Quota Deregulation and Organic versus Conventional Milk –
A Bayesian Distance Function Approach

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Abstract

Milk quota trading rules differ across EU member countries. In Denmark a biannual milk quota exchange was set up in 1997 to promote a more efficient reallocation of milk quotas as well as to reduce transaction costs related to the searching and matching of sellers and buyers. Using two comprehensive panel data sets on organic and conventional milk farms this study attempts to disentangle the effects of the introduction of quota transferability on the production structure of those farms as well as the probability of market entry/exit. Bayesian estimation techniques are used to estimate an input oriented generalized Leontief distance function as well as a curvature constrained specification. The results suggest that the deregulation in the quota allocation mechanism led to an increased allocative efficiency of organic as well as conventional milk production as well as a relative shift of the PPF in favor of the production of organic milk.

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1. Introduction

Milk production accounts for a large proportion of conventional as well as organic farming in Europe. However, the EU milk market is regulated by a quota system on farm level tackling to balance future milk production. Quota transfers have been allowed in the EU since 1987, although trading rules differ across member countries. Each EU country was allocated a national quota covering the total production of a quota year. In June 2003 the EU agricultural ministers agreed, among other measures, on a prolongation of the milk quota system until 2014-2015 in combination with a milk increase of 1.5 per cent in three yearly steps starting in 2006. The relevant economic literature suggests that by restricting quantities supplied, the imposition of quotas generates economic inefficiency relative to a free market policy, though quotas could improve efficiency relative to price supports, especially in the case of transferable quotas (Alston, 1981). Further, it has been argued that if quotas are freely tradable, more efficient farmers will buy quota from less efficient farmers, the result of this exchange being that the global quota is produced at minimum costs (Burrell, 1989). However, Alston (1992) stresses that transferability is seldom unconstrained because of political costs of free transferability. In Denmark, milk quotas have been traded in different ways. Until 1997 quotas were traded along with farmland, and were bought and redistributed (without land) by the Danish Dairy Board. In 1997, a biannual milk quota exchange was set up to promote a more efficient reallocation of milk quotas as well as to reduce transaction costs related to the searching and matching of sellers and buyers (effective in 1998). In the last ten years milk farming in Denmark had undergone a significant structural development: the number of farms has diminished by 50 per cent and correspondingly the average quota per farm has more than doubled bringing the Danish producers close to those in the UK. This structural development has also consolidated Denmarks role as a leading country in the EU with respect to organic milk production.

Using two comprehensive panel data sets on organic and conventional milk farms both for the period of 1986 to 2005 this study attempts to disentangle the effects of the introduction of quota transferability on the production structure of those farms as well as the probability of market entry/exit. Applying Bayesian techniques - a Markov Chain Monte Carlo (MCMC) method based on a Gibbs sampling process - we estimate a generalized Leontief distance function. As milk production is quota restricted we assume cost minimization as the behavioural principle and consequently formulate an input oriented specification estimated by a fixed effects procedure. The fixed effects model is further estimated in a curvature constrained specification using an importance sampling process. Beside technical efficiency also allocative efficiency is measured by using output specific shadow price estimates. Further, substitutional relations between organic milk and non-milk output as well as between conventional milk and non-milk output are investigated. Finally output and input specific bias measures are estimated for organic as well as conventional milk production. The following section overviews milk production in the EU and Denmark by highlighting the importance of organic milk farming as well as the milk quota trading system in place (section 2). Section 3 outlines the theoretical framework used to analyse the effects of a deregulation in the quota allocation system on producers' decisions and efficiency. This is followed by section 4 on the empirical modelling and the data sets used whereas section 5 introduces the applied estimation procedure. Section 6 reports and discusses the estimation results and finally section 7 concludes.

2. Milk Production and Milk Quota Allocation

The dairy sector is of great importance to the European Union (EU) in a variety of ways. Milk production takes place in all EU member states and represents a significant proportion of the value of EU agricultural output (approximately 14%). The share of milk in total production varies between Member States, from 5.8% to 33.5% in 2006 whereas the share tends to be higher in northern Europe and is below 10% in Mediterranean countries (EC, 2006). In the early 1980's, the EU experienced a large surplus production of milk and dairy produce. To prevent further increase and to limit milk production, it was decided to introduce a milk quota scheme as a measure to control production. Each EU country was allocated a national quota covering the total production of a quota year, starting on 1st of April and ending on 31st of March. This milk quota system (effectively introduced in 1984) has put an effective limit on the amount of milk EU dairy farmers produce each year, and generally speaking, total EU production in any given year tends to match quota. If a farmer, hence, delivers more milk than his/her quota in any one year he/she can be penalised financially involving the payment of a 'superlevy'.

All former EU-15 member states have experienced a radical structural development in dairy farming in recent years as a result of the pursued agricultural policy and the WTO agreement as well as intensified technological development, implying intensified competition in the world market for dairy products (EC, 2006). As the national quotas have not changed in recent years, the large fall in number of farms in these member countries has enabled the remaining milk farms to expand proportionally on average. In the period from 1995 to 2005 the average milk quota per dairy farm increased from about 380 tons to nearly 700 tons for the UK, from about 310 tons to about 750 tons for Danish farms, and from about 280 tons to nearly 500 tons for milk farms in the Netherlands. Denmark is one of the countries with the most significant structural development, the number of dairy farms decreased from about 33,000 in the quota year 1984/85 to about 5,900 in 2004/05 with an average number of 95 cows per herd (Danish Milk Board, 2006). Following experts' forecasts only about 3,000 dairy farms will be left in 2014/15.

Organic milk production accounts for about 10% of total milk production in Denmark and is the largest individual product category among organic products on the domestic Danish market (about 60%). The number of organic milk farms increased from about 130 in 1993/94 to about 830 in 2000/01 with an average quota of about 550 tons per farm. During recent years organic production has been on decline in number of farms as well as in total milk quota. However, in comparison with conventional production the decline has been at a minimum in the past years and in 2004/05 about 500 organic milk farms produced with an average quota of about 800 tons (Danish Milk Board, 2006). In 2005 approximately 25% of the total milk sold in Denmark was organically produced whereas the Danes are world leader in percent consumption of organic milk (Kraemer and Holgaard, 2007).

In Denmark, milk quotas have been traded in different ways. Until 1997 quotas were traded along with farmland, and were bought and redistributed (without land) by the Danish Dairy Board (Rasmussen and Nilesen, 1985). During this period (1984 - 1997) it was required by law that milk quota could not be transferred without land and that the Milk Board as the main regulatory body had to be notified about all transfers. Indirect quota transfers were distinguished from direct quota transfers. In the case of the former the milk producer purchased an entire or part of a farm including the milk quota. In the case of the latter the milk producer purchased an entire or part of a farm including the milk quota which was then merged with existing quota linked to his own farm. Milk quota could be either purchased or leased, the distance between the farm and the newly acquired land could not exceed 15 km in the case of a direct quota transfer, and the maximum transfer was limited to 10 tons per hectare. Finally, an establishment of a joint ownership between two or more parties could be formed by merging the milk quotas without deduction (Danish Milk Board, 2000). In 1997, a biannual milk quota exchange was set up to promote a more efficient reallocation of milk quotas as well as to reduce transaction costs related to the searching and matching of sellers and buyers (effective in 1998). Since then practically all transfer of milk quota in Denmark takes place at the milk quota exchange.

Figure 1 The Danish Milk Quota Exchange Mechanism

Initially the Milk Board ran 2 quota exchanges a year. By 2005, however, 4 exchanges are run a year – on 1 May, 15 August, 1 November, and 1 February. Two months after the exchange the quota is transferred to the purchaser and can be immediately used. However, 1% is deducted and transferred to the 'free quantities' to be used for allocation to newly established farms. All conventional and organic milk producers are entitled to place one bid for quota purchase or quota sale at the exchange stating quantity and minimum price (sale) or quantity and maximum price (purchase). No limit on the total amount of quota to purchase exists. All bids received are recorded in a supply and a demand curve whereas the intersection point constitutes the equilibrium price or the market clearing price. The latter is based on an average fat content of 4.36%, the individual bids will be adjusted by a conversion factor in relation to the farm's representative fat content. Producers willing to sell at a price lower or equal to the clearing price will sell, producers willing to buy at a price higher or equal to the clearing price will purchase. Remaining offers are rejected by the Milk Board, however, such producers can again place an offer at the following quota exchange round (Danish Milk Board, 2006). Figure 1 shows a simplified model of the quota exchange mechanism and figure 2 gives a summary of the reallocated quota as well as the clearing prices from December 1997 to August 2005. The leading role of the Danish dairy sector in terms of structure and quantity as well as the relatively innovative quota allocation system in place justify the empirical focus of this study.

Figure 2 Reallocation and Market Clearing Prices 1997 to 2005

3. Theoretical Framework

Several studies so far investigate milk production in the EU from a more theoretical and/or empirical perspective. Rasmussen and Nielsen (1985) develop a model for the optimal adjustment of milk production on farm level given a nontradable quota constraint where they first derive the criterion for optimality assuming homogenous and secondly assuming heterogenous production functions. They found that the process of adjustment is highly depending on the relation between fixed and variable costs. Stefanou et al. (1992) estimate a multiple output and mulitple input model to investigate the economic behaviour of dairy producers in the Federal Republic of Germany during the first half of the 1980s. Their results suggest that the changes in producers' responses were driven by changes in variable input use and the evolution from a symmetric to asymmetric adjustment of quasi-fixed factors. Considerable excess capacity in production was found. Guyomard et al. (1996) use the duality theory framework to analyse producer behaviour given the lease or rent out of milk quota for one production cycle and assuming tradable quota rights. The model is then applied on a sample of French milk producers for the year 1991 determining efficiency gains and regional shifts in production. A similar study is done for the Dutch dairy sector by Boots et al. (1997). Here the efficiency loss due to distortions in quota trade is analysed by means of a simulation exercise applied to potential quota trade for 1992/93 subject to various restrictions. The simulations showed that free tradability of milk quotas increases profit by 9 percent. The authors conclude that welfare gains can be obtained if restrictions on quota trade are removed, however, trade restrictions work in favor of small farms.

Colman (2000) summarizes the existing theory on the economic effects of quotas in agricultural production (following Burrell, 1989; Harvey, 1983 and Dawson, 1991) and applies it to analyse inefficiencies in the UK milk quota system. By cost scenario analyses based on the year 1996/97 he finds that significantly more quota is needed to be transferred from less to more efficient producers and that a large number of inefficient producers remained in milk production as a consequence of the quota restrictions. Assuming an endogeneity of some of the inputs Ooms and Peerlings (2005) estimated a milk production function applying a generalised methods of moments estimator on an unbalanced panel of Dutch milk farms to analyse the effects of the 2003 EU dairy policy reform. The authors conclude in a threat for many small milk farms by the reform steps analysed. Alvarez et al. (2006) use a panel of Spanish dairy farms to explore the relationship between milk quota values and economic efficiency. Estimated quota values are then decomposed into efficiency, price, and scale effects to assess the relative influence of these factors. The study concludes that efficiency is important in explaining quota values but is not correlated with farm characteristics which questions the success of policy measures to allocate milk quotas to efficient farms.

Ewasechko and Horbulyk (1995) as well as Lambert et al. (1995) have computed potential gains from a deregulation in milk quota transferability with respect to provinces in Canada. While the former calculated marginal production cost based on survey data using a linear programming model the latter stochastically estimate quota demand and supply. However, these studies focus the regional level as well as the interregional quota allocation. Balcombe et al. (2007) analysed the effects of deregulation on the Australian dairy manufacturing industry. Bogetoft et al. (2003) provide an in depth analysis of the Danish milk quota allocation system focusing the single-bid restriction on quota exchanges. Their analysis is mainly based on auction theoretical considerations demonstrating that multiple-bid auctions are superior to single-bid auctions. The latter creates distortions in two ways: First, milk quota buyers try to reduce the risk of foregoing profitable trade by submitting higher bids (the uncertainty effect) and second, buyers' behaviour can not be consistent with a downward sloping demand curve and hence demand and supply will be underestimated on the market level (the aggregation effect). To illustrate the empirical importance of their findings the authors use data from the milk quota exchange in Ontario/Canada which is based on a multiple bid mechanism.

