A new approach to identify market power along agri-food supply chains – the German dairy supply chain

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Abstract

In this paper a new approach for the estimation of oligopsony market power along a supply chain is developed. The theoretical framework relies on NEIO theory. Two subsequent markets with oligopsony power are modeled. Price equations, farm-processor and processor-retailer, are embedded in a price transmission framework. The reduced error correction representation is estimated via the Kalman-Filter to allow for time-variation in the long-run cointegration parameters. A dynamic factor model is applied to extract common factors from the time-varying coefficients and with the estimated results the processing industry's and retail sector's average input conjectural variations are calculated. The framework is applied to the German dairy supply chain over the time period January 2000 to March 2011. Results indicate lower levels of market imperfections on the raw milk and dairy output market.

Keywords: market power, imperfect competition, conjectural variation, dairy industry

1 Introduction

For a long time agricultural markets were regarded as prime example of perfect competition in economics (Sexton 2013). However, heavy concentration and consolidation processes at the food processing level altered the market structure and shifted bargaining power to this level, since only a few producers of food products remained and the retail sector continued to be heterogeneous. For example, in the U.S. food processing sector 50% of the value added in this sector was achieved by only 20 manufacturers in 1995, while in 1954 they accounted only for half of the share (Sexton 2000). Consequently, research in the 1970s and 1980s focused more and more on the food processing sector as a possible source of oligopoly power with welfare loss implications, in particular for retailers and final consumers. The notion of competitive farm commodity markets persisted.

In the late 1980s focus shifted slowly towards the idea of oligopsony power on the raw agricultural commodity markets, since apart from the retail level also an atomic farm sector interacts with the highly concentrated food processing industry. Nevertheless, research on oligopsonistic behavior of retailers remained scarce. The cause is that, even though high level of oligopsony power can be devastating for the income of farmers, the share of the farm product in the final retail price is often less than 1/5. Consequently, oligopsony power on these markets never sounded alarming as a main source of welfare losses (Alston, Sexton and Zhang 1997; Sexton 2000).

Recent developments at the retail level seemed to have changed the bargaining power along agri-food supply chains again. Starting in the mid-1990s mergers and acquisition have heavily promoted concertation at the retail level in the EU and the US, much higher than concentration in the food processing industry has ever been. In the EU the top20 retailers accounted for 40% of the total revenue at the beginning of the 2000s, in contrast the top20 food processor, which only accounted for 15% (Clarke et al 2003). By the mid-2000s, in some EU countries, such as Germany or UK, the five largest enterprises encompass more than 70% of retailers' total turnover (Consultative Commission on Industrial Change 2008). Only a few studies have factored in this development and the possible thread of retailers' buyer power on the food industry output market in their empirical applications (i.e. Gohin and Guymard 2000).

With the concentration and consolidation processes at the processing and retail level in mind, it is not surprising to hear that since the start of the 2000s the German antitrust agency has received a growing number of complaints by farmers and processors on the procurement behavior of downstream buyers, respectively the processing industry and retailing sector. One supply chain with a particularly high number of complaints has been the dairy supply chain. While dairy farmers have been criticizing that dairies asymmetrically transmit prices, price decreases on the dairy output market are faster transmitted to them than prices increases, dairies have been accusing retailers to abuse their bargaining position to lower the prices for dairy products by colluding. As a result an official investigation was started by the anti-trust agency in 2008 with its final report published in 2012. The German anti-trust agency stated that even though procurement prices are low and the structure along the chain seems to favor the position of buyers, no evidence on the abuse of market power was found (Bundeskartellamt 2012 and 2009).

The aim of the paper is therefore to present an approach that contributes to the identification of market power along a supply chain. Our overall goal is to determine the level of price mark-down due to market power abuse at the sequential markets, raw milk and dairy output market, of the German dairy supply chain from January 2000 to March 2011. Price transmission is normally empirically investigated via time-series data and in a price transmission framework. In a classic price transmission framework the price series of the input and the output product would be analyzed for the exist-ence of price asymmetries. However, it is incorrect to assume that disproportional movements of the prices are solely due to the exercise of market power. The reason for the price asymmetries could also be changes in the cost structure due to exogenous variables (Just and Chern, 1980). For this reason, our approach combines classic price transmission methodology with new empirical industrial organization (NEIO) structural market models, which provide the theoretical basis for the inclusion of exogenous covariates, and uses solely price data for the estimation of buyers' market conduct.

