Revised version presented at University of California, Davis, February 24, 2015

Component Supply Response in Dairy Production

Daniel Muluwork Atsbeha[1], Dadi Kristofersson[2] and Kyrre Rickertsen[1]

Abstract

Under multiple component pricing schemes, the price of milk depends on its content of components such as fat, protein, and lactose. A theoretical model for component supply under a tradable quota regime is developed. A system of component supply and input demand equations is derived and estimated for a panel of Icelandic dairy farms. Overall, results show that milk component supply responds to price incentives in the short run despite rigidities in component production technology. The own-price supply elasticities of fat and protein are 0.26 and 0.23 in the quota milk market and 0.02 and 0.25 in the surplus milk market.

Keywords: dairy production, milk composition, milk supply response, multiple component pricing, profit function

JEL classification: D22, Q12

[1] School of Economics and Business, Norwegian University of Life Sciences

[2] Department of Economics, University of Iceland

The authors gratefully acknowledge The Agricultural Economics Institute, Reykjavik, The Farmers’ Association of Iceland, and MS Icelandic Dairies for providing data.

1. Introduction

The value of milk in dairy processing depends on its composition. Since the introduction of the Babcock and Gerber tests in, respectively, 1890 and 1891 milk processors have been able to adjust raw milk prices according to the fat composition of the milk. Component pricing schemes were initially based on fat content, and prices were adjusted according to deviations from the expected content. However, several developments in dairy markets since the 1960s have increased the need for pricing schemes that also consider other components. First, the use of milk as an input by the dairy processing industry has increased relative to its use as a beverage. For example, the percentage of milk, which was sold as fluid milk within the U.S. federal milk marketing orders declined from 64.2% in 1960 to 42.7% in 1990 (Cropp and Wasserman, 1993). The value of milk in manufacturing depends on the content of fat and protein. Second, consumer preferences in many developed countries have been changing towards low- and non-fat dairy products since the 1960s. This change has led to lower relative value of fat in the dairy market.[1] Given these two trends, milk pricing based on only fat content became inefficient and inequitable (Cropp and Wasserman, 1993). As a result, multiple component pricing (MCP) schemes began to evolve in the 1960s, and such schemes operates presently in different forms in, for example, New Zealand, Denmark, Netherlands, Australia, Norway, Iceland, six out of ten federal milk marketing orders in the U.S. (Dairy Policy Analysis Alliance, 2010),[2] and several provinces in Canada.

Milk composition can vary for many reasons, including the breed of cattle, seasonal factors, the stage of lactation, and management decisions (Manchester and Blayney, 2001). The

---

[1] Recently, new trends towards low-carb and high-fat diets have been emerging. Such diets have increased the relative value of fat as indicated by the fat shortages observed in some countries like Norway in 2011 and Iceland in 2006 and 2013.

[2] Although not part of the federal milk marketing order, California operates its own state order and introduced MCPs in 1962 (Cropp and Wasserman, 1993; Dairy Policy Analysis Alliance, 2010).

effects on component supply of many of these factors are mainly observable in the intermediate or long run. However, management practices like the choice of feed affects the milk composition in the short run. Few studies have analysed the responsiveness of component supply functions to price changes under MCP schemes. Kirkland and Mittelhammer (1986) investigated the effects of fat-based milk pricing in the U.S. by treating the pricing scheme as a MCP scheme after having derived implicit prices for non-fat solids. They used a nonlinear programming model and found that a 1% increase in the price resulted in a 0.07% increase in the supply of fat and a 0.01% increase in the supply of non-fat solids. Iizuka (1995) used non-statistical inverse marginal cost functions to calculate the price responsiveness of component supply in many states of the U.S.[3] While some of the calculated elasticities have unexpected signs (e.g., for fat and milk), the marginal cost elasticities indicated inelastic supply response. Other studies have investigated the component production technology itself (e.g., Buccola and Iizuka, 1997; Cho, Nakane and Tauer, 2009; Roibas and Alvarez, 2012), the returns of MCP schemes to the farm (e.g., Bailey *et al*., 2005), by the breed (e.g., Elbehri, 1994), and to society (Lenz *et al*., 1991).

Our objective is to estimate the responsiveness of component supply functions to changes in component prices and quantities of quasi-fixed inputs under a MCP scheme, where the value of milk is primarily determined by the content of fat and protein. To do so, we develop a theoretical model for the supply of different components by a dairy farm that operates under a tradable quota regime. We use data from a panel of 311 Icelandic dairy farms between 1997 and 2006. This study is different as compared with Kirkland and Mittelhammer (1986) in several respects: (i) methodology (i.e., programming versus econometric), (ii) data (i.e., farm level versus experimental, time period, breed, and country), and (iii) incentive scheme (i.e., multiple

---

[3] In particular, Iizuka (1995) calculated the change in the supply of milk and its components with respect to changes in marginal cost. These cost elasticities were interpreted as a response to price changes, assuming a farm operating in a perfectly competitive market.

versus single component pricing). These differences may have implications for the estimated component supply responses. For example, experimental data are generated by agents that are unlikely to behave as profit maximizers and, consequently, estimated supply responses may differ from what would be observed on actual farms.[4] Such differences in supply responses have been observed for the productivity effects of breeding (e.g., Byerlee, 1993).

The rest of the article is organized as follows. In Section 2, some information about the dairy sector in Iceland is provided. The theoretical model is developed in Section 3, and in Section 4 the econometric model is described. In Section 5 the data are presented and in Section 6 some estimation issues are discussed. In section 7, the empirical results are presented and discussed before we conclude in Section 8.

2. Milk production and pricing in Iceland

Icelandic dairy farms have traditionally been small family-owned enterprises. Milk production has on average provided more than 85% of the sales revenue and meat output has largely been a by-product of the milk production. During the 1970s, milk production increased significantly, and by the late 1970s production exceeded domestic demand. To balance supply with domestic demand, non-tradable production quotas were introduced in 1980 (Agnarsson, 2007). Such non-tradable quotas are likely to slow the productivity growth by preventing farms from operating at an optimal size and thereby hindering the efficient utilization of available resources (e.g., Richards and Jeffrey, 1997). To reduce the efficiency losses associated with non-tradable quotas, the system evolved to a system with freely tradable quotas in 1992.

---

[4] Buccola and Iizuka (1997) used farm-level data from the U.S. However, they focused mainly on the characterization of the dairy technology and less on the estimation of supply responses to changes in component prices.

The late 1990s were characterized by considerable quota trading and subsequent reductions in the number of farms. From 1995 to 2007, the number of dairy farms declined by 50%, and the average milk production per farm more than doubled (Bjarnadottir and Kristofersson, 2008). In addition to scale economies (Atsbeha *et al*., 2012), several changes in the dairy sector enabled this large increase in output (The Farmers Association of Iceland, 2009). For example, feed quality improved significantly because of better feed processing and storage methods, including the introduction of round hay bales in the late 1980s. Furthermore, the widespread cultivation of high-quality forage (e.g., timothy grass), increased local production of concentrates (primarily barley), mechanization of feeding, and the introduction of automated milk parlours contributed to the growth in output.

Dairy production in Iceland is based on a native breed, which is called Icelandic dairy cattle. Average annual yield is approximately 5,000 kilograms per cow with an average content of 3.4% protein and 4.0% fat. Despite relatively low milk yields, Icelandic dairy cows have desirable characteristics such as a good adaptation to difficult geographic and climate conditions and a milk composition that is favourable to cheese production (Johannesson, 2010).