To our knowledge, an empirical study investigating the effects of an increase in milk quota transferability on the individual producer level over time does not exist so far. Further, no such empirical study does exist taking into account the differing production structure of conventional and organic milk farming. The following analysis tries to address these gaps by analysing the effects of a deregulation in the milk quota transfer regime on the production structure of conventional as well as organic milk farms in Denmark for a period of 20 years (1986 - 2005), namely the introduction of a milk quota exchange system in December 1997. Instead of simulating a change in the transferability of the quota we use panel data on 427 conventional and 66 organic farms (2938 and 493 observations) before and after the change in quota regulation. We aim to analyse potential effects on the farms' relative efficiency, resulting changes in the farms substitution between milk and non-milk output as well as input and output specific deregulation effects over time. We assume a significantly different production structure for conventional and organic milk farms, hence evaluate the models for each sample of milk farms separately. The specific research hypotheses to investigate by the empirical analysis are (1) deregulation in the milk quota allocation system has positive effects on the milk farms efficiency over time; and (2) deregulation in the milk quota allocation system has significant effects on the farms production structure, namely the output composition based on the substitutability between milk and non-milk output as well as organic and non-organic output.

Subsequently a theoretical framework is outlined to empirically analyse the behaviour of milk producers in a situation where the market is highly restricted due to predefined production quota. Different cases can be distinguished with respect to the milk quota allocation mechanism in place:

Case I: We consider a profit-maximising conventional or organic milk farmer who produces milk output y_m as well as non-milk output y_{nm} according to the well-behaved short-run or restricted cost structure $C(y_m,y_{nm},x,Z)$ where w is the market price vector of variable input quantities (as e.g. fodder, energy, veterinary expenses) and Z is the vector of quasi-fixed factor quantities (as e.g. land, labor, capital). The farmer is a price taker on all output and variable input markets. As none of the outputs is constrained by quotas, producer behaviour can be described by an unrationed restricted profit function $\pi(p_m,p_{nm},w,Z)$ where p_m is the milk output price and p_{nm} is an aggregated price for non-milk output. Short-run profit is maximised by

$$\pi\left(p_m, p_{nm}, w, Z\right) \equiv \max_{y_m, y_{nm}} \left[p_m y_m + p_{nm} y_{nm} - C\left(y_m, y_{nm}, w, Z\right)\right] \tag{1}$$

This case describes the pre-1984 period for all European milk sectors.

Case II: When output y_m is constrained by a quota at level y_m' and if quotas are not traded among milk producers, the individual farmer chooses short-run cost minimisation based on a partly rationed restricted profit function $\pi_{sr}^r(p_m,y_m',p_{nm},w,Z)$. Short-run profit – the maximum profit attainable given the regime of non-tradable milk quotas - is then maximised by

$$\pi^r\left(p_m, y_m', p_{nm}, w, Z\right) \equiv \left[p_m y_m' - \min_{C_m}\left(C_m\left(y_m', w, Z\right)\right)\right] + \max_{y_{nm}}\left[p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right] \tag{2}$$

Long-run profit, however, is described by a partly rationed but unrestricted profit function $\pi_{lr}^{r}(p_m, y_m', p_{nm}, w)$ where all inputs are variable and consequently (see also Burrell, 1989)

$$\pi_{lr}^{r}\left(p_m, y_m', p_{nm}, w\right) \equiv \left[p_m y_m' - \min_{C_m}\left(C_m\left(y_m', w\right)\right)\right] + \max_{y_{nm}}\left[p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w\right)\right] \quad (3)$$

Case III: If milk quotas can be freely leased and v is the rental price of the quota, then the individual farmer's behaviour is defined by

$$\begin{aligned}&\pi^{l}\left(p_m, y_m', p_{nm}, w, Z, v\right) \equiv \\ &\max_{y_m, y_{nm}, q}\left[\left(p_m y_m - C_m\left(y_m, w, Z\right) - vq; y_m = y_m' + q; y_m \geq 0\right) + \left(p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right)\right] \\ &\equiv \max_{y_m, y_{nm}}\left[\left(\left((p_m - v) y_m - C_m\left(y_m, w, Z\right); y_m \geq 0\right) + v y'\right) + \left(p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right)\right]\end{aligned} \quad (4)$$

where vq represents the cost of renting additional quota at a price v per unit ($vq \geq 0$) or the revenue from leasing out part or all of the initial quota at a price v per unit ($vq \leq 0$). Π^{l} is the maximum profit attainable in the regime of free milk quota lease (see Guyomard et al., 1996). This case describes the pre-1997/98 period for the Danish milk sector and corresponds to a decrease in the milk price received by producers (p_m-v) but no change in the consumer price for milk. Tradable rights to use milk quota hence work like a tax which restores marginal cost pricing in the diary industry while protecting the rents of the initial quota owners (Guyomard et al., 1996).

Case IV: If finally milk quotas are freely tradable among producers, but their trade is restricted to certain dates of the production year (e.g. bi-annually or quarterly), the individual farmer's behaviour at time t_0 can be described as follows

$$\begin{aligned}&\pi_{t_0}^{ex}\left(p_m, y_{m,t_0}', p_{nm}, w, Z\right) \equiv \\ &\left[p_m y_{m,t_0}' - \min_{C_m}\left(C_m\left(y_{m,t_0}', w, Z\right)\right)\right] + \max_{y_{nm}}\left[p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right]\end{aligned} \quad (5)$$

after the first (bi-annual) quota exchange at time t_1

$$\begin{aligned}&\pi_{t_1}^{ex}\left(p_m, y_{m,t_1}', p_{nm}, w, Z, p_{q,t_1}\right) \equiv \\ &\left[p_m y_{m,t_1}' - \min_{C_m}\left(C_m\left(y_{m,t_1}', w, Z, p_{q,t_1}\right)\right)\right] + \max_{y_{nm}}\left[p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right]\end{aligned} \quad (6)$$

and after the n-th (bi-annual) quota exchange at time t_n

$$\pi_{t_n}^{ex}\left(p_m, y'_{m,t_n}, p_{nm}, w, Z, p_{q,t_n}\right) \equiv \left[p_m y'_{m,t_n} - \min_{C_m}\left(C_m\left(y'_{m,t_n}, w, Z, p_{q,t_n}\right)\right)\right] + \max_{y_{nm}}\left[p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right] \quad (7)$$

where the output levels $y'_{m,t0}$ is again the initial constrained output level y_m, $y'_{m,t1}$ is the quota constrained output level after one quota exchange round at time period t_1 and represents the adjusted but still quota constrained output level $y'_{m,t1} = y'_{m,t0} + \Delta y_{m,t1}$, and $y'_{m,tn}$ is the quota constrained output level after n quota exchange rounds up till time period t_n and represents the adjusted but still quota constrained output level $y'_{m,tn} = y'_{m,tn-1} + \Delta y_{m,tn}$. This follows from the regulatory constrained that milk production quotas q can be exchanged betweem producers but the exchange is limited to certain pre-defined dates (t_1 to t_n). Hence, the behaviour of the individual producer in the short-run is described by a partly rationed restricted profit function $\pi_{sr}^{ex}(p_m,y'_m,p_{nm},w,Z,p_q)$. Short-run profit equals maximum profit attainable in a time period given the regime of tradable milk quotas at certain points in time (see Bogetoft et al., 2003 and Alvarez et al., 2006). This case describes the post 1997/98 period for the Danish milk sector. Long-run profit, however, is described by a partly rationed but unrestricted profit function $\pi_{lr}^{ex}(p_m,y'_m,p_{nm},w,p_q)$ where all inputs are variable.

$$\pi_{lr,t_n}^{ex}\left(p_m, y'_{m,t_n}, p_{nm}, w, p_{q,t_n}\right) \equiv \left[p_m y'_{m,t_n} - \min_{C_m}\left(C_m\left(y'_{m,t_n}, w, p_{q,t_n}\right)\right)\right] + \max_{y_{nm}}\left[p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w\right)\right] \quad (8)$$

Case V: Finally, if milk production quota are fully tradable on a completely free market without any legally set quota exchange regime as well as no time restrictions for the price and quantity bids, case III can be adjusted as follows

$$\begin{aligned}
&\pi^f\left(p_m, y'_m, p_{nm}, w, Z, p_q\right) \equiv \\
&\max_{y_m, y_{nm}, q}\left[\left(p_m y_m - C_m\left(y_m, w, Z, p_q\right) - p_q q; y_m = y'_m + q; y_m \geq 0\right) + \left(p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right)\right] \quad (9)\\
&\equiv \max_{y_m, y_{nm}}\left[\left(\left((p_m - p_q) y_m - C_m\left(y_m, w, Z\right); y_m \geq 0\right) + p_q y'\right) + \left(p_{nm} y_{nm} - C_{nm}\left(y_{nm}, w, Z\right)\right)\right]
\end{aligned}$$

where $p_q q$ represents the cost of purchasing additional quota at a price p_q per unit ($p_q q \geq 0$) or the revenue from selling part or all of the initial quota at a price p_q per unit ($p_q q \leq 0$). π^f is the maximum profit attainable in the regime of free milk quota trade in the short-run. This corresponds to a decrease in the milk price received by producers (p_m-p_q) but no change in the consumer price for milk.

Following cases III and IV outlined above, an adequate representation of the multi-output and multi-input production structure of conventional or organic milk producing farms has to be formulated which can then be translated into an estimable empirical model. Accounting for the multi-output nature of production one could choose a dual representation of the production technology such as a cost or profit function. However, the distance function representation of a production technology, proposed by Shephard (1953, 1970), provides a multi-output primal alternative which requires no aggregation of outputs, no prices and no behavioural assumptions. By using such a framework the relative switch from organic milk to inorganic crop or livestock production and vice versa can be investigated by simply measuring the substitution between organic milk and other outputs produced over time. This could give an indication if the existing quota allocation scheme significantly increases or decreases the probability of entering and/or exiting organic milk production. An input-distance function considers by how much the input vector may be proportionally contracted with the output vector held fixed (Faere, 1988; Faere et al., 1994; Grosskopf et al., 1997; Coelli, 2000). Such a function seems adequate to represent a partially rationed profit framework implying a cost minimisation problem for the milk output as well as a profit maximisation problem for the non-milk outputs produced (see equations (3) and (8)). A theoretical input-distance function may be defined on the input set L(y,u), as

$$D_I(x, y, u) = \max\left\{\phi : \left(x/\phi\right) \in L(y,u)\right\} \tag{10}$$

where ϕ is the scalar distance by which the input vector can be deflated, and L(y,u) as the set of all input vectors $x \in R^K_+$ comprising all production inputs named above, which can produce the output vector, $y \in R^M_+$ comprising milk and non-milk output given the exogenous factors u (i.e. a vector of external production determinants such as technical and regulatory factors as e.g. the quota allocation system in place). That is,

$$L(y,u) = \left\{x \in R^K_+ : x \text{ can produce } y \text{ given } u\right\} \tag{11}$$

$D_I(x,y,u)$ is non-decreasing, positively linearily homogenous and concave in x, and increasing in y, finally $D_I(x,y,u) \geq 1$ if $x \in L(y,u)$.

4. Empirical Modelling

To empirically implement the distance function outlined in (10) a functional form must be specified. According to Diewert (1973) a flexible functional form provides a second order approximation to the real production structure by an arbitrarily chosen set of parameters. Hence, a functional form can be denoted as flexible if its shape is only restricted by theoretical consistency. This implies the absence of unwanted a priori restrictions and is paraphrased by the methaphor of "providing an exhaustive characterization of all (economically) relevant aspects of technology." (Fuss and McFadden, 1978). Morrison-Paul et al. (2000) stress that the minimization of a priori restrictions implied by the choice of the functional form is particular important in a multi-output and multi-input context. Thus, a flexible technological representation allowing for substitution and regulatory impacts within the function is desirable as a basis for an empirical application. Lovell et al. (1994), Coelli and Perelman (1996), Grosskopf et al. (1997), Morrison-Paul et al. (2000) as well as Balcombe et al. (2007) use the common translog (TL) functional form. However, restricted for correct curvature (i.e. consistency with the underlying behavioural assumptions) the TL shows no longer second order flexibility as curvature correctness has to be imposed at every individual observation (see e.g. Sauer, 2006). Unlike the TL, the generalized Leontief (GL) functional form can be globally restricted for curvature correctness by parameter restrictions (see Diewert and Wales (1987), requires no mathematical manipulations of the original data as e.g. taking logs of the variables, but incorporates all second-order (interaction- or cross-) terms across outputs and inputs and allows investigation of substitution possibilities without restrictive assumptions about the shape of the underlying technological relationship. Hailu and Veeman (2000) demonstrate that a theoretically consistent input distance function is non-decreasing and concave in inputs and non-increasing and quasi-concave in outputs.