2 German dairy supply chain

The German dairy supply chain consists of three main stages. Dairy farmers produce fresh milk, which is then almost entirely (96.7%) delivered to and processed by domestic dairies in a maximum distance to the primary production of about 250 km, because of the perishable nature of raw milk (BMLEV 2013; Bundeskartellamt 2012). The dairies in turn sell their output to retailers, wholesalers, the food industry, smaller costumers, such as restaurants, hospitals or schools, or export it. However, the bulk of products is sold to the retail level, around 84% of dairy output value in 2000, which also organizes exports, around 9% in 2011(Bundeskartellamt 2014).

The German dairy supply chain is one of the most important branches of the German food industry. German dairy farmers, the 6th largest producers of raw milk in the world, generated in 2011 around 10.3 billion € of production value, what accounted for about 19.5% of the total domestic agricultural production value (52.2). The dairy industry itself created revenue of 26.8 billion € in the same year (BMLEV 2014). In addition, dairy products are one of the most frequently purchased product categories by consumers. Consequently, consumers have a precise knowledge of dairy product prices and are highly price sensitive. Thus, this product category is of utter importance to retailers and their procurement as well as marketing strategies (Loy et al., 2016).

Structural, including concentration and consolidation processes of divergent speed and magnitude, as well as policy changes have reshaped the German dairy supply chain since 2000. In 2000, about 136,000 dairy farmers operated with approximately 4.5 million dairy cows (about 33 cows per farm). Although the number of dairy farmers decreased rapidly by approximately 1/3 to 89,000 in 2011, the head count of dairy cows on German farms was only lowered slightly to 4.2 million. Thus, the average seize of German dairy farms grew to around 47 dairy cows per farm (BMLEV 2013). Nevertheless, the development has been quite heterogeneous. While in 1999 approximately 79.2% of all dairy cows were held in farms with less than 100 dairy cows, the share decreased to 58.2% (BMLE 2014).

On the subsequent stage, the dairy industry, also structural change has been noticeable. Between 2000 and 2011, the number of German dairies declined by around 20% to 126 (BMLEV 2013). The decline was mainly due to mergers and acquisitions among dairy companies to increase processing capacities to drive cost-minimizing strategies or to expand brand product portfolio (Theuvsen and Ebneth 2005). In particular, mergers between large dairy cooperatives, e.g. Nordmilch and Humana Milch in 2011, resulted in high concentration at the dairy level. 50% of the delivered raw milk is processed by only five dairy companies and the six largest dairy companies regarding revenue accounted for 31.8% of total dairy industry's revenue (BMLEV 2013).

The fastest and strongest consolidation and concentration process for this period were observed on the retail level. While in 1999 the eight largest retailers summed up 70% of the market share concerning 'fast moving consumer goods', 12 years later only four enterprises, Aldi, Edeka, Rewe and the Schwarz Group, divided up 85% of market shares. Regarding solely milk, the market is slightly more heterogeneous and 70% of all revenue from milk is generated in after all six retailers. Nevertheless, only three firms, Aldi, Rewe and Edeka, cover around 50% to 65% of all milk demand in the retail sector. Through establishment of procurement alliances between larger retailers and smaller retailers with market shares of less than 5% as well as the fact that retailers manage dairies' exports, of which 50% is marketed internationally by only two retailers, at most six retailers market more than 90% of the German dairy industry's output (Bundeskartellamt 2014).

Policy changes further promoted the restructuring of the German dairy supply chain. In 2006, the EU began to slowly increase the milk quota with its final abolishment in 2015. The lift of the quota, which has limited production at the farm level ever since its introduction in 1984, is part of the EU's attempt to liberalize its agricultural markets. In addition, reductions in the intervention levels for dairy products, and the expiration of dairy export subsidies were implemented (Bouamra Mechemache et al., 2008). Researchers predict that the abolishment will increase supply, lower the price for raw milk, and thus intensifying the structural change at the farm level (Vőneki et al. 2015; Hirsch and Hartmann 2014). Indeed, raw milk supply increased by around 6.6% between 2005 and 2011, while between 2000 and 2005 it was rather stable with almost no growth, and heavy structural change was observed at the farm level (BMLEV 2013).