The Icelandic MCP scheme is based on the content of fat and protein in the milk, and the price of milk is the sum of the value of fat and protein whereas there is no payment for lactose or the fluid carrier itself. However, there are lower prices for milk that does not meet the required standards concerning somatic cell count and antibiotic residues. Furthermore, the component prices are different for milk that is delivered within and outside the quota. Each year, a pricing committee appointed by the government determines the component prices for milk that is delivered within the quota. These prices are effective from dates that are published well in advance. The component prices in the surplus market are determined late in the spring for the next year. The prices in the surplus market are mainly determined by developments in domestic demand. However, if the world market prices for protein or fat allow for profitable exports, the world market prices will determine the prices in the surplus market. The component prices are typically lower in the surplus than the quota market (Johannesson and Agnarsson, 2004). Consistent with demand for dairy products, the Icelandic MCP scheme has valued protein three times more than fat in the quota market and thirteen times more in the surplus market during the study period. However, after a recent butter shortage, fat prices in the surplus market have increased.

3. Theoretical model

Consider a dairy farm in a quota-regulated dairy market.[5] Let y^{q} and y^{o} be milk output delivered within and outside of the quota. The total output of milk is $y = y^{\mathrm{q}} + y^{\mathrm{o}}$. Furthermore, assume milk is priced according to its content, and the prices of components are different for milk delivered within and outside of the quota. Let b_i be the proportion of component $i = 1,...,I$ per kilogram of milk, let p_i^{q} be the price per kilogram of component *i* in milk delivered within the quota, and let p_i^{o} be the price per kilogram of component *i* in milk delivered outside of the quota. The unit value of milk delivered within and outside of the quota will then be $\sum_{i=1}^{I} p_i^{\mathrm{q}} b_i$ and $\sum_{i=1}^{I} p_i^{\mathrm{o}} b_i$, respectively. The quantity of component *i* delivered within the quota is $q_i^{\mathrm{q}} = y^{\mathrm{q}} b_i$, the quantity of component *i* delivered outside of the quota is $q_i^{\mathrm{o}} = y^{\mathrm{o}} b_i$, and the gross revenue of milk produced within and outside of the quota is $\sum_{i=1}^{I} p_i^{\mathrm{q}} q_i^{\mathrm{q}} + \sum_{i=1}^{I} p_i^{\mathrm{o}} q_i^{\mathrm{o}}$.

---

[5] To avoid notational clutter, we do not use farm- and time-specific subscripts on the variables in the theoretical model. However, all variables are time specific. Furthermore, all variables except for netput prices are assumed to be farm-specific.

The dairy farm uses a vector of variable inputs $\mathbf{x} = \left(x_1, ..., x_M\right)$ with input prices $\mathbf{w} = \left(w_1, ..., w_M\right)$ and a vector of services from quasi-fixed inputs $\mathbf{z} = \left(z_1, ..., z_K\right)$ to produce the component vector $\mathbf{q} = \left(q_1, ..., q_I\right)$, where $q_i = yb_i$. As a by-product of milk production, meat q_m is produced and sold for a price of p_m per kilogram. The associated variable cost function is $C\left(\mathbf{w}, \mathbf{q}, q_m; \mathbf{z}\right)$.[6] Each year a farm will have an initial quota $\bar{y}$, and we assume that there is a leasing market in which the farm can lease in or out quotas for a price *r*. Let the quota lease be Δy^{q}. Then the net quota holding is $y^{\mathrm{q}} = (\bar{y} + \Delta y^{\mathrm{q}})$ and the revenue (i.e., $\Delta y^{\mathrm{q}} < 0$) or cost (i.e., $\Delta y^{\mathrm{q}} > 0$) from quota transactions will be $r\Delta y^{\mathrm{q}}$.

Although the farm is quota-regulated on its main output, there are three reasons for assuming that the farm maximizes profits. First, the quota is fully tradable, and hence it is not binding at the farm level. Second, there is a surplus milk market where excess milk can be sold. The existence of the surplus milk market implies that the quota is not binding even at the aggregate level. Finally, farmers are paid for the quantities of components while the quota is specified in litres of milk. This divergence allows for some control of the revenue side of the

---

[6] We assume that there can be made some adjustments in the use of all the inputs in the short run, and our inputs are considered to be either variable or quasi fixed. However, the possible adjustments in the use of quasi-fixed inputs are limited in the short run. It may also be noted that inputs that are used to change the production of one component may affect the quantities of other components; i.e., some inputs such as feed and labour can be non-allocable component wise. Roibas and Alvarez (2012) provide a framework to model component production that considers both allocable and non-allocable inputs. Furthermore, there are limited substitution possibilities among milk components especially when short-run measures such as feed are used to manipulate composition. Empirical evidence of such limited substitution has been provided by Buccola and Iizuka (1997). These limitations may affect the empirical specification of the production technology and hence the variable cost function. A discussion concerning how these restrictions can be modelled is provided in Atsbeha (2012: 123-128).

profit equation through component manipulation. Therefore, the farmer is assumed to maximize profit, or:[7]

$$\text{Max}\,\pi = \sum_{i=1}^{I} p_i^{\mathrm{q}} q_i^{\mathrm{q}} + \sum_{i=1}^{I} p_i^{\mathrm{o}} q_i^{\mathrm{o}} + p_m q_m - C\left(\mathbf{w}, \mathbf{q}, q_m; \mathbf{z}\right) - r\Delta y^{\mathrm{q}}. \tag{1}$$

Solving the first-order conditions, we get choice functions for component supply within quota, component supply outside of quota, meat supply, variable input demand, and net quota lease. The associated restricted profit function $\pi\left(\mathbf{p^q}, \mathbf{p^o}, p_m, \mathbf{w}, r; \mathbf{z}\right)$ is assumed to be continuous, convex, monotonic, and linearly homogeneous in output, input, and quota lease prices.[8]

We apply the envelope theorem to the restricted profit function to obtain component supply functions within and outside of the quota, the meat supply function, the variable input demand functions, and the net quota lease function. These functions are specified as:

$$\frac{\partial \pi}{\partial p_i^{\mathrm{q}}} = q_i^{\mathrm{q}}\left(\mathbf{p^q}, \mathbf{p^o}, p_m, \mathbf{w}, r; \mathbf{z}\right) \tag{2a}$$

$$\frac{\partial \pi}{\partial p_i^{\mathrm{o}}} = q_i^{\mathrm{o}}\left(\mathbf{p^q}, \mathbf{p^o}, p_m, \mathbf{w}, r; \mathbf{z}\right) \tag{2b}$$

$$\frac{\partial \pi}{\partial p_m} = q_m\left(\mathbf{p^q}, \mathbf{p^o}, p_m, \mathbf{w}, r; \mathbf{z}\right) \tag{2c}$$

$$\frac{\partial \pi}{\partial w_j} = -x_j\left(\mathbf{p^q}, \mathbf{p^o}, p_m, \mathbf{w}, r; \mathbf{z}\right) \tag{2d}$$

$$\frac{\partial \pi}{\partial r} = -\Delta y^{\mathrm{q}}\left(\mathbf{p^q}, \mathbf{p^o}, p_m, \mathbf{w}, r; \mathbf{z}\right) \tag{2e}$$

---

[7] In equation (1), the case without a quota implies that $r = 0$. The case with a non-tradable quota implies that $r\Delta y^{\mathrm{q}}$ will be replaced by $r\bar{y}$ where r is interpreted as a shadow price. For more details on modelling producer behaviour under a quota see Guyomard *et al*. (1996) and Boots (1999).