An input-oriented distance function based on a generalized Leontief functional form with L outputs, K inputs and for I farms is given by

$$D_{In,i} = \alpha_0 + \sum_{l=1}^{L} \gamma_l y_{li} + 2\sum_{l=1}^{L} \sum_{n=1,n\neq l}^{L} \gamma_{ln} y_{li} y_{ni} + \sum_{k=1}^{K-1} \beta_k x_{ki} + 2\sum_{k=1}^{K-1} \sum_{o=1,o\neq k}^{K-1} \beta_{ko} x_{ki} x_{oi} + 2\sum_{k=1}^{K-1} \sum_{l=1}^{L} \delta_{kl} x_{ki} y_{li} \quad (12)$$

where In indicates an input-oriented distance function. Homogeneity of degree 1 is imposed by normalizing the function by one of the inputs (see Coelli, 2000). Incorporating a milk quota exchange deregulation related variable *qex*, technical change related dummies *t*, yearly based fixed effects *a* as well as a vector of other control variables *c* we reformulate (12) to

$$\begin{aligned}
-x_{ki} = &\sum_{l=1}^{L}\gamma_l y_{li} + 2\sum_{l=1}^{L}\sum_{n=1,n\neq l}^{L}\gamma_{ln} y_{li} y_{ni} + \sum_{k=1}^{K-1}\beta_k (x_{ki} - x_{Ki}) + \\
&2\sum_{k=1}^{K-1}\sum_{o=1,o\neq k}^{K-1}\beta_{ko}(x_{ki} - x_{Ki})(x_{oi} - x_{Ki}) + 2\sum_{k=1}^{K-1}\sum_{l=1}^{L}\delta_{kl}(x_{ki} - x_{Ki}) y_{li} + \psi_{qex} qex_i + \\
&\sum_{k=1}^{K-1}\phi_{kqex}(x_{ki} - x_{Ki}) qex_i + \sum_{l=1}^{L}\phi_{lqex} y_{li} qex_i + \kappa_t t_i + \kappa_{tt} t_i^2 + \sum_{s=1}^{S}\varphi_s c_{si} + \sum_{a=1}^{A}\eta_{at} a_{ti} - d_{In,i}
\end{aligned} \tag{13}$$

where the outputs L are conventional or organic milk produced and other conventionally produced non-milk output, the inputs K are land, labor, capital, fodder, energy and veterinary expenses, *qex* is the quota deregulation related dummy, as well as *c* for off farm income, age of the farmer, proportion of land rented, proportion of hired labor, debt to own capital ratio, and the debt to total assets ratio of the farm i in question.[1] Although our GL specification of the input distance function satisfies homogeneity and symmetry by construction, monotonicity in outputs (non-increasing) and inputs (non-decreasing) as well as concavity in inputs and quasi-concavity in outputs have to be checked and imposed respectively. With respect to the parameters of the estimated function this implies the following restrictions:

$\partial d_{In} / \partial x_k > 0 \; for \; k = 1,2,...K-1,$ and $\partial d_{In} / \partial y_l < 0 \; for \; 1 = 1,2...L$, $\beta_{ko} > 0 \; for \; k = 1,2,...K-1$ and $\delta_{kl} \geq 0 \; for \; 1 = 1,2,...L$ and $k = 1,2,...K-1$.

Absolute, relative, and proportional measures for both inputs and outputs can be constructed by using the distance function in (13) and building the first- and second-order elasticities with respect to the arguments of the function. A broad range of input and output substitutability and compositional patterns can then be summarized (see e.g. Morrison-Paul et al., 2000). The duality of the distance function with the revenue function can be used to define r_l* as the revenue-deflated shadow price of y_l via a distance-function oriented Shephard's lemma based on the derivative (see Faere, 1988)

$$\partial D_{In}(\mathbf{x},\mathbf{y}) / \partial y_l = r_l^*(\mathbf{x},\mathbf{y}) = \gamma_l + 2\sum_{n=1,n\neq l}^{L}\gamma_{ln} y_n + 2\sum_{k=1}^{K-1}\delta_{kl}(x_k - x_K) + \phi_{lqex} qex \tag{14}$$

[1] Milk quota is not used as an explanatory variable in the model as auxiliary regressions showed an almost complete (deterministic) relationship between milk output and quota input. Further severe collinearity has been detected with respect to other variable inputs as e.g. cows. This approach is also followed by Stefanou et al., 1992; Ooms and Peerlings, 2005 and Alvarez et al., 2006.

The ratio of these shadow values for conventional or organic milk output y_m and non-milk output y_{nm} represents the slope of the production possibility frontier (PPF), or the marginal rate of transformation (MRT)

$$MRT_{m,nm} = \frac{r_m^*}{r_{nm}^*} \quad (15)$$

Analogue to the marginal product concept, these measures provide an indication of the valuation of the output in terms of its contribution to resulting overall output. The ratio in (15) is analogue to the ratio of the marginal products representing the marginal rate of technical substitution ($MRTS_{ko}$) for the inputs. It can be used to assess allocative efficiency by comparing it with the ratio of observed output prices where the two ratios are equal if profit maximization effectively takes place. This would mean for the overall milk market

$$AE_m = \frac{mp_{org} / mp_{con}}{r_{org}^* / r_{con}^*} \quad (16)$$

where mp is the observed milk price for organically or conventionally produced milk. The development of technical efficiency per year is measured by using the estimated parameters for the fixed effects η_{at} and correcting for the 'best' year by calculating the level of technical inefficiency τ_{at} in year t

$$TE_t = (1 - \tau_{at}) = (1 - (\max_t(\eta_{at}) - \eta_{at})) \quad (17)$$

following the approach by Kumbhakar (1989) and Sauer and Frohberg (2007).[2] Hence, by controlling for such sectoral technical inefficiency variation by year and rearranging the equation in (16) the shadow values obtained by (14) can be used to obtain the ouput specific allocative efficiency per individual farm as e.g. for (organic or conventional) milk output

$$OSAE_{mi} = \frac{r_{coni}^*}{mp_{coni}} = \frac{r_{orgi}^*}{mp_{orgi}} \quad (18)$$

which relates the estimated shadow values to the observed values of the output per farm i. Consequently, such output specific allocative efficiency reflects potential market distortions, e.g. regulatory impacts by the milk quota regime in place or the impacts by subsidies for organic production (see Lau and Yotopoulos,

[2] Our primary focus is on measuring the effects of quota deregulation on the production structure as well as the allocative efficiency, the substitutional relations and the entry/exit behaviour of farms in the milk sector over time. As the technical efficiency on producer level has been investigated before (Sauer et al., 2006) we do not explicitly model an error-components based distance frontier but control for significant changes in the technical efficiency on sector level over time by a fixed effects model specification.

1971 and Sauer and Balint, 2008). The difference between the observed milk price and the estimated shadow milk price as a proxy for allocative inefficiency (i.e. allocative inefficiency due to distortions by the quota system in place, due to other market distortions as well as due to managerial optimization failure on farm level) could be used as an indicative price for milk quota per kg and year. Such a proxy can be interpreted as an upper ceiling for the average price per quota unit used in the sector.

Grosskopf et al. (1995) showed that the MRT measure is increasing in terms of levels as the ratio of outputs falls as the increased production of one output alone occurs at higher opportunity cost. By normalizing the marginal rate of transformation it reflects the substitutability between two outputs, as e.g. between milk and non-milk output

$$sub_{m,nmi} = \frac{r^*_{mi} / r^*_{nmi}}{y_{nmi} / y_{mi}} = \left(\frac{\gamma_m + 2\sum_{n=1,n\neq m}^{L} \gamma_{m,n} y_{ni} + 2\sum_{k=1}^{K-1} \delta_{k,m}(x_{ki} - x_{Ki}) + \phi_{m,qex} qex_i}{\gamma_{nm} + 2\sum_{n=1,n\neq nm}^{L} \gamma_{nm,n} y_{ni} + 2\sum_{k=1}^{K-1} \delta_{k,nm}(x_{ki} - x_{Ki}) + \phi_{nm,qex} qex_i} \right) / \left(\frac{y_{nmi}}{y_{mi}} \right) \tag{19}$$

where $sub_{m,nm} > 1$ (< 1) implies relative difficulty (ease) in y_m - y_{nm} substitution and hence, measures changes in output composition for farm i. With respect to the production of organic milk this measure can then be used to assess the development in the probability of milk farmers entering or exiting the organic milk market over time as in our framework the aggregated non-milk output is totally based on conventional production. The further exploration of second-order relationships of milk and non-milk outputs may deliver insights in the curvature of the PPF over time given exogenous effects of quota regulation changes. Cross-terms with respect to the y_l variables are interpretable as the effect these variables have on the contribution or valuation of y_l from a shift in the distance function. To distinguish the reform impact on organically produced milk, we can compute

$$B_{org,qexi} = \partial S_{orgi} / \partial qex_i = \frac{\frac{\partial D_{In}}{\partial y_{org}}}{\partial qex_i} = \frac{\gamma_{org} + 2\sum_{n=1,n\neq l}^{L} \gamma_{org,n} y_{ni} + 2\sum_{k=1}^{K-1} \delta_{k,org}(x_{ki} - x_{Ki}) + \phi_{org,qex} qex_i}{\partial qex_i} = \phi_{org,qex} \tag{20}$$

where S_{li} denotes the cost share in a cost function context and the proportional marginal product or implicit share measure in a distance function context (Morrison-Paul et al., 2000). The bias measure $B_{l,qexi}$ provides a relative measure of the productive impact of *qex* on output production and composition (as well as input composition by $B_{k,qexi}$) indicating whether a change in the quota regulation regime causes a change in the slope of the PPF or a twist of the PPF which for constant prices results in a movement around it. Whereas the overall impact of the regulatory change *qex* is obtained by the first-order *qex* elasticity $\varepsilon_{l,qex}$, the second-order bias term in (20) reflects differential impacts on inputs or outputs implying e.g. an increase in the value, share, or contribution of y_l relative to total output.

5. Bayesian Estimation and Data

The normalized input-oriented GL distance function is estimated as a fixed effects specification. We opt for the application of Bayesian estimation methods because of the following reasons: Beside disentangling the effects of regulatory policy measures on milk production we are also interested in the discrepancies between econometric measurement and economic theory with respect to the underlying behavioural assumption of output maximisation (see O'Donnel/Coelli, 2005; Sauer, 2006; Lancaster, 2006). So far, there are exclusively frequentist applications in the literature on milk production in Europe. However, a Bayesian approach enables the researcher to impose curvature constraints on the parameters of a GL distance function by means of importance sampling.

We estimate our input-oriented distance function described in (13) as a normal linear regression model with an independent Normal-Gamma prior (see Koop, 2005) assuming prior independence between β as the parameters to be estimated and h as the error precision defined as $1/\sigma^2$ with σ^2 as the variance. In particular, we assume prior independence between β and h defined by $p(\beta,h) = p(\beta)p(h)$ with p(β) as the prior distribution for β being Normal

$$p(\beta) = \frac{1}{(2\pi)^{\frac{k}{2}}} |\underline{V}|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}(\beta - \underline{\beta})'\underline{V}^{-1}(\beta - \underline{\beta}) \right] \tag{21}$$

and p(h) as the prior distribution for h being Gamma

$$p(h) = c_G^{-1}\ h^{\frac{h\underline{v}}{2\underline{s}^{-2}}} \exp\left(-\frac{h\underline{v}}{2\underline{s}^{-2}} \right) \tag{22}$$

where cG is the integrating constant for the Gamma p.d.f., $\underline{\beta} = E(\beta | y)$ as the prior mean of the conditional probability of β given the dependent variable y, the mean of the Gamma distribution μ and $\underline{s}^{-2}$ and $\underline{v}$ as the prior mean and degrees of freedom of h, $\underline{V}$ denoted the prior covariance matrix of β. The likelihood function for the normal linear regression is given by

$$p\left(y|\beta,h\right) = \frac{h^{\frac{N}{2}}}{(2\pi)^{\frac{N}{2}}}\left\{\exp\left[-\frac{h}{2}(y-X\beta)'(y-X\beta)\right]\right\} \quad (23)$$

with N as the total number of observations and X as the vector of exogenous variables. Consequently, we obtain as the joint posterior density for β and h

$$p\left(\beta,h|y\right) \propto \left\{\exp\left[-\frac{1}{2}\left\{h(y-X\beta)'(y-X\beta)+(\beta-\underline{\beta})'\underline{V}^{-1}(\beta-\underline{\beta})\right\}\right]\right\} h^{\frac{N+\underline{v}-2}{2}} \exp\left[-\frac{h\underline{v}}{2\underline{s}^{-2}}\right] \quad (24)$$

which requires posterior simulation as a simple analytical solution is not feasible (Koop, 2005, p. 62). By matrix simulation and mathematical rearrangements we obtain the conditional posteriors for β

$$p(\beta| y,h) \propto \exp\left[-\frac{1}{2}(\beta-\overline{\beta})'\overline{V}^{-1}(\beta-\overline{\beta})\right] \quad (25)$$

and h

$$p(h| y,\beta) \propto h^{\frac{N+\underline{v}-2}{2}} \exp\left[-\frac{h}{2}\left\{(y-X\beta)'(y-X\beta)\right\}+\underline{vs}^2\right] \quad (26)$$

where $\overline{\beta}$ and $\overline{V}$ are the posterior hyper-parameters and which are used by the Gibbs sampler as a posterior simulator to produce estimates of posterior properties. The Markov Chain Monte Carlo (MCMC) method of Gibbs sampling is used (Cassella and George, 1992; Zellner and Min, 1995; Geweke, 1994 and 1999) to approximate the marginal posterior distribution of a parameter of interest by generating a sample drawn from the marginal posterior distribution. The sample is derived by making random draws from the full conditional distributions of all parameters in a model. Estimates of the parameter vector β and the error precision h can be achieved by making successive sequential draws from the full posterior conditional distributions β given h, and h given β. The collection of random draws $\beta^{(s)}$ and $h^{(s)}$ for s = 1,…,S can then be averaged to produce estimates of posterior properties. We discard an initial S_0 = 5000 burn-in-replications and include S_1 = 50000 replications. To assess the approximation error in the MCMC algorithm we report different diagnostic measures: The numerical standard error following

$$NSE = \frac{\hat{\sigma}_g}{\sqrt{S_1}} \tag{27}$$

as well as the convergence diagnostic introduced by Geweke (1994);

$$CD = \frac{\hat{g}_{S_A} - \hat{g}_{S_C}}{\frac{\hat{\sigma}_A}{\sqrt{S_A}} + \frac{\hat{\sigma}_C}{\sqrt{S_C}}} \tag{28}$$

where $\hat{g}_{S_A}$ and $\hat{g}_{S_C}$ are the estimates of $E\left[g(\theta)\middle| y\right]$ with $g(\cdot)$ representing any function of θ as a p-vector of parameters using the first (S_A) and the last (S_C) replications after the burn-in and consequently $\hat{\sigma}_A / \sqrt{S_A}$ and $\hat{\sigma}_C / \sqrt{S_C}$ as the numerical standard errors of these two estimates.[3] Sufficiently low values of CD indicate that $\hat{g}_{S_A}$ and $\hat{g}_{S_C}$ are quite similar, hence a sufficiently large number of draws has been taken. In a second modelling step we estimate our input-oriented distance function described in (13) as a constrained normal linear regression model again with an independent Normal-Gamma prior assuming prior independence between β and h following the steps outlined above. However, correct curvature (i.e. monotonicity in outputs and inputs as well as concavity in inputs and quasi-concavity in outputs) is imposed through individual parameter inequality restrictions which implies a global restriction for the chosen GL functional form. Hence, we assume that a region of the parameter space β which is not within the relevant (i.e. courvature correct) region A is a priori impossible and should receive a prior weight of 0. Accordingly, our prior is given by

$$p(\beta) = \left\{ \frac{1}{(2\pi)^{\frac{k}{2}}} \left|\underline{V}\right|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}(\beta - \underline{\beta})' \underline{V}^{-1} (\beta - \underline{\beta}) \right] \right\} 1(\beta \in A) \tag{29}$$

where $1(\beta \in A)$ is the indicator function, which equals 1 if $\beta \in A$ and 0 otherwise. The posterior is accordingly given by

[3] The S draws from the Gibbs sampler are divided into an initial S_0 which are discarded as burn-in replications and the remaining S_1 draws which are included. These latter draws are further divided into a first set of S_A draws, a middle set of S_B draws and a last set of S_C draws.

$$p\left(\beta \middle| y,h\right) \propto \exp\left[-\frac{1}{2}(\beta-\overline{\beta})'\overline{V}^{-1}(\beta-\overline{\beta})\right]1(\beta \in A) \tag{30}$$

For a general choice of A an analytical method is not appropriate (Koop, 2005, p. 78). The use of Gibbs sampling and/or Metropolis-Hastings to impose curvature constraints is becoming more common (e.g. O'Donnell/Coelli, 2005). However, Gibbs sampling may be highly inefficient where the rejection rate becomes large, hence importance sampling is used based on the following theorem (see Geweke, 1999 or Bauwens, 1984): Let $\beta^{(s)}$ for s = 1,..,S be a random sample from q(β) as the importance function with β as a vector of parameters and define g(.) as the function of interest with the estimate

$$\hat{g}_S = \frac{\sum_{s=1}^{S} w(\beta^{(s)})g(\beta^{(s)})}{\sum_{s=1}^{S} w(\beta^{(s)})} \tag{31}$$

where $w(\beta^{(s)}) = \frac{p(\beta=\beta^{(s)}|y)}{q(\beta=\beta^{(s)})}$. Then $\hat{g}_S$ converges to $E\left[g(\beta)\middle| y\right]$ as S approaches infinity.[4] To assess the approximation error in the importance sampling algorithm we report again the numerical standard error following (27) and the convergence diagnostic based on (28). Further we report posterior odds ratios calculated as the Bayes Factor based on the Savage-Dickey density ratios to compare nested models where both have the same inequality restrictions imposed (Verdinelli and Wasserman, 1995; Koop, 2005):

$$BF_{12} = \frac{\overline{c} f_t(\beta=\beta_0|\overline{\beta},\overline{s}^2\overline{V},\overline{v})}{\underline{c} f_t(\beta=\beta_0|\underline{\beta},\underline{s}^2\underline{V},\underline{v})} \tag{32}$$

where $\underline{c}$ and $\overline{c}$ are the prior and posterior integrating constants ensuring that the densities integrate to one.[5] In order to elicite reasonable informative priors some preliminary OLS regressions were performed based on different production function specifications. As this is not more than a first informed choice, little weight has been put to the prior for h (about 10%) reflecting the weight given to the data information. For the prior variances relatively low values have been selected as well as prior covariances of the value zero as any prior

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[4] Under weak conditions, i.e. *q(β)* having support of $p(\beta|y)$ and $E\left[g(\beta)\middle| y\right]$ existing (see Kloek/van Dijk, 1978).

[5] With $\overline{c} = \frac{1}{p(M_1|y)} = \frac{1}{\int f_t(\beta|\overline{\beta},\overline{s}^2\overline{V},\overline{v})1(\beta\in A)d\beta}$ obtained by using importance sampling on the prior.

guesses on the values of the latter would seem to be rather arbitrary for a complex functional form (see Koop, 2005).

We estimate the constrained and unconstrained distance function using a sample of 493 organic diary farms and a sample of 2938 conventional diary farms for the period 1986 to 2005. By this we assume that the underlying production technology of organic farms significantly differs from those of conventional farms as we suspect that the former is more labor the latter more capital and fertilizer intensive. We test for this assumption by running a simple regression using the pooled data set. The coefficient for conventional or organic showed to be highly significant at the 0.0001 level of significance, tests performed on the significance of the estimate rejected the null hypothesis with a high level of confidence. Table A1 and A2 in the appendix give a brief descriptive overview of the two samples. We use as outputs (organic or conventional) milk produced and an aggregate of other farm which is completely non-organically produced in the case of organic diary farms. We choose to aggregate over all non-milk outputs as our interest is primarily in the deregulation effects on milk production. Further the chosen functional form demands the inclusion of a large number of cross terms. This practice is in line with previous contributions (see e.g. Ooms and Perlings, 2005). As inputs land, labor, capital (as an aggregate for machinery, buildings, and stocks), cows, fodder, energy, and veterinary expenses are considered beside time related and quota deregulation related individual and cross terms. Finally off farm income, the age of the farmer, the share of rented land, the share of hired labor, the debt to equity ratio, and the debt to total assets ratio are included as control variables. Soil quality differences as well as climatic variations can be neglected for homogenous small countries as Denmark. Various auxiliary regressions including such variables confirmed this assumed insignificance (see also Rasmussen/Nielsen, 1985 and Danish Milk Board, 2005). Ooms and Perlings (2005) assume significant endogeneity with respect to some production inputs. However, using a Hausman test formula such endogeneity could not be verified for none of the inputs used in this study (the null hypothesis of complete exogenous determination could not be rejected at the 10% level of significance). Some authors have suggested that the estimates of the parameters of distance functions may be affected by simultaneous equation bias (Sickles et al., 1996; Atkinson et al., 1999; Alvarez, 2000). However, Coelli (2000) shows that consistent estimates of the input distance function can be obtained as by infering the cost-minimizing first order conditions only ratios of input quantities remain in the distance function.

6. Results and Discussion

We estimated an unrestricted and restricted model for a sample of organic farms as well as for a sample of conventional farms, i.e. nearly 300 parameters were estimated. Due to space limitations we do not report the individual coefficients here but they can be obtained from the authors. The standard deviations of the estimates indicate that nearly all of them are statistically significant. The numerical standard errors for the approximation of $E(\beta | y)$ indicate the accuracy of the estimates based on 50,000 replications and 5,000 burn ins. The results for 'Geweke's CD', comparing the estimate of $E(\beta | y)$ based on the first replications (after the burn-ins) to that based on the last replications, suggest that the effect of the initial condition has vanished and an adequate number of draws have been taken for all parameters etsimated. Noting that CD is asymptotically standard normal, it can be concluded that convergence of the algorithms has been achieved as the highest CD value found is 1.79 in absolute value. Finally, as assumed, the unrestricted models showed to be inconsistent with respect to the underlying theoretical requirements of monotonicity, concavity in inputs and quasi-concavity in outputs. However, as different contributions concluded in a trade-off between statistical significance and theoretical consistency (see Terrell, 1996; Sauer, 2006) we report the results for both model specifications.

Figure 3 Marginal density of observed milk prices and estimated shadow prices

Table 1 Observed milk price, shadow milk price, and output specific allocative efficiency (organic)

Table 2 Observed milk price, shadow milk price, and output specific allocative efficiency (conventional)

Figure 3 shows the marginal density of the observed milk price and the estimated shadow milk price for both organic and conventional farms. The means of the prices per year and the 99%-credible intervals are reported in tables 1 and 2.[6] Further the output specific allocative efficiency for organic and conventional milk production on farm level is reported. This measure refers to the part of the individual farm's allocative efficiency due to output production decisions (i.e. the relative quantities produced and the different input

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[6] Following the common definition of $\Pr_{\Theta|X=x}\left(u(x) < \Theta < v(x)\right) = 1-\alpha$ for α = 0.99 and the unknown true value of θ.

ratios employed). Accordingly, the gap between the shadow price and the observed market price for milk on farm level has been reduced during the time period investigated, especially in the subperiod following the quota deregulation in 1998. These estimates reveal three crucial findings: 1) the allocative efficiency for the production of organic and conventional milk increased in the period investigated by up to 30% (organic) and 27% (conventional) respectively; 2) the increase in efficiency in the period after the deregulation of the quota exchange mechanism has been relatively larger than in the period before the quota deregulation for both forms of milk production; and 3) the increase in allocative efficiency after the implementation of the quota deregulation has been relatively larger for organic milk production (by up to 3.5%). Figure 4 illustrates these developments of output specific allocative efficiency on the individual farm level. Figure 5 shows the development of the allocative efficiency with respect to the overall market for milk in Denmark, i.e. with respect to the different forms of milk produced. It is evident that both models suggest a higher price for organic milk in the period after the deregulation (i.e. a shadow price ratio of > 1) but also a diminishing gap between the estimated shadow price ratio and the observed price ratio in the period after the deregulation. This has been found to be more pronounced for the unrestricted model as the restricted price ratio estimates are closer to the oberved price ratio over the whole period investigated. The unrestricted models suggest an increase in allocative efficiency on the market level of about 5.5%.

Figure 4 Output specific allocative efficiency on farm level

Figure 5 Shadow and observed price ratios on market level

The allocative inefficiency with respect to the production of organic or conventional milk on farm level can be interpreted as a proxy for existing market distortions (see Lau and Yotopoulos, 1971 and Lovell and Sickles, 1983). If we assume that those market distortions are predominantly due to the quota regime in place based on the current CAP framework, then the difference between the observed and the estimated shadow price for milk can be interpreted as the maximum shadow price per unit milk quota used (here kg organic or conventional milk). Figure 6 shows these maximum average quota prices per year and kg of organic or conventional milk produced for the post deregulation period. In accordance with our previous findings these maximum shadow quota prices decrease over the period investigated as well as experience a relatively larger decrease in the post deregulation period (of up to 51% for organic and up to 46% for conventional milk).

Figure 6 Quota clearing price and average quota shadow price

Technical efficiency estimates are shown in table A3 in the appendix. Following the chosen approach of a fixed effects model we report the mean technical efficiency per year for the sample of organic as well as the sample of conventional milk farms. Beside the relatively high level of technical efficiency no significant differences between organic and conventional milk farms were found for the period investigated. Both models suggest 2002 as the year with the highest technical efficiency for both farm types. In 2005 a mean efficiency value of about 0.989 for organic farms and of about 0.992 for conventional farms is reported by the unrestricted model and a value of about 0.924 and 0.927 by the restricted model. No significant difference in the mean technical efficiency before 1998 and after could be found for the two samples.

Given our research hypotheses more interesting are the empirical findings with respect to the substitutability between milk and non-milk output on farm level as well as organic and conventional milk on sector level. Our estimated substitution measures for organic milk and (non-organic) non-milk output and conventional milk and non-milk output are illustrated in figures 7 and 8. A value >1 (<1) implies relative difficulty (ease) in y_m and y_{nm} substitution. The individual values per year are summarized by table A4 in the appendix. Accordingly, the marginal rate of transformation for the different years reflects a decreasing substitutability between organic milk and non-milk output as well as between conventional milk and non-milk output ($subst_{om,nm}$ and $subst_{m,nm}$ are increasing). Beside others this implies that after the invention of the quota exchange it has become increasingly difficult to switch from organic milk production to the production of other output and vice versa. Hence, the regulatory change with respect to the allocation of milk quota led to a relative shift in the output composition on farm level in favor of the production of organic milk and in disfavor of other output produced. Consequently, the probability of farms exiting organic milk production has been decreased during these years. However, on the other hand, the probability of farms entering organic milk production from non-milk production has been also decreased during these years.

Figure 7 Substitutability between milk and other output

Figure 8 Substitutability between organic and conventional milk

On the level of the milk sector we found that the marginal rate of transformation for the different years indicates an increasing substitutability between organic milk and conventional milk output ($subst_{om,m}$ is decreasing). Hence, farmers have experienced decreasing costs of switching between these two forms of milk production over the years. Figure 8 shows that this has been especially true for the post deregulation period where the value of the substitutability measure dropped by nearly 36% until 2005. Beside others this implies that after the invention of the quota exchange it has become increasingly easy to switch from conventional milk production to organic milk production and vice versa. Hence, the mobility in the milk sector has been increased as the costs of switching has been decreased. Consequently, the regulatory change with respect to the allocation of milk quota led to a relative shift of the PPF, or output composition on sector level, in favor of the production of organic milk and in disfavor of conventional milk produced. This implies that the probability of farms entering organic milk production has been increased during these years and corresponds well to the observed entry and exit behaviour of organic farms over the period investigated: The number of organic milk farms drastically increased up to 2000/01 and during recent years organic production declined at a significant lower rate than conventional production (Danish Milk Board, 2006).

These results are backed up by the empirical findings regarding a potential deregulation bias with respect to different outputs and inputs. These can be considered as relative measures for the productive impact of the quota deregulation (see tables 3 and 4). Both model specifications (unrestricted and restricted) indicate that a change in quota regulation generated a change in the slope of the PPF implying for constant prices a movement around it. The regulatory change with respect to the allocation of milk quota led to a relative shift of the PPF in favor of the production of organic milk (B_{om}=0.030 and 0.046) and in disfavor (or to the expense) of other output produced (B_{nm}=-0.004 and 0.021). Hence, the probability of organic market exit has been reduced in the post deregulation period. On the other hand our estimates suggest that the regulatory change with respect to the allocation of milk quota led to a relative shift of the PPF in disfavor of the production of conventional milk (B_{om}=-0.847 and -1.200) and in disfavor (or to the expense) of other output produced (B_{nm}=-0.509 and -0.495). However, the negative productive effect on milk production has been relatively stronger than on non-milk output. Hence, on the milk sector level this can be interpreted as an increasing probability of conventional farms entering organic milk production in the post deregulation period. Both models further suggest that the regulatory change with respect to the allocation of milk quota led to an increasing use of the inputs land as well as a decreasing use of the inputs capital and energy for organic milk producers. For conventional milk producers both models suggest an increasing use of land, labor and veterinary expenses as well as a decreasing use of capital, fodder and energy in the post deregulation period.

Table 3 Deregulation biases for organic farms

Table 4 Deregulation biases for conventional farms

Given the reported estimates we can conclude that both our initially formulated research hypotheses can not be rejected by our empirical analysis: Hence, a deregulation in the milk quota allocation system had indeed positive effects on the milk farms' efficiency over time. Further, the deregulation in the milk quota allocation system had significant effects on the farms production structure, namely the output composition based on the substitutability between milk and non-milk output as well as organic and non-organic output. Finally, it can be derived that in the post deregulation period the probability of farms entering organic milk production has been significantly increased and the probability of farms exiting organic milk production has been significantly decreased.

Contrasting our results with previous findings the following points have to be discussed: In general economists agree that transferable quotas are more efficient than non transferable quotas as they allow for cost minimisation on producer level and hence the maximisation of producer gains given product price and production quota (Alston, 1981 and 1992; Harvey, 1984; Guyomard et al., 1996). Further, marketable quotas should lead to a more efficient resource allocation by a quota transfer from high to low marginal cost producers. However, transferable quotas do not eliminate welfare losses by suboptimal marginal social cost pricing (see Guyomard et al., 1996). Finally, the costs of quotas are mainly borne by the consumer and new market entrants. The latter being confronted with either higher direct or indirect costs of market entry. Our empirical analysis confirmed these general economic considerations showing that a more market oriented quota allocation mechanism leads to higher efficiency in the production of organic and conventional milk as well as a higher efficiency with respect to the production possibility frontier on the market level. Further our analysis revealed that the costs for entering organic milk production have decreased after the deregulation of the quota allocation mechanism. Our results confirm the conclusions drawn by Stefanou et al. (1992) suggesting that the milk producers' responses to policy changes were driven by changes in the use of variable inputs indicated by the bias measures especially with respect to land and capital. In addition to the findings by Boots et al. (1997) our results suggest profit increases by efficiency gains for both organic and conventional milk producers as a consequence of the introduction of a more flexible quota trading mechanism. However, the productive effects by deregulation proved to be in favor of organic production and in disfavor of conventional production. Corresponding to Colman (2000) we find that a deregulation in the quota allocation mechanism is leading to a higher amount of quota transferred to more efficient producers shown by the relative allocative efficiency as well as the substitution and bias measures obtained. Finally, our analysis somehow contradicts the findings by Alvarez et al. (2006) who question the success of policy measures to allocate milk quotas to efficient farms. Despite the fact that a single-bid system still creates market distortions (see Bogetoft et al., 2003), we found, that the deregulation measures with respect to the milk quota allocation mechanism have been successful in allocating milk quotas to more efficient farms leading to an increase in overall market efficiency over time.

7. Conclusions

Milk quota trading rules differ across EU member countries. In Denmark a biannual milk quota exchange was set up in December 1997 to promote a more efficient reallocation of milk quotas as well as to reduce transaction costs related to the trading of quotas. The preceeding analysis uses two comprehensive panel data sets on organic and conventional milk farms for the period 1986 to 2005 to disentangle the effects of the introduction of an increased quota transferability on the production structure of those farms as well as the probability of market entry and exit. Bayesian estimation techniques are used to estimate an input oriented generalized Leontief distance function as well as a curvature constrained specification. Based on our empirical analysis we can conclude that our initially formulated research hypotheses can not be rejected for the two samples: Hence, a deregulation in the milk quota allocation system had indeed positive effects on the milk farms efficiency over time. Further, the deregulation in the milk quota allocation system had significant effects on the farms' production structure, namely the output composition based on the substitutability between milk and non-milk output as well as organic and non-organic output. Finally, it can be derived that in the post deregulation period the probability of farms entering organic milk production from conventional milk production has been significantly increased and the probability of farms exiting organic milk production to produce other non-organic output has been significantly decreased. However, the results of our study are subject to some qualifications. The model is based on production side factors only, hence, non-productive factors for the decision to enter or exit the organic or conventional milk market are not captured by our analysis. Such factors could be general environmental values or beliefs and anticipated expectations with respect to the future development of organic versus conventional milk production as well as a multitude of other individual factors. Future research should also focus on this part of the decision of getting engaged in organic milk farming or not by regressing on adequate survey data.

The successful transition of the phasing out of the milk quotas in 2014/15 is a crucial item on the CAP Health Check agenda. Different options are currently discussed ranging from the 'big bang approach' - a once-off increase in each member state's quota in 2008/09 in addition to the already foreseen increase under the Mid Term Review and the removal of milk quotas entirely in 2015 – to the 'soft landing approach' – a series of incremental annual increases in the period 2008/09 to 2014/15 and a final removal of milk quotas entirely in 2015 (Teagasc, 2007). Our empirical findings show that the gradual deregulation of a quota allocation system based on decentralised quota bids can lead milk producers to an efficient adjustment of their production structure. Hence, a third policy option could consist of a complete introduction of a milk quota allocation system in the short run based on single or multiple quota price bids by individual producers. This could be linked to incremental quota increases for organic and/or conventional milk production per country and year distributed via the bidding mechanism in place. After a transition period of 5-10 years in which this system will have led to a more efficient market oriented at the overall PPF frontier a total phasing out of the milk quota system could be agreed on. Future research should focus on quantitatively analysing the implications of such a scenario with respect to the development of milk quantity and price as well as organic and conventional production.