Overall, the evolving structure of the German dairy supply chain created growing asymmetries in the number of sellers and buyers on both its markets. A fast decreasing, but still vast number of dairy farmers with growing output, in particular since the star of the gradual quota abolishment, faces a decreasing number of large dairies. In turn, the output of dairies is almost completely marketed by maximum six retailers. The preferential position of buyers in the chain as well as the need to market raw milk and dairy products fast, due their perishable nature, create a realistic thread of oligopsony along the German dairy supply chain. In the next section, a structural approach, which considers the described market structures along the chain, is theoretically modelled.

3 Theoretical Model

The first to account for the assumption on oligopsonistic behavior in agricultural markets using a NEIO framework was Schroeter (1988) with his extension of Appelbaum's oligopoly model (1982). Because of the application of fixed proportion technology at the processing level, the authors were able to infer the same level of market power on the input and output market power for the U.S. beef packing industry. The assumption of fixed proportions technology was challenged by evidence of variable proportion technologies in food processing (Wohlgenant 1989; Goodwin and Brester 1995). Consequently, Murray (1995) developed a model that allowed the estimation oligopsony power with a variable production technology. For proper estimation of this approach quantity data on nonspecialized inputs are needed, which are hardly obtainable in most cases. Muth and Wohlgenant (1999) solved this issue and presented a model that allowed the estimation of oligopsony power without the requirement of quantity data on nonspecialized inputs.

Our model extends the approach of Muth and Wohlgenant (1999) with a sequential downstream market. We assume that the German dairy industry consists of n firms producing solely a homogenous product and sourcing their main input, raw milk, only from local German farms. This seems conclusive since raw milk is a fast perishable product and cannot be transported over far distances without great costs. Consequently, we don't consider imports and exports as significant for our model. For the acquisition of all other nonspecialized inputs, either at the farm, dairy or retail level, we accept the assumption of competitive markets.

To model the unknown technology at all stages as smooth as possible, we use second order-differential quadratic forms of all production, cost, and revenue functions listed in the course of the paper (see the Appendix for explicit functional forms) (Chambers, 1988). Given the cost function of farmers and the assumption that farms are price takers on the raw milk market, due to their low bargaining power, we can derive the inverse supply function of raw milk, since their marginal costs equal the farm gate price for raw milk p^f,

$$p^f = {S^f}^{-1}(x^f, z_h^f, t^f) \tag{1}$$

where z_h^f is a vector of h nonspecialized input prices, x^f is the aggregated supply quantity, and t^f is a trend variable depicting technical change at the farm level. Given this supply relation we can formulate i^{th} processor's profit function

$$\pi_i^p = R_i^p(p^p, x_i^f, x_{ki}^{z\,*}, t^p) - p^f x_i^f - z_{ki}^p x_{ki}^{z\,*} \qquad (2)$$

where p^p demarks the output price, $R_i^p(p^p, x_i^f, x_{ki}^{z\,*}, t^p)$ is the revenue function of the i^{th} processor, $x_{ki}^{z\,*} = x_{ki}^z(x_i^f, p^p, z_{ki}^p)$ is a vector of *k* nonspecialized inputs at their optimal quantity conditional on the i^{th} processor's chosen level of the raw milk input x_i^f, z_{ki}^p a vector of the corresponding nonspecialized input prices, and t^p captures technological change at the processing level. Profit maximization with respect to the choice of x_i^f yields the following first-order condition

$$\frac{\partial \pi_i^p}{\partial x_i^f} = \frac{\partial R_i^p(p^p, x_i^f, x_{ki}^{z\,*}, t^p)}{\delta x_i^f} + \frac{\partial R_i^p(p^p, x_i^f, x_{ki}^{z\,*}, t^p)}{\delta x_{ki}^{z\,*}} \frac{\partial x_{ki}^{z\,*}}{\partial x_i^f} - p^f - \Theta^p{}_i \frac{\partial S^{f^{-1}}(x_i^f, z_h^f, t^f)}{\partial x_i^f} x_i^f - z_{ki}^p \frac{\partial x_{ki}^{z\,*}}{\partial x_i^f} = 0 \qquad (3)$$

Under the assumption of procurement of the nonspecialized inputs $x_{ki}^{z\,*}$ in competitive input markets, and aggregating across firms by averaging over all dairies' marginal product (3) can be reduced and rