.M. (1999). Differences in farm efficiency in market and transition economies: empirical evidence from west and east Germany. *European Review of Agricultural Economics* 26: 331–347.

Vries, S.D. and Vohra, R.V. (2003). Combinatorial auctions: a survey. *INFORMS Journal on Computing* 15: 284–309.

Weisstein, E.W. (1999). NP-Hard Problem. From MathWorld – A Wolfram Web Resource. http://mathworld.wolfram.com/NP-HardProblem.html. Accessed 15 January 2007.

Corresponding author. Peter Bogetoft, Institute of Food and Resource Economics, University of Copenhagen, Rolighedsvej 25, 1958 Frederiksberg C, Denmark. *E-mail*: pb@life.ku.dk