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Appendix

Tables/Figures

Figure 1 The Danish Milk Quota Exchange Mechanism

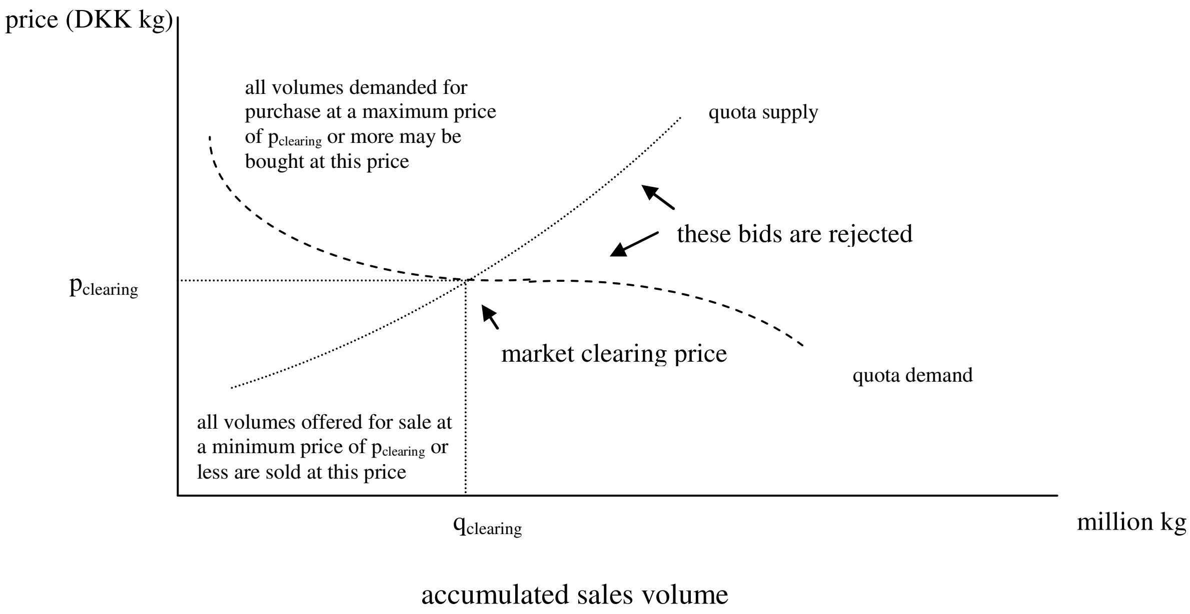


Figure 2 Reallocation and Market Clearing Prices 1997 to 2005

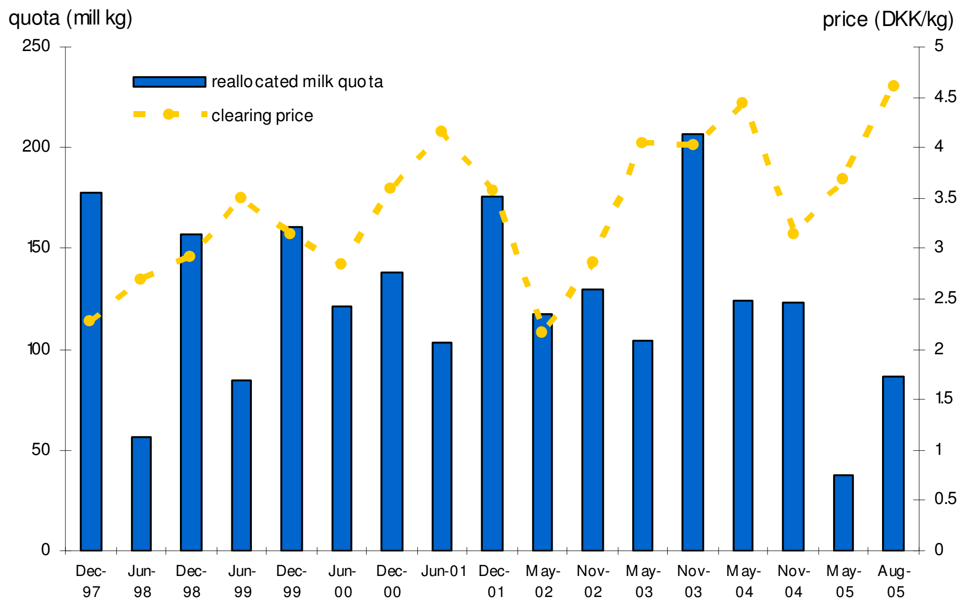
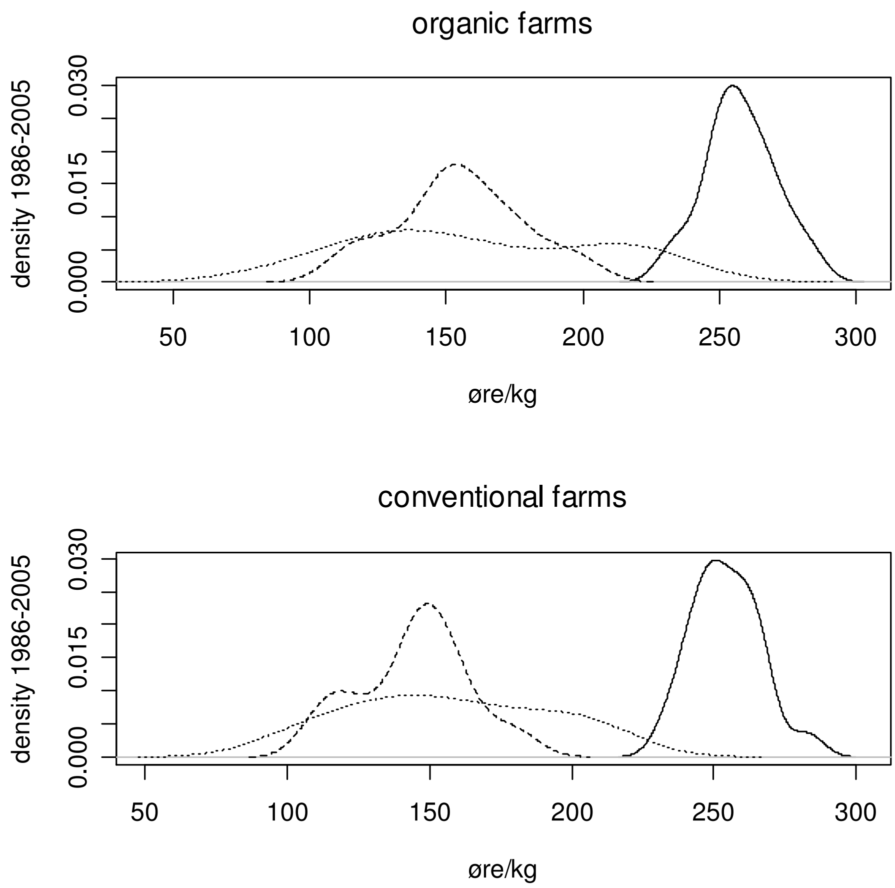


Figure 3 Marginal density of observed milk prices and estimated shadow prices



solid line: observed market price
dashed line: estimated shadow price unrestricted model
dotted line: estimated shadow price restricted model

Table 1 - Observed milk price, estimated shadow prices, and estimated output specific allocative efficiency for organic farms

					unrestricted model					*restricted model*				
year	milk price (øre/kg)	stddev	99%-credible interval		shadow price (øre/kg)	stddev	99%-credible interval		allocative efficiency	shadow price (øre/kg)	stddev	99%-credible interval		allocative efficiency
1986	232.803	4.213	228.702	236.904	123.922	8.532	115.616	132.229	0.532	122.638	25.887	97.435	147.841	0.527
1987	235.734	6.221	229.677	241.791	115.856	15.806	100.468	131.244	0.491	110.051	16.133	94.345	125.757	0.467
1988	255.757	8.712	247.276	264.239	114.240	2.613	111.697	116.784	0.447	103.643	8.889	94.989	112.297	0.405
1989	266.914	20.985	246.483	287.344	158.472	6.381	152.259	164.685	0.594	131.854	20.289	112.102	151.607	0.494
1990	268.252	37.209	245.662	290.843	131.413	1.484	130.512	132.314	0.490	84.920	2.577	83.355	86.484	0.317
1991	263.383	16.003	253.926	272.840	147.189	3.057	145.383	148.996	0.559	123.153	15.863	113.779	132.527	0.468
1992	259.753	16.880	249.778	269.728	144.847	3.080	143.027	146.667	0.558	139.944	13.893	131.734	148.154	0.539
1993	248.536	15.372	239.682	257.389	155.454	4.353	152.946	157.961	0.625	134.913	18.675	124.157	145.670	0.543
1994	249.428	27.342	235.616	263.239	150.208	3.813	148.281	152.134	0.602	138.580	7.730	134.675	142.485	0.556
1995	248.068	27.442	234.205	261.930	143.602	2.096	142.543	144.660	0.579	150.550	5.405	147.820	153.281	0.607
1996	248.093	27.815	234.305	261.882	170.928	3.806	169.042	172.815	0.689	166.464	22.002	155.557	177.371	0.671
1997	250.482	29.972	235.341	265.622	154.620	3.559	152.822	156.418	0.617	156.432	3.482	154.673	158.191	0.625
1998	255.663	27.929	240.978	270.347	158.571	0.931	158.082	159.060	0.620	169.008	10.681	163.392	174.624	0.661
1999	256.248	12.191	249.700	262.795	195.292	14.342	187.589	202.995	0.762	214.081	26.349	199.929	228.233	0.835
2000	266.976	8.377	262.571	271.380	148.740	0.991	148.219	149.261	0.557	215.301	20.345	204.604	225.998	0.806
2001	278.627	14.987	270.204	287.051	197.910	7.109	193.914	201.905	0.710	226.819	23.910	213.379	240.258	0.814
2002	283.499	11.632	279.693	287.304	173.124	5.624	171.284	174.964	0.611	225.568	16.258	220.249	230.886	0.796
2003	272.387	13.015	268.095	276.679	162.185	4.039	160.853	163.517	0.595	216.514	13.114	212.189	220.839	0.795
2004	259.499	9.494	256.259	262.738	174.560	5.966	172.524	176.595	0.673	188.052	17.124	182.210	193.894	0.725
2005	253.784	11.511	249.749	257.819	180.581	5.074	178.803	182.359	0.712	207.334	16.898	201.410	213.257	0.817

Table 2 - Observed milk price, estimated shadow prices, estimated output specific allocative efficiency for conventional farms

					unrestricted model					*restricted model*				
year	milk price (øre/kg)	stddev	99%-credible interval		shadow price (øre/kg)	stddev	99%-credible interval		allocative efficiency	shadow price (øre/kg)	stddev	99%-credible interval		allocative efficiency
1986	242.879	25.750	217.810	267.948	118.426	4.343	114.198	122.655	0.488	123.248	10.528	112.998	133.498	0.507
1987	244.485	26.283	218.897	270.073	112.285	3.872	108.515	116.054	0.459	111.611	10.054	101.823	121.400	0.457
1988	266.075	31.557	235.352	296.799	110.96	3.740	107.319	114.601	0.417	105.83	9.865	96.226	115.435	0.398
1989	282.761	33.968	249.690	315.832	146.682	6.514	140.341	153.024	0.519	135.722	7.834	128.096	143.349	0.480
1990	265.919	32.318	246.298	285.541	127.938	5.081	122.990	132.885	0.481	99.4593	6.446	93.183	105.735	0.374
1991	267.612	30.333	249.687	285.536	144.275	8.345	136.151	152.400	0.539	125.524	9.310	116.460	134.588	0.469
1992	263.292	30.563	245.231	281.353	121.052	4.997	116.187	125.916	0.460	142.003	7.777	134.431	149.575	0.539
1993	262.388	30.625	244.749	280.028	145.856	5.600	140.403	151.308	0.556	137.687	9.971	127.979	147.394	0.525
1994	257.828	29.850	242.749	272.907	149.288	7.413	142.071	156.505	0.579	142.726	9.927	133.061	152.391	0.554
1995	248.735	29.000	234.085	263.385	141.056	5.323	135.873	146.238	0.567	151.985	9.332	142.900	161.070	0.611
1996	251.153	30.385	236.090	266.215	159.261	6.742	152.697	165.825	0.634	166.296	11.512	155.088	177.504	0.662
1997	251.897	29.093	237.200	266.594	150.841	5.697	145.295	156.387	0.599	156.715	10.853	146.148	167.281	0.622
1998	253.946	28.877	238.763	269.130	152.631	6.731	146.077	159.184	0.601	168.664	10.962	157.991	179.336	0.664
1999	242.522	28.967	226.964	258.080	182.292	18.364	164.414	200.170	0.752	215.304	13.662	202.003	228.604	0.888
2000	247.909	29.153	232.581	263.237	134.637	5.065	129.706	139.568	0.543	197.09	14.189	183.276	210.904	0.795
2001	259.459	30.255	242.453	276.465	174.09	7.879	166.420	181.761	0.671	207.647	24.727	183.573	231.721	0.800
2002	257.084	31.343	246.831	267.338	159.856	6.492	153.535	166.177	0.622	202.866	25.887	177.663	228.069	0.789
2003	247.96	27.678	238.832	257.088	145.256	4.388	140.984	149.528	0.586	193.891	24.037	170.489	217.293	0.782
2004	237.863	29.165	227.912	247.813	153.495	3.927	149.672	157.318	0.645	169.102	9.036	160.304	177.899	0.711
2005	233.614	30.750	222.835	244.393	161.49	8.118	153.587	169.394	0.691	182.399	26.564	156.537	208.261	0.781

Figure 4 – Output specific allocative efficiency on farm level (annual means)

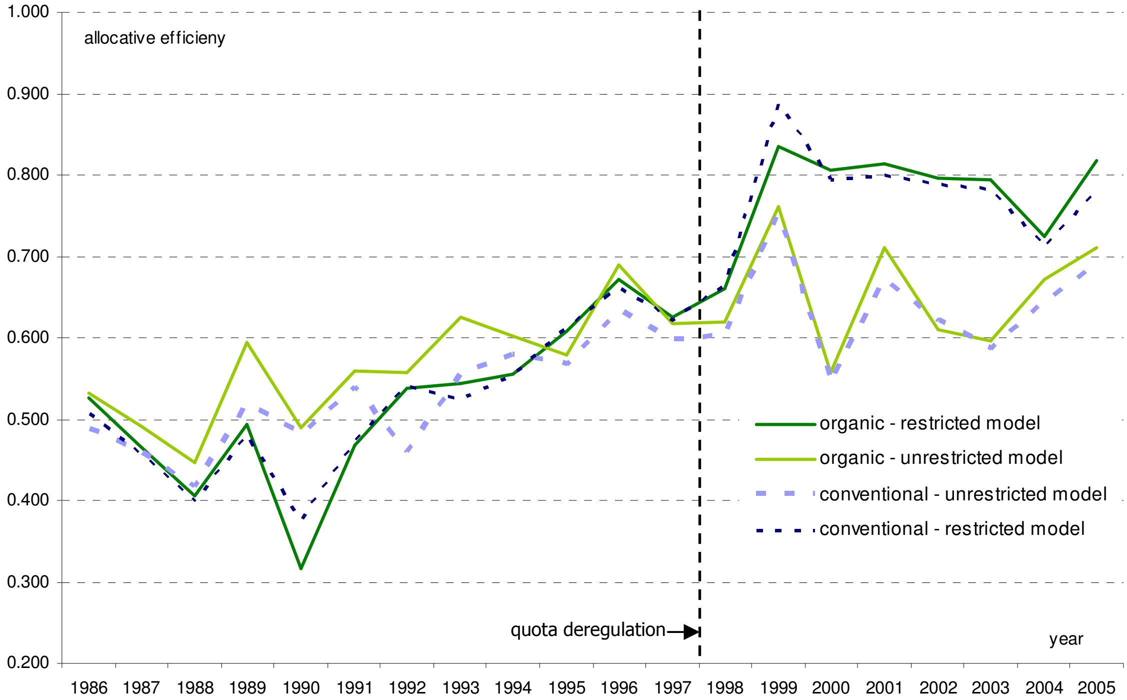


Figure 5 – Shadow and observed price ratios on market level

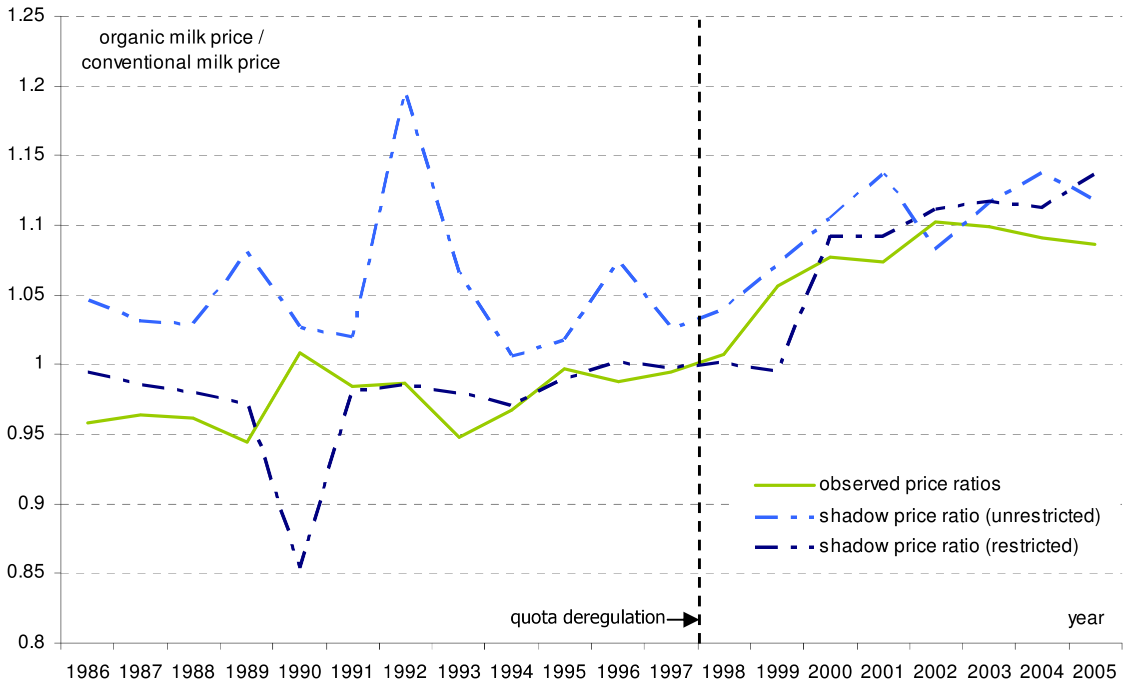


Figure 6 – Quota clearing price and average quota shadow price

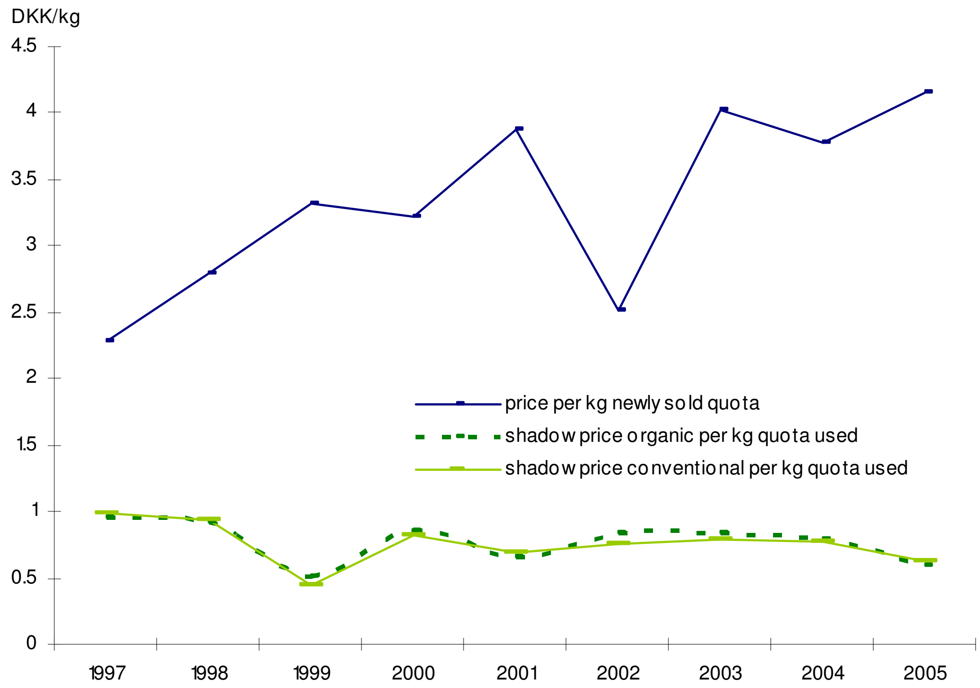


Figure 7 – Substitutability between milk and other output

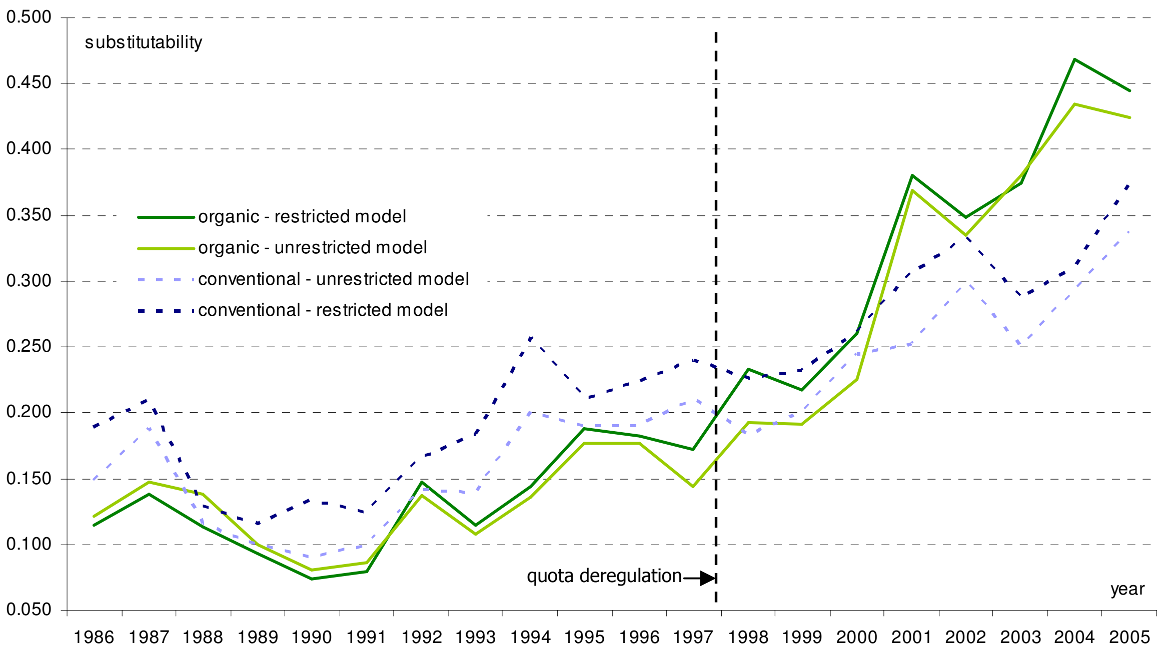


Figure 8 – Substitutability between organic and conventional milk

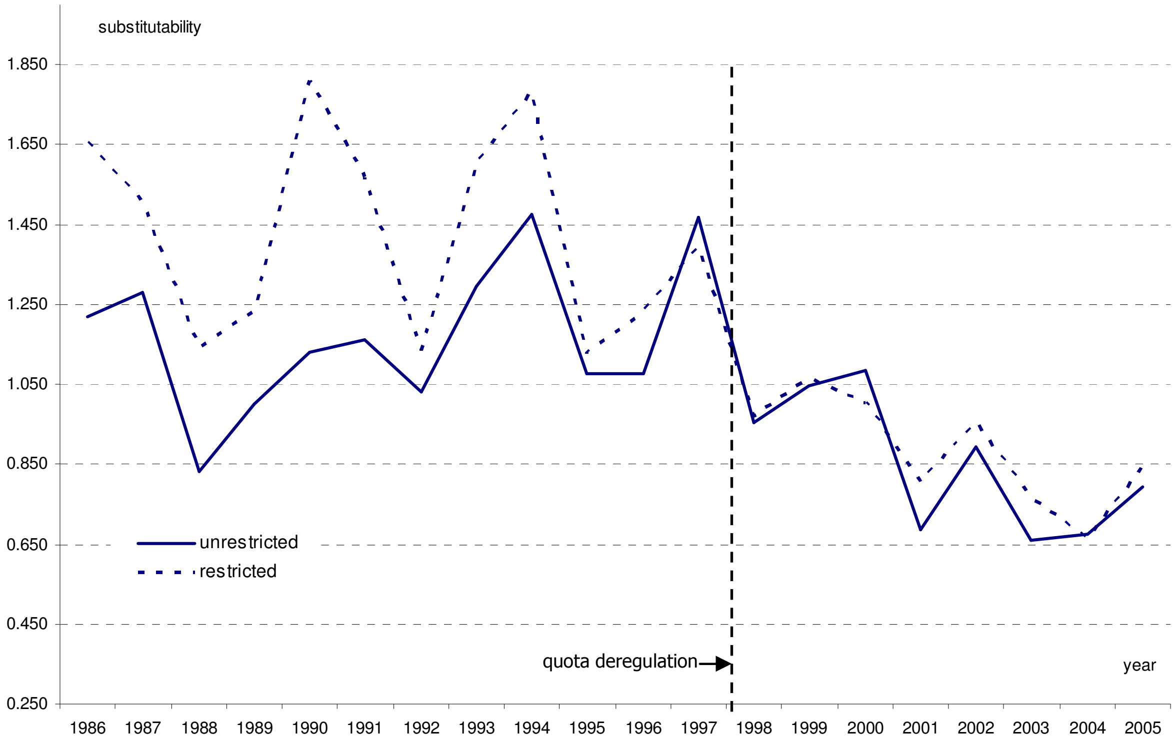


Table 3 – Deregulation biases for organic farms

	unrestricted model				*restricted model*			
Outputs	B_{kR}	stddev	99%-credible interval		B_{kR}	stddev	99%-credible interval	
organic milk	0.030	0.001	-0.030	-0.030	0.046	0.002	-0.046	-0.045
other output	-0.004	0.000	0.004	0.004	0.021	0.001	-0.022	-0.021
inputs	B_{iR}	stddev	99%-credible interval		B_{iR}	stddev	99%-credible interval	
land	0.456	0.009	-0.457	-0.455	0.255	0.011	-0.256	-0.254
labor	-0.676	0.024	0.673	0.679	1.305	0.053	-1.311	-1.299
capital	-0.841	0.024	0.838	0.844	-2.057	0.053	2.051	2.063
fodder	-0.729	0.027	0.725	0.732	0.506	0.054	-0.513	-0.500
energy	-1.133	0.024	1.130	1.136	-0.893	0.022	0.890	0.895
veterinary	-0.470	0.023	0.467	0.473	0.959	0.197	-0.982	-0.936