[8] To save space, the Kuhn-Tucker conditions to problem (1) are not shown here. However, they imply that when $p_i^{\mathrm{q}} b_i - r \geq C_y^{'}$, then $y^{\mathrm{q}} > 0$. Otherwise $y^{\mathrm{q}} = 0$ and $\Delta y^{\mathrm{q}} = -\bar{y}$, which implies that the dairy farm will lease out its initial quota holding. Furthermore, $y^{\mathrm{o}} > 0$ $\left(\text{and hence } q_i^{\mathrm{o}} > 0\right)$ only when $p_i^{\mathrm{o}} b_i > p_i^{\mathrm{q}} b_i - r$. Note also that Δy^{q} is an output when $\Delta y^{\mathrm{q}} < 0$ and an input when $\Delta y^{\mathrm{q}} > 0$.

The change in the supply of a component to a change in a price is the sum of a quantity and a composition effect. The quantity effect is the change in milk quantity and the composition effect is the change in component proportions. For example, the effect of a price change of component *i* in the quota milk market on the supply of component *i* in the quota market is $\frac{\partial q_i^{\mathrm{q}}}{\partial p_i^{\mathrm{q}}} = \frac{\partial y^{\mathrm{q}} b_i}{\partial p_i^{\mathrm{q}}} = b_i \frac{\partial y^{\mathrm{q}}}{\partial p_i^{\mathrm{q}}} + y^{\mathrm{q}} \frac{\partial b_i}{\partial p_i^{\mathrm{q}}}$. Rewriting this expression in elasticity form, we obtain $e_{ii}^{\mathrm{q}} = \frac{p_i^{\mathrm{q}}}{q_i^{\mathrm{q}}} \frac{\partial q_i^{\mathrm{q}}}{\partial p_i^{\mathrm{q}}} = \frac{p_i^{\mathrm{q}}}{y^{\mathrm{q}} b_i} \frac{\partial y^{\mathrm{q}} b_i}{\partial p_i^{\mathrm{q}}} = \frac{p_i^{\mathrm{q}}}{y^{\mathrm{q}}} \frac{\partial y^{\mathrm{q}}}{\partial p_i^{\mathrm{q}}} + \frac{p_i^{\mathrm{q}}}{b_i} \frac{\partial b_i}{\partial p_i^{\mathrm{q}}}$. The first term on the left hand side is the own-price supply elasticity of component *i* given constant composition, and the second term is the own-price supply elasticity of component *i* given constant quantity.

The elasticities of intensity are derived by taking the partial derivatives of equations (2a) to (2e) with respect to the relevant quasi fixed input. For example, the effect of a change in the use of quasi fixed input *k* on the supply of component *i* in the quota market is $e_{ik}^{\mathrm{q}} = \frac{\partial q_i^{\mathrm{q}}}{\partial z_k} \frac{z_k}{q_i^{\mathrm{q}}}$.

4. Econometric model

The symmetric normalized quadratic (SNQ) functional form (Diewert and Wales, 1987; Kohli, 1993) is used to approximate the restricted profit function. This flexible functional form allows for negative profits and the global imposition of curvature properties without risking flexibility.

For notational simplicity, the price variables are collected in the vector $\mathbf{v} = \left(\mathbf{p}^{\mathbf{q}}, \mathbf{p}^{\mathbf{o}}, p_m, \mathbf{w}, r\right)$. In this vector, v_n represents the nth element, where $n = 1,\ldots, N = 2 \times I + 1 + M + 1$. The corresponding netput quantities are collected in the vector $\mathbf{s} = (\mathbf{q}^{\mathbf{q}}, \mathbf{q}^{\mathbf{o}}, q_m, \mathbf{-x}, -\Delta y^{\mathrm{q}})$. Furthermore, let z_k be the kth quasi-fixed input $k = 1,\ldots,K$ and t a trend variable introduced to account for the effect of technical change. The restricted profit function for farm h in period t is:

$$\pi_{ht} = \sum_{n=1}^{N} \alpha_{nh} v_{nt} + \frac{1}{2}\left(\sum_{n=1}^{N} \omega_n v_{nt}\right)^{-1} \sum_{n=1}^{N}\sum_{p=1}^{N} \alpha_{np} v_{nt} v_{pt} + \sum_{n=1}^{N}\sum_{k=1}^{K} \varphi_{nk} v_{nt} z_{kht} + \sum_{n=1}^{N} \gamma_n v_{nt} t$$

$$+\left(\sum_{n=1}^{N} \omega_n v_{nt}\right)\left[\frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} z_{kht} z_{lht} + \sum_{k=1}^{K} \delta_k z_{kht} t + \frac{1}{2}\tau t^2\right]. \qquad (3)$$

Equation (3) allows for unobserved farm heterogeneity, since the first-order price coefficients α_{nh} are farm-specific. Furthermore, following Diewert and Wales (1992), ω_n is a fixed weight for each price constructed as $\omega_n = v_{nt}^{*}\left|\bar{s}_n\right| \cdot \left(\sum_{n=1}^{N} v_{nt}^{*}\left|\bar{s}_n\right|\right)^{-1}$, where v_{nt}^{*} is a price in the reference price vector and $\bar{s}_n$ is the mean quantity of the nth netput. Following Diewert and Wales (1992), we choose a vector of ones as the reference price vector and this vector is created by scaling all prices with their respective mean values.

The SNQ is homogeneous of degree one by construction and symmetry is imposed by requiring $\alpha_{np} = \alpha_{pn}$ and $\beta_{kl} = \beta_{lk}$. Furthermore, convexity with respect to prices is satisfied when the matrix **A** consisting of parameters α_{np} is positive semidefinite, and concavity with respect to quasi-fixed inputs is satisfied when the matrix **B** consisting of parameters β_{kl} is negative semidefinite (Diewert and Wales, 1987). These conditions do not necessarily hold, and when violations occur, they can be imposed globally by using a method due to Wiley, Schmidt and Bramble (1973). As shown by Diewert and Wales (1987), convexity of prices can be imposed by setting $\mathbf{A} = \mathbf{\Gamma\Gamma}'$, where the elements of the $N \times N$ matrix $\mathbf{\Gamma}$ are d_{np} for $\forall n \geq p$ and 0 for $\forall n < p$.[9] In a similar manner, concavity of the profit function in quasi-fixed inputs can be imposed by setting $\mathbf{B} = -\mathbf{EE}'$, where $\mathbf{E}$ is a lower triangular matrix with the same structure as

---

[9] As shown by Tombazos (2003), a sufficient condition for a square matrix of dimension M to be positive (negative) semidefinite is that its leading principal minor of order $M - 1$ are positive (negative) semidefinite. This condition allows curvature conditions to be imposed on **A** without violating homogeneity of degree one. In our case, convexity in prices requires that the eigenvalues of $\mathbf{A}' = \left(\alpha_{n-1,p-1}\right)$ are non-negative.

Γ. Finally, local flexibility of the SNQ at v_{nt}^{*} requires that the restrictions $\mathbf{Av}^{*}=\mathbf{0}$ and $\mathbf{Bz}^{*}=\mathbf{0}$ where $\mathbf{z}^{*}=\mathbf{1}$ (Diewert and Wales, 1987). These restrictions imply that all row sums of **A** are zero at the selected reference point and all row sums of **B** equals 1 when $\mathbf{z}^{*}$ is rescaled by the mean values.

A system of supply and input demand functions can be derived from equation (3) as:

$$s_{nht}=\alpha_{nh}+\left(\sum_{n=1}^{N}\omega_{n}v_{nt}\right)^{-1}\sum_{p=1}^{N}\alpha_{np}v_{pt}-\frac{1}{2}\omega_{n}\left(\sum_{n=1}^{N}\omega_{n}v_{nt}\right)^{-2}\sum_{n=1}^{N}\sum_{p=1}^{N}\alpha_{np}v_{nt}v_{pt}+\sum_{k=1}^{K}\varphi_{nk}z_{kht}+\gamma_{n}t$$

$$+\omega_{n}\left[\frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}z_{kht}z_{lht}+\sum_{k=1}^{K}\delta_{k}z_{kht}t+\frac{1}{2}\tau t^{2}\right], \qquad (4)$$

where s_{nht} is the quantity of netput *n* used by farm *h* at time period *t*. Given equation (4), the first derivative with respect to a netput price is:

$$\frac{\partial s_{nht}}{\partial v_{pt}}=\frac{\alpha_{np}}{\left(\sum_{n=1}^{N}\omega_{n}v_{nt}\right)}-\frac{\omega_{n}\sum_{p=1}^{N}\alpha_{np}v_{pt}-\omega_{n}\sum_{n=1}^{N}\alpha_{np}v_{nt}}{\left(\sum_{n=1}^{N}\omega_{n}v_{nt}\right)^{2}}+\frac{\omega_{n}\omega_{p}\sum_{n=1}^{N}\sum_{p=1}^{N}\alpha_{np}v_{nt}v_{pt}}{\left(\sum_{n=1}^{N}\omega_{n}v_{nt}\right)^{3}}. \qquad (5)$$

When calculated at the reference price vector $\mathbf{v}^{*}$ under the restriction $\mathbf{Av}^{*}=\mathbf{0}$, equation (5) simplifies to $\partial s_{nht}/\partial v_{pt}=\alpha_{np}$ and the own- and cross-price elasticities calculated at mean values become $e_{np}=\alpha_{np}\cdot\overline{v}_{p}/\overline{s}_{n}$.

The derivatives of equation (4) with respect to the quantity of each quasi-fixed input is:

$$\frac{\partial s_{nht}}{\partial z_{kht}}=\varphi_{nk}+\omega_{n}\left(\sum_{k=1}^{K}\beta_{kl}z_{kht}+\delta_{k}t\right). \qquad (6)$$

The elasticity of intensity computed at mean values become $e_{nk}=\partial\overline{s}_{n}/\partial\overline{z}_{k}\cdot\overline{z}_{k}/\overline{s}_{n}$. Furthermore, the derivative with respect to the trend is:

$$\frac{\partial s_{nht}}{\partial t}=\gamma_{n}+\omega_{n}\left(\sum_{n=1}^{N}\delta_{k}z_{kht}+\tau t\right). \qquad (7)$$

The growth rate of netput quantity *n* calculated at mean netput quantity is $e_{nt} = \partial \bar{s}_n / \partial \bar{t} \cdot 1/\bar{s}_n$.

The parameters of equation (3) are found by estimating the stochastic version of the system of equations (4). An advantage of estimating this system of netput equations is that the farm-specific intercepts disappear after the within transformation of the variables. A random error term ε_{nht} is added to each of the netput equations (4). We allow for different variances across netputs. The variances are assumed to be constant across farms and over time, i.e., $\varepsilon_{nht} \sim N\left(0, \sigma_{nn}^2\right)$ where $\sigma_{nn}^2 = \mathrm{var}\left(\varepsilon_{nht}, \varepsilon_{nht}\right)$. Furthermore, we allow for non-zero covariances across netputs (contemporaneous correlation). However, the covariances are assumed to be constant across farms and over time (serially uncorrelated), i.e., $\sigma_{np}^2 = \mathrm{var}\left(\varepsilon_{nht}, \varepsilon_{pht}\right)$ for $n \neq p$ and $\mathrm{var}\left(\varepsilon_{nht}, \varepsilon_{nht'}\right) = 0$ for $t \neq t'$.

5. Data

The sample is an unbalanced panel consisting of 311 Icelandic dairy farms with 1,177 observations for the period from 1997 to 2006. All the farms with only one observation were removed from the sample before the within transformation was performed to remove time constant heterogeneity across farms. A total of 1,127 observations from 261 farms were used for the estimation, and these farms had been observed for 4.3 years on average.

Data for the quantities and costs of variable inputs, except for quota leases, were provided by the Agricultural Economics Institute (Hagþjónusta landbúnaðarins). They also provided the data for prices of fats, protein and meat; the stocks of quasi fixed inputs, litres of milk produced within and outside the quota and meat output.[10] According to analysis by the Agricultural Economics Institute, the dataset is representative for Icelandic farms (Hagþjónusta landbúnaðarins, 2010). The variable inputs included in our model are fertilizers, concentrates, and milk quota transactions. The prices of fertilizer and concentrates were calculated as unit values from the cost and quantity data. To correct for outliers in the quantity data, unit values that deviated by more than 50% from the median values were replaced by the median values to calculate the fertilizer quantities.[11] Table 1 shows that the average farm used approximately 21,000 kilograms of fertilizers and nearly 36,000 feed units of concentrates each year. The quasi-fixed inputs are labour, capital, land, and the number of cows.[12] The average farm used approximately 25 man months of labour annually, farmed approximately 47 hectares of land, and had approximately 32 cows.

Data on milk quota transactions were collected by The Farmers' Association of Iceland. The average net seller sold quota rights for approximately 6,000 litres, while the average net buyer purchased three times as much. As shown in Table 1, the average farm is a net buyer, and its annual purchase of quota rights is for 5,027 litres. The average positive purchase of quota rights may be explained by farms leaving the sample by selling all of their quota holdings. For

---

[10] Farmers contribute their data to the institute on a voluntary basis. The raw data contain sensitive farm-level financial information, and its use is subject to strict confidentiality agreements. Therefore, the data cannot be made publicly available.

[11] Because it is optional for farmers to report quantity data for fertilizers, we used tax records to calculate the quantities. Storage of fertilizers further contributes to make the reported quantity data less reliable. For example, 22% of the observations for fertilizer use indicate that no fertilizers was used without having compatible cost entries. Our correction of the quantity data is chosen to handle zero observations and other obvious errors in reported quantities. Note also that fertilizer quantities are reported as gross quantities of artificial fertilizer. If we assume a 21.5% content of nitrogen in this artificial fertilizer, the average application according to our calculated data is about 100 kilograms per hectare. This figure is in line the figure reported by The Farmer's Association of Iceland (2009), who reported that the average application of nitrogen in Iceland is 100 – 140 kilograms per hectare.

[12] Capital consumption (e.g., depreciation and purchases of non-depreciable equipment) is used to measure the flow of services from capital. The cost of capital services is transformed to 1997 prices by deflating current values with the price index for farm products. Furthermore, the number of cows is measured in terms of cow years, which take into account the number of days that each cow has produced milk in a year. One cow year represents a cow producing milk for 365 days in a year and a cow that produced milk for smaller number of days is counted as (# of milking days per year / 365).

legal reasons, a quota lease market does not exist in Iceland, while a quota sale market exists (Bjarnadottir and Kristofersson, 2008).

Table 1. Descriptive statistics

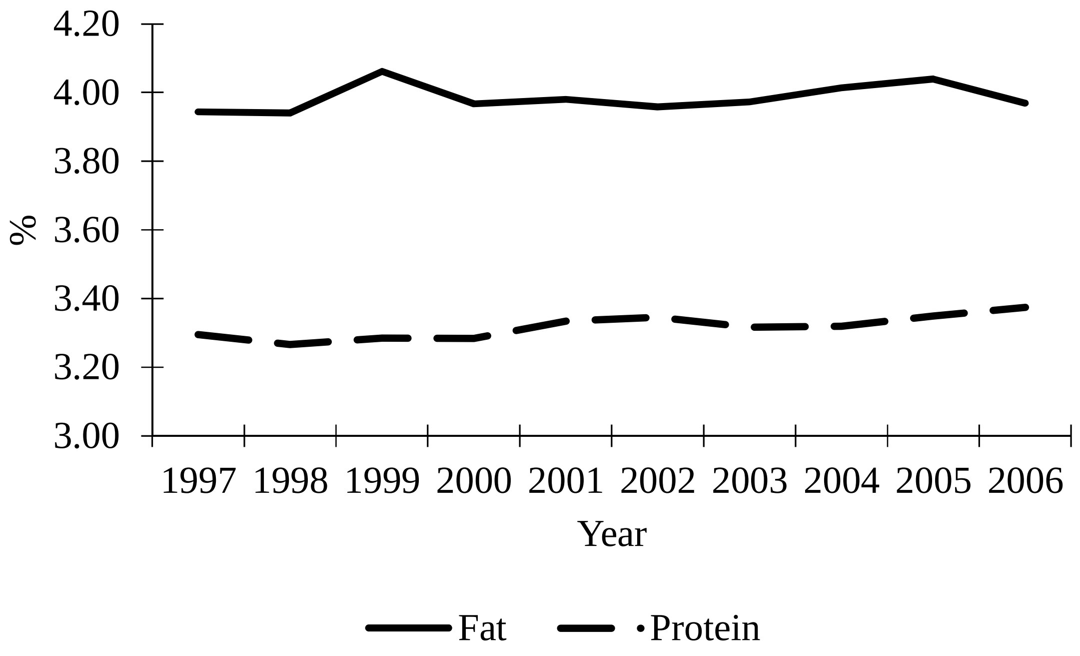
Variable and Symbol	Unit	Mean	Std. Dev.	Minimum	Maximum
Prices					
Fat^q, p_1	ISK per kilogram	241.84	31.72	188	287
Fat^o, p_2	ISK per kilogram	57.44	95.33	0	297
Protein^q, p_3	ISK per kilogram	872.72	113.59	676	1036
Protein^o, p_4	ISK per kilogram	747.67	238.45	314	1070
Meat, p_5	ISK per kilogram	262.89	50.11	107	447
Fertilizer, w_1	ISK per kilogram	26.36	7.37	11	56
Concentrates, w_2	ISK per feed unit	37.02	5.75	19	62
Quota lease, r	ISK per litre	10.94	3.37	6	16
Quantities					
Fat^q, q_1	Kilograms	5,323.32	2,513.30	1,174	20,853
Fat^o, q_2	Kilograms	322.89	527.57	0	6,505
Protein^q, q_3	Kilograms	4,436.02	2,120.56	942	17,472
Protein^o, q_4	Kilograms	269.10	440.77	0	5,409
Meat, q_5	Kilograms	1,979.25	1,244.62	64	10,268
Fertilizers, x_1	Kilograms	21,209.94	18,592.38	42	140,185
Concentrates, x_2	Feed units	35,891.07	21,860.38	1,859	195,227
Quota lease, Δy^q	Litres	5,026.91	16,714.99	–174,720	133,976
Quasi-fixed inputs					
No. of cows, z_1	Cow years	31.95	12.91	5	119
Capital, z_2	Thousands 1997 ISK	2,504.02	1,762.99	283	16,596
Land, z_3	Hectares	47.03	17.96	13	138
Labour, z_4	Months per year	24.50	8.24	4	74
Trend, t	t =1 for 1997	5.49	2.91	1	10

Note: The superscript q on a variable denotes production within the quota and the superscript o denotes production outside of the quota.

However, since a quota represents the right to sell in a preferred market currently as well as in the future, quota is perceived as an asset (Moschini, 1989). We therefore used the reported asset prices to construct the quota lease price. Following Newell *et al*. (2007: 260), we assume that the quota price is equal to the present value of all the future earnings of the quota, and the corresponding lease price is equal to the annual earnings from holding the quota.[13]

Assuming constant discount rates, we set the annual quota lease price to 5% of the asset price. This discount rate was also used in Bjarnadottir and Kristofersson (2008). As shown in Table 1, the resulting average annual lease price for quota is approximately ISK 11 per litre.[14]

Data on milk composition were collected by the dairy cooperative in Iceland, MS Icelandic Dairies, which controlled the entire dairy market during the period. The data are based on weekly measurements of milk composition for each farm. Figure 1 shows the development of protein and fat percentages in a kilogram of milk during the study period. The composition per kilogram of milk appears to remain stable during the study period.



---

[13] According to Newell *et al*. (2007: 260), the price of an income-generating asset like a milk quota, p^q, should be determined by the real per period expected profits from the asset and the real expected discount rate, i. Furthermore, the lease price of the quota, r, should equal the expected profits. We follow Newell *et al*. (2007: 260) and assume that the lease price and discount rate remain constant in the future. According to the formulae for the present value of a perpetual income flow $r = i{\cdot}p^q$.

[14] On January 27, 2015: 1 USD = 134.04 ISK (Source: http://www.cb.is/exchange-rate/)

Fig.1. Fat and protein content per kg. of milk, 1997–2006.

Table 1 shows that the average Icelandic dairy farm delivered 5,323 kilograms of fat and 4,436 kilograms of protein annually to the quota milk market and 323 kilograms of fat and 269 kilograms of protein to the surplus milk market. As shown in Table 1, the average price per kilogram of fat and protein in the quota milk market were ISK 242 and ISK 873, respectively. The corresponding prices in the surplus milk market were ISK 57 and ISK 748 per kilogram of fat and protein, respectively. The difference in price between fat and protein is due to high demand for protein in Iceland, while the demand for fat has traditionally been quite low. However, recently the price of fat in the surplus market has increased on the back of fat shortages. Finally, the average farm delivered nearly 2 tons of meat.

6. Estimation

An initial set of parameters was obtained by using iterative seemingly unrelated regression. The estimated function was checked for monotonicity by looking at the signs of the predicted netput quantities. The average predicted quantities of all netputs have the expected signs, which suggest that the estimated profit function is monotonic with respect to netput prices. Three eigenvalues of the **A** matrix were negative and two eigenvalues of the **B** matrix were positive. This suggests that curvature conditions with respect to prices and quasi-fixed inputs are not satisfied by the estimated function, and we imposed curvature conditions globally by using the procedure described above and re-estimated the model.

The re-parameterized model is nonlinear in parameters and convergence problems were encountered as commonly found in similar specifications (Moschini, 1998). In the event of nonconvergence, Diewert and Wales (1988) suggested to specify a semiflexible model by reducing the ranks of **A** and **B**. There are several alternative ways to specify such a model and we followed the rule-of-thumb suggested by Moschini (1998) to specify our model. He recommended to specify a semiflexible model in which the rank of the relevant matrix does not exceed the number of eigenvalues with the correct sign required to meet the curvature conditions. The full rank of our **A** and **B** matrices are seven (after imposing $\mathbf{Av}^* = \mathbf{0}$) and four, and we reduced their ranks to five and two, respectively. Due to convergence problems we had to further reduce the rank of **A** to three before the model converged. The Stata routine nlsur (StataCorp, 2009) was used to estimate the model using iterative nonlinear seemingly unrelated regression. The estimated parameters are provided in the appendix.

7. Results

Based on the parameter estimates, the own-and cross-price elasticities of all netputs and the elasticities of intensity are discussed below.

7.1. Effects of changes in output prices

All own-price elasticities are positive for outputs and negative for inputs. Except for fat supply to the surplus market and quota lease, they are significantly different from zero at the 5% level of significance.[15] In the quota market, the own-price elasticity for fat and protein are 0.26 and 0.23, respectively. These elasticities are substantially higher than those reported in Kirkland and Mittelhammer (1986). As discussed above, several factors related to data, methodology, breed, and characteristics of the pricing schemes may explain the difference. The values of the own-

---

[15] The Doornik-Hansen test for multivariate normality (Doornik and Hansen, 2008) rejected the null hypothesis that the error terms of the system are jointly normally distributed. Therefore, some caution is needed in the interpretation of the hypotheses tests.

price elasticity of fat supply in the surplus market is quite different. A 1% increase in the price of protein results in a 0.25% increase in protein supply, while a 1% increase in the price of fat only results in a 0.02% increase in fat supply. The low price responsiveness to fat in the surplus market can mainly be explained by the low price of fat as measured in both absolute and relative terms in this market. According to Table 1, protein was valued 13 times as much as fat in the surplus market, while it was valued only 3.6 times more in the quota market. Furthermore, the mean price of fat in the surplus market was less than 25% of the mean price in the quota market. Given the low value of fat in the surplus market, a small price change of fat has negligible effects on the profitability and provides weak incentives to change any management practices to produce more or less fat. On the other hand, price changes of protein in both markets and fat in the quota market provide much stronger incentives to change management practices. Changes in the relative price of fat and protein may change the feed composition. Jenkins and McGuire (2006) showed that high concentrate intensity in the feeding regime boosts the protein content and milk output while it tends to depress the fat content. On the other hand, low concentrate intensity boosts the fat content while it reduces the protein content and the milk output. For example, an increased price of fat in the quota market will give an incentive to lower the concentrate intensity to be able to boost the fat content. But this will be at the cost of reducing protein content and milk output.

The responses in protein supply to price changes for protein is almost identical in the two markets. The price of protein is almost 20% higher in the quota market but it also incurs costs in the form of quota leases to produce for this market. Finally, the own-price elasticity of meat is 0.09, which suggests some responsiveness to changes in meat price.

Table 2. Own- and cross-price elasticities

Netput	Price							
	Fat^q	Fat^o	Protein^q	Protein^o	Meat	Fertilizers	Concentrates	Quota lease
Fat^q	0.260***	–0.004***	–0.069	–0.031***	0.041***	–0.130***	–0.102***	0.034***
	(0.093)	(0.001)	(0.099)	(0.006)	(0.007)	(0.011)	(0.016)	(0.010)
Fat^o	–0.255***	0.020*	–0.135	0.232*	–0.009	0.694***	–0.473***	–0.075
	(0.052)	(0.010)	(0.128)	(0.120)	(0.049)	(0.132)	(0.159)	(0.047)
Protein^q	–0.023	–0.001	0.234***	–0.010	0.039***	–0.145***	–0.092***	–0.002
	(0.033)	(0.001)	(0.037)	(0.007)	(0.006)	(0.012)	(0.018)	(0.006)
Protein^o	–0.198***	0.021*	–0.198	0.253**	–0.014	0.676***	–0.468***	–0.073
	(0.040)	(0.011)	(0.125)	(0.120)	(0.053)	(0.131)	(0.160)	(0.054)
Meat	0.102***	–0.000	0.288***	–0.005	0.091***	–0.170***	–0.314***	0.010
	(0.016)	(0.002)	(0.045)	(0.021)	(0.029)	(0.051)	(0.066)	(0.014)
Fertilizers	0.299***	–0.023***	1.006***	–0.243***	0.158***	–1.446***	0.172***	0.076*
	(0.026)	(0.004)	(0.085)	(0.047)	(0.047)	(0.105)	(0.073)	(0.040)
Concentrates	0.099***	0.007***	0.267***	0.071***	0.123***	0.073***	–0.632***	–0.007
	(0.016)	(0.002)	(0.051)	(0.024)	(0.026)	(0.031)	(0.058)	(0.022)
Quota lease	–0.802***	0.025	0.132	0.267	–0.091	0.774*	–0.164	–0.142
	(0.240)	(0.016)	(0.433)	(0.199)	(0.134)	(0.405)	(0.543)	(0.102)

Note: Standard errors are in parentheses. The superscript q on a variable denotes production within the quota, and the superscript o denotes production outside of the quota. Stars denote significance levels: *** 1%, ** 5% and * 10% significance level.

There are twenty cross-price elasticities between output prices and quantities, and eight of them are significant at the 5% level. Several cross-price effects may be noted. First, the supply of fat to one market responds negatively to changes in the price of fat in the other market. The effect is strongest for a price change in the quota market. A 1% increase in the price of fat in the surplus market reduces the supply of fat to the quota market by only 0.004%, while a 1% increase in the price of fat in the quota market reduces the supply of fat to the surplus market by 0.26%. The relatively strong supply response in the surplus market to a fat price change in the quota market can be an effect of a reduction in concentrate intensity to boost milk fat content, which also reduces milk output and thereby the fat delivered to the surplus market. Furthermore, an increased price of fat in the quota market gives incentives to deliver to the quota market by leasing quotas and less will be delivered to the surplus market. The weak fat supply response in the quota market to a fat price change in the surplus market may be due to the very low price of fat in the surplus milk market.

Second, an increase in the price of fat in the quota market has a negative effect on the supply of protein to the surplus market. This reduction may be a result of reduced concentrate intensity to boost the fat content. As discussed above, reduced concentrate intensity will reduce the protein content and the milk output. Consequently, the availability of milk for the surplus market will be reduced and the milk will contain less protein.

Third, an increase in the price of protein in the surplus market has a negative effect on the fat supply to the quota market. This reduction is likely to be composition driven. A price increase of protein gives dairy farmers an incentive to increase the protein content of their milk by using high concentrate intensity feeding regimes. Such a regime is favourable to milk output but will reduce the fat content. The average farm produces slightly above its quota, and the positive quantity effect will only be minor for fat supply to the quota market, and the negative composition effect will dominate.

Fourth, all the significant cross-effects for meat are with components in the quota market. An increase in the price of meat has small and positive effects on the supply of fat and protein to the quota market. One possible explanation for these positive effects is that higher meat price results in increased culling rates. The best cows with the most profitable milk output and composition will remain. The overall result may be an increase of component supply to the quota market but a reduction in component supply to the surplus market due to the smaller herd size and the consequent reduction in overall production. In our case, however, the negative effects on component supply to the surplus market are statistically insignificant.

Fifth, component price increases in the quota market apparently have positive effects on the meat supply. A 1% increase in the price of fat results in a 0.1% increase in the meat supply while an equivalent increase in the price of protein results in a 0.3% increase in meat supply. One possible explanation for these somewhat surprising effects is the relationship between optimal feeding for component production and the associated effects on milk output. For example, a higher protein price in the quota market will encourage increasing concentrate intensity to boost the protein content. However, milk output will also increase and the entire milk output cannot be sold in the quota market. To avoid selling for the lower prices in the surplus market some farmers may increase their culling rates.

There are ten cross-price elasticities between output prices and input quantities. All of these elasticities are significant at the 5% level. Eight cross-price elasticities are positive, which suggests that increasing output prices increases input demand. Contrary to in the quota market, the cross-price elasticities between component prices in the surplus market and the demand for fertilizers are negative. These surprising negative relationships are difficult to explain and they could be due type I error. Finally, the only output price that affects the quantity of quota leases is the price of fat in the quota market. The demand for quota decreases as fat prices in the quota milk market increase. When the negative sign is interpreted, we have to recall that quota leases can be negative as well as positive. A price increase of fats in the quota market may result in a higher quota lease price, which may result in some farmers who decide to leave dairy farming and sell their entire quota holding.

7.2. Effects of changes in input prices

All the cross-price elasticities between input prices and output quantities are significant at the 5% level. As expected, eight of these cross-price elasticities are negative, which suggests that increasing input prices decreases component supply. The positive cross-price elasticities between the price of fertilizers and the supplies of fat and protein to the surplus market are unexpected. However, the cross-price elasticities between fertilizer and concentrates are positive and significant, and fertilizer (i.e., forage) and concentrates are substitutes in the milk production. Increased fertilizer price will cause a substitution of concentrates for forage, and the resulting increase in the concentrate intensity could increase milk output and hence component supply, however, the effect is surprisingly large and only observed in the surplus market.

The own-price elasticities for inputs are as expected negative and significant for fertilizers and concentrates. Only one cross-price elasticity of netput quantities with respect to a change in the quota lease price is statistically significant. The supply of fat to the quota market increases slightly as the quota lease price increases. Again, we have to recall that quota leases can be negative as well as positive. A price increase of quota leases may result in some farmers who decide to leave dairy farming and sell their entire quota holding. The quotas are likely to be sold to farmers who are able to produce milk with a higher component content.

7.3. Effects of changes in quasi-fixed inputs

Table 3 shows elasticities of intensity and the percentage growth in the supply or use of each netput. Ten out of twenty elasticities of intensity for output supply are statistically significant at the 5% level. An increase in number of cows has a positive effect on the supply of all outputs.

Table 3. Elasticities of intensity and growth rates

Netputs	Quasi-Fixed Inputs				Trend
	No. of Cows	Capital	Land	Labour	
Fat^{q}	0.692^{***}	0.118^{***}	–0.023	0.008	0.012^{***}
	(0.045)	(0.029)	(0.036)	(0.070)	(0.003)
Fat^{o}	4.765^{***}	–0.935	0.923	1.934^{**}	0.118
	(1.178)	(0.727)	(1.007)	(0.943)	(0.414)
Protein^{q}	0.687^{***}	0.119^{***}	–0.025	–0.025	0.014^{***}
	(0.050)	(0.032)	(0.039)	(0.072)	(0.004)
Protein^{o}	1.969^{***}	-0.450^{***}	-0.537^{**}	0.030	0.071^{*}
	(0.320)	(0.134)	(0.245)	(0.244)	(0.041)
Meat	0.439^{***}	0.033	0.063	–0.041	–0.002
	(0.091)	(0.042)	(0.072)	(0.091)	(0.012)
Fertilizers	0.468^{***}	-0.398^{***}	–0.096	0.202^{*}	-0.056^{***}
	(0.117)	(0.052)	(0.090)	(0.105)	(0.013)
Concentrates	1.140^{***}	0.015	0.123^{**}	0.029	0.031^{***}
	(0.065)	(0.034)	(0.050)	(0.078)	(0.005)
Quota lease	2.841^{***}	–0.314	-1.391^{**}	0.268	–0.068
	(0.737)	(0.345)	(0.577)	(0.558)	(0.148)

Note: Standard errors are in parentheses. The superscript q on a variable denotes production within the quota, and the superscript o denotes production outside of the quota. Stars denote significance levels: *** 1%, ** 5% and * 10% level of significance.

As expected, the supplies of components to the surplus market are more affected than the supplies to the quota market. An increase in the use of capital increases the supplies of components to the quota market, but reduces the supply to the surplus market, which suggests that more capital intense farms prefer to use the quota market. An increase in the area of land also reduces the supply of protein to the surplus market. This reduction may be the result of increased production of forage, which results in reduced protein content of the milk. Finally, we find that an increase in labour supply has a positive effect on the supply of fat to the surplus market maybe due to increased production of forage.

As expected, an increase in the herd size leads to an increase in the demand for fertilizer and concentrates, and the demand for concentrates increase twice as much as the increase for fertilizer. On the other hand, an increase in capital has a negative effect on fertilizer demand, suggesting that concentrate intensity is likely to be higher on farms with high capital intensity. Finally, increased land is associated with higher demand for concentrates. This could be the result of new cultivars that are making the local production of crops such as barley increasingly possible under the difficult growing conditions of Iceland. Two elasticities of intensity for quota lease are statistically significant. As can be expected, an increase in herd size results in increased demand for milk quota. For a 1% increase in herd size, the demand for quota increases by 2.8%. A more surprising result is that that an increase in the quantity of land reduces the demand for quota.

Table 3 also shows the percentage growth rates of the respective netputs over time. The supplies of fat and protein have increased by about 0.01% annually in the quota market. We also find that protein supply to the surplus milk market has increased annually by 0.07%. But this increase only becomes significant at the 10% level of significance. Furthermore, fertilizer use has declined by 0.06% per year and concentrates use has increased by 0.03% per year.

8. Conclusions

Milk is a heterogeneous product, which consists of several components. MCP schemes channel component value information to farmers and provide direct incentives for the supply of milk with the components that the market is willing to pay for. We propose a model for milk component supply under a MCP scheme for a profit-maximizing dairy farm, which operates under a tradable quota regime. The model can easily be modified to situations without quotas or with non-tradable quotas. We derive a system of component supply and input demand functions that was estimated with a panel data of Icelandic dairy farms for the period 1997 to 2006.

Our results show that component supplies respond to price changes in the short run. As the component price in the quota market increase by 1%, for fat and protein, the supplies of fat and protein to the quota market increases by 0.26% and 0.23%, respectively. In the surplus market, a 1% increase in component prices for fat and protein results in a 0.02% increase in supply of fat and a 0.25% increase in the supply of protein. The difference in supply response for fat between the two markets can mainly be explained by differences in price levels of fats in the two markets.

With respect to within-component cross-price effects, there are several effects. First, the supply of fat to one market responds negatively to changes in the price of fat in the other market. The effect is strongest for a price change in the quota market. A 1% increase in the price of fat in the surplus market reduces the supply of fat to the quota market by only 0.004%, while a 1% increase in the price of fat in the quota market reduces the supply of fat to the surplus market by 0.26%. The relatively strong supply response in the surplus market to a fat price change in the quota market can be an effect of a reduction in concentrate intensity to boost milk fat content, which also reduces milk output and thereby the fat delivered to the surplus market. Second, fat supply to the quota market is negatively affected by changes in the price of protein in the surplus market, and protein supply to the surplus market is negatively affected by changes in the price of fat in the quota market. The former effect is explained as a composition driven response generated by shifts in feeding regimes towards mixes that are favourable for protein content and milk output but are unfavourable for fat content. The latter effect is explained as a partly a composition and partly a quantity driven response, which are generated by feeding regimes that boost fat content but reduce milk output and protein content. With respect to quasi-fixed inputs a change in the number of cows has positive effects on the supply of all outputs with larger effects on component supply to the surplus milk market. This is likely to be driven by strong milk quantity effects of a large herd size.

References

Agnarsson S. (2007). A tale of two quota systems. Paper presented at the 11th Annual Conference of the International Society for New Institutional Economics (ISNIE), Reykjavik, Iceland. http://www.isnie.org/assets/files/papers2007/agnarsson.pdf. Accessed 31 January 2015.

Atsbeha, D. M. (2012). The Economics of Dairy Production: Effects of Breeding and Marketing Quotas. Ph.D. Thesis 2012: 22, School of Economics and Business, Norwegian University of Life Sciences: Ås.

Atsbeha, D. M., Kristofersson, D. and Rickertsen, K. (2012). “Animal breeding and productivity growth of dairy farms.” *American Journal of Agricultural Economics* 94: 996–1012.

Bailey, K. W., Jones, C. M. and Heinrichs, A. J. (2005). Economic returns to Holstein and Jersey herds under multiple component pricing. *Journal of Dairy Science* 88: 2269–2280.

Bjarnadottir, E. and Kristofersson, D. M. (2008). The cost of the Icelandic transferable dairy quota system. *Icelandic Agricultural Sciences* 21: 29–37.

Boots, M. (1999). Microeconomic Analysis of Alternative Policies for Dutch Dairy Farming. Ph.D. Dissertation number 2725, Wageningen University: Wageningen.

Buccola, S. and Iizuka, Y. (1997). Hedonic cost models and pricing of milk components. *American Journal of Agricultural Economics* 79: 452–462.

Byerlee, D. (1993). Technical change and returns to wheat breeding research in Pakistan's Punjab in the post-green revolution period. *The Pakistan Development Review* 32: 69–86.

Cho, J., Nakane, M. and Tauer, L. W. (2009). Altering Milk Components Produced by the Dairy Cow: Estimation by a Multiple Output Function. Working Paper 2009-15, Department of Applied Economics and Management, Cornell University: Ithaca.

Cropp, R. and Wasserman, W. (1993). Issues and options for using multiple component pricing to set pricing in federal milk marketing orders. http://dairy.wisc.edu/pubPod/pubs/O8.pdf Accessed 31 January 2015.

Dairy Policy Analysis Alliance. (2010). Dairy policy issues for the 2012 farm bill. Food and Agricultural Policy Research Institute (FAPRI), University of Missouri-Columbia and Department of Agricultural and Applied Economics, University of Wisconsin-Madison. http://www.fapri.missouri.edu/outreach/publications/2010/Dairy_Policy_Issues_April2010.pdf . Accessed 31 January 2015.

Diewert, W. E. and Wales, T. J. (1987). Flexible functional forms and global curvature conditions. *Econometrica* 55: 43–68.

Diewert, W. E. and Wales, T. J. (1988). A normalized quadratic semiflexible functional form. *Journal of Econometrics* 37: 327–342.

Diewert, W. E. and Wales, T. J. (1992). Quadratic spline models for producer's supply and demand functions. *International Economic Review* 33: 705–722.

Doornik, J. A. and Hansen, H. (2008), An omnibus test for multivariate normality. *Oxford Bulletin of Economics and Statistics* 70: 927–939.

Elbehri, A., Yonkers, R. D., Ford, S. A. and Gripp, S. I. (1994). The relative profitability of Jersey versus Holstein farms under alternative milk pricing systems. *Journal of Dairy Science* 77: 1296–1305.

Guyomard, H., Delache, X., Irz, X and Mahe, L. P. (1996). A microeconometric analysis of milk quota transfer: Application to French producers. *Journal of Agricultural Economics* 47: 206-223.

Hagþjónusta landbúnaðarins. (2010). Ársskýrsla 2009 (Annual Report 2009 of the Agricultural Economics Institute). Hagþjónusta landbúnaðarins Hvanneyri: Reykjavik.

Iizuka, Y. (1995). Supply of Milk Components on U.S. Dairy Farms: A Cost Function Analysis. Master Thesis in Agricultural and Resource Economics, Oregon State University: Corvallis.

Jenkins, T. C. and McGuire, M. A. (2006). Major advances in nutrition: Impact on milk composition. *Journal of Dairy Science* 89: 1302–1310.

Johannesson, S. and Agnarsson, S. (2004). Bóndi er bústólpi, bú er landstólpi. (The Farmer is the Pillar of the Farm, Farms are Pillars of Society). Institute of Economic Studies, University of Iceland: Reykjavik.

Johannesson, T. (2010). Agriculture in Iceland: Conditions and characteristics. Agricultural University of Iceland, Reykjavik. http://eu.mfa.is/media/landbunadarmal/Agriculture-in-Iceland---Conditions-and-Characteristics.pdf Accessed 31 January 2015.

Kirkland, J. J. and Mittelhammer, R. C. (1986). A nonlinear programming analysis of production response to multiple component pricing. *American Journal of Agricultural Economics* 69: 44–54.

Kohli, U. (1993). A symmetric normalized quadratic GNP function and the U.S. demand for imports and supply of exports. *International Economic Review* 34: 243–255.

Lenz, J. E., Mittelhammer, R. C. and Hillers, J. K. (1991). Pricing milk components at retail via hedonic analysis. *Journal of Dairy Science* 74: 1803–1814.

Manchester, A. C. and Blayney, D. P. (2001). Milk pricing in the United States. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture. Agriculture Information Bulletin No. 761. http://www.ers.usda.gov/media/306483/aib761_1_.pdf. Accessed 31 January 2015.

Moschini, G. (1989). Modelling supply response of supply-managed industries: A review of issues. *Canadian Journal of Agricultural Economics* 37: 379-392.

Moschini, G. (1998). The semiflexible almost ideal demand system. *European Economic Review* 42: 349–364.

Newell, R. G., Papps, K. L. and Sanchirico, J. N. (2007). Asset pricing in creating markets. *American Journal of Agricultural Economics* 89: 259–272.

Roibas, D. and Alvarez, A. (2012). The contribution of genetics to milk composition: Evidence from Spain. *Agricultural Economics* 43: 133–141.

Richards, T. J. and Jeffrey, S. R. (1997). The effect of supply management on herd size in Alberta dairy. *American Journal of Agricultural Economics* 79: 555–565.

StataCorp. (2009). *Stata Statistical Software: Release 11*. College Station, TX: StataCorp LP.

The Farmers Association of Iceland. (2009). Icelandic agricultural statistics 2009: Reykjavik. http://bondi.is/lisalib/getfile.aspx?itemid=2211. Accessed 31 January 2015.

Tombazos, C. G. (2003). A production theory approach to the imports and wage inequality nexus. *Economic Inquiry* 41: 42–61.

Wiley, D. E., Schmidt, W. H. and Bramble, W. J. (1973). Studies of a class of covariance structure models. *Journal of the American Statistical Association* 68: 317–323.