Table 4 – Deregulation biases for conventional farms

	unrestricted model				*restricted model*			
outputs	B_{kR}	stddev	99%-credible interval		B_{kR}	stddev	99%-credible interval	
milk	-0.847	0.001	0.847	0.847	-1.200	0.165	1.181	1.219
other output	-0.509	0.023	0.506	0.512	-0.495	0.000	0.494	0.495
inputs	B_{iR}	stddev	99%-credible interval		B_{iR}	stddev	99%-credible interval	
land	0.166	0.026	-0.168	-0.163	0.619	0.006	-0.620	-0.618
labor	0.811	0.023	-0.814	-0.808	0.813	0.072	-0.821	-0.804
capital	-0.086	0.023	0.083	0.088	-0.054	0.017	0.052	0.056
fodder	-0.425	0.002	0.424	0.425	-0.510	0.084	0.501	0.520
energy	-0.651	0.023	0.649	0.654	-0.628	0.002	0.628	0.628
veterinary	0.127	0.024	-0.130	-0.124	0.121	0.001	-0.121	-0.121

Table A1 – Descriptive statistic organic sample (n = 493)

variable	*mean*	*stdev*	*min*	*max*
organic milk (in '000 DKK)	1707.189	806.867	0.1	4273.8
other (non-organic) output (in '000 DKK)	644.984	321.221	52.4	2303.3
land (in ha)	114.463	56.552	12.6	479
labor (in '000 h)	4779.018	1357.991	1500	10100
capital (machinery, buildings, stocks, in '000 DKK)	9997.568	6068.41	1728.2	32414.1
cows (n)	91	37	15	223
fodder (in '000 DKK)	447.001	264.924	12.3	2096.9
energy (in MWh)	64.329	40.533	7.991	337.57
veterinary expenses (in '000 DKK)	47.775	30.474	3.249	185.499
off farm income (in '000 DKK)	890.269	453.321	0	2480.75
age (in years)	44	7.742	23	65
share of rented land	0.324	0.206	0	1
share of hired labor	0.355	0.204	0	0.904
leverage ratio 1 (debt/equity in %)	291.536	74.506	71.912	433.792
leverage ratio 2 (debt/total assets in %)	65.15	16.65	16.07	96.94

1: all monetary values are deflated to the base year 1986; the producer price index was used for agricultural materials; price index for milk and dairy products; price index for machinery and buildings (sources: OECD, Danmark Statistic, FOI).

Table A2 – Descriptive statistic conventional sample (n = 2938)

variable	*mean*	*stdev*	*min*	*max*
milk (in '000 DKK)	1095.584	626.006	6.3	4068.5
other output (in '000 DKK)	574.4515	549.8222	8.3	7735.9
land (in ha)	73.592	43.621	14.3	270.3
labor (in '000 h)	4265.709	1587.31	910	12900
capital (machinery, buildings, stocks, in '000 DKK)	5665.542	4716.469	712.969	3.74e+04
cows (n)	66	33	11	221
fodder (in '000 DKK)	371.153	294.736	8.013	3134.535
energy (in MWh)	36.223	27.199	2.574	274.729
veterinary expenses (in '000 DKK)	37.568	32.331	0	469.777
off farm income (in '000 DKK)	541.3911	385.9189	0	2948.525
age (in years)	46	8.484	24	77
share of rented land	0.227	0.200	0	1
share of hired labor	0.264	0.218	0	1.2
leverage ratio 1 (debt/equity in %)	292.732	75.702	73.108	434.988
leverage ratio 2 (debt/total assets in %)	66.346	17.846	17.266	98.136

1: all monetary values are deflated to the base year 1986; the producer price index was used for agricultural materials; price index for milk and dairy products; price index for machinery and buildings (sources: OECD, Danmark Statistic, FOI).

Table A3 – Estimated average technical efficiencies per year

year	*organic farms*								*conventional farms*							
	unrestricted model				*restricted model*				*unrestricted model*				*restricted model*			
	technical efficiency	stddev	99%-credible interval		technical efficiency	stddev	99%-credible interval		technical efficiency	stddev	99%-credible interval		technical efficiency	stddev	99%-credible interval	
1986	0.915	0.023	0.912	0.918	0.934	0.071	0.926	0.943	0.899	0.023	0.896	0.901	0.918	0.026	0.915	0.921
1987	0.918	0.024	0.915	0.920	0.987	0.073	0.979	0.996	0.903	0.014	0.901	0.904	0.972	0.040	0.968	0.977
1988	0.915	0.020	0.912	0.917	0.958	0.069	0.950	0.966	0.901	0.027	0.898	0.904	0.944	0.012	0.943	0.945
1989	0.913	0.014	0.912	0.915	0.963	0.069	0.955	0.970	0.900	0.023	0.898	0.903	0.950	0.028	0.946	0.953
1990	0.896	0.021	0.893	0.898	0.929	0.065	0.922	0.937	0.884	0.023	0.881	0.887	0.917	0.118	0.904	0.931
1991	0.957	0.022	0.954	0.959	0.928	0.072	0.920	0.937	0.945	0.023	0.943	0.948	0.917	0.200	0.894	0.941
1992	0.917	0.024	0.914	0.920	0.955	0.068	0.947	0.963	0.907	0.022	0.904	0.910	0.945	0.065	0.937	0.952
1993	0.920	0.025	0.917	0.922	0.939	0.069	0.930	0.947	0.911	0.023	0.908	0.913	0.930	0.010	0.928	0.931
1994	0.915	0.024	0.913	0.918	0.952	0.067	0.944	0.960	0.907	0.023	0.905	0.910	0.944	0.096	0.933	0.955
1995	0.899	0.022	0.896	0.901	0.862	0.071	0.854	0.871	0.892	0.022	0.889	0.894	0.855	0.047	0.850	0.861
1996	0.875	0.023	0.873	0.878	0.980	0.061	0.973	0.987	0.869	0.022	0.867	0.872	0.974	0.229	0.947	1.000
1997	0.856	0.023	0.853	0.858	0.849	0.069	0.841	0.857	0.851	0.024	0.848	0.853	0.844	0.059	0.837	0.850
1998	0.858	0.024	0.855	0.861	0.933	0.069	0.925	0.941	0.854	0.024	0.851	0.857	0.929	0.034	0.925	0.933
1999	0.878	0.024	0.875	0.881	0.970	0.065	0.963	0.978	0.875	0.045	0.870	0.880	0.967	0.000	0.967	0.967
2000	0.876	0.023	0.874	0.879	0.939	0.066	0.932	0.947	0.874	0.032	0.871	0.878	0.937	0.101	0.926	0.949
2001	0.883	0.024	0.881	0.886	0.896	0.069	0.888	0.904	0.882	0.031	0.879	0.886	0.895	0.077	0.886	0.904
2002	1.000	0.024	0.997	1.003	1.000	0.066	0.992	1.008	1.000	0.026	0.997	1.003	1.000	0.003	1.000	1.000
2003	0.863	0.022	0.860	0.865	0.825	0.069	0.817	0.833	0.864	0.023	0.861	0.866	0.826	0.027	0.823	0.829
2004	0.898	0.023	0.896	0.901	0.802	0.065	0.795	0.810	0.900	0.025	0.897	0.903	0.804	0.038	0.800	0.809
2005	0.989	0.024	0.986	0.991	0.924	0.067	0.916	0.932	0.992	0.025	0.989	0.995	0.927	0.007	0.926	0.928

Table A4 – Substitutability measures

year	*organic farms (organic milk – non-organic other output)*								*conventional farms (conventional milk – other output)*							
	unrestricted model				*restricted model*				*unrestricted model*				*restricted model*			
	sub_{mnm}	stddev	99%-credible interval		sub_{mnm}	stddev	99%-credible interval		sub_{mnm}	stddev	99%-credible interval		sub_{mnm}	stddev	99%-credible interval	
1986	0.122	0.009	0.112	0.131	0.114	0.009	0.105	0.123	0.148	0.008	0.140	0.155	0.189	0.013	0.176	0.202
1987	0.147	0.016	0.132	0.162	0.139	0.015	0.124	0.154	0.188	0.020	0.169	0.207	0.209	0.010	0.200	0.219
1988	0.139	0.006	0.133	0.145	0.113	0.007	0.106	0.120	0.116	0.003	0.112	0.119	0.129	0.004	0.125	0.133
1989	0.100	0.008	0.092	0.108	0.093	0.008	0.086	0.101	0.100	0.005	0.095	0.106	0.115	0.008	0.108	0.123
1990	0.080	0.005	0.077	0.083	0.074	0.004	0.071	0.076	0.091	0.006	0.087	0.095	0.133	0.013	0.126	0.141
1991	0.086	0.007	0.082	0.090	0.080	0.007	0.076	0.083	0.100	0.007	0.096	0.104	0.125	0.010	0.119	0.131
1992	0.137	0.009	0.132	0.143	0.147	0.011	0.140	0.153	0.142	0.013	0.134	0.149	0.167	0.016	0.157	0.176
1993	0.108	0.007	0.103	0.112	0.114	0.007	0.110	0.118	0.140	0.011	0.133	0.146	0.183	0.014	0.175	0.191
1994	0.136	0.008	0.132	0.139	0.144	0.011	0.139	0.149	0.200	0.010	0.195	0.205	0.256	0.018	0.248	0.265
1995	0.177	0.013	0.170	0.183	0.187	0.015	0.180	0.195	0.190	0.012	0.184	0.196	0.211	0.015	0.204	0.219
1996	0.177	0.012	0.171	0.182	0.182	0.014	0.175	0.189	0.190	0.015	0.183	0.197	0.224	0.018	0.215	0.233
1997	0.143	0.011	0.138	0.149	0.172	0.011	0.167	0.178	0.211	0.010	0.206	0.216	0.240	0.015	0.233	0.248
1998	0.192	0.026	0.178	0.206	0.233	0.028	0.218	0.248	0.184	0.012	0.177	0.190	0.226	0.015	0.218	0.234
1999	0.191	0.014	0.184	0.198	0.218	0.014	0.210	0.225	0.200	0.015	0.192	0.208	0.232	0.020	0.222	0.243
2000	0.226	0.011	0.220	0.231	0.260	0.010	0.255	0.265	0.245	0.019	0.235	0.254	0.261	0.030	0.245	0.277
2001	0.369	0.057	0.337	0.401	0.380	0.058	0.348	0.412	0.253	0.017	0.243	0.263	0.306	0.056	0.275	0.338
2002	0.335	0.019	0.328	0.341	0.348	0.019	0.342	0.355	0.299	0.031	0.289	0.309	0.333	0.033	0.322	0.344
2003	0.380	0.053	0.362	0.397	0.375	0.056	0.356	0.393	0.250	0.029	0.241	0.260	0.287	0.048	0.272	0.303
2004	0.434	0.052	0.417	0.452	0.468	0.054	0.450	0.487	0.293	0.029	0.283	0.303	0.312	0.039	0.298	0.325
2005	0.424	0.032	0.413	0.435	0.445	0.033	0.433	0.456	0.337	0.016	0.331	0.342	0.375	0.020	0.368	0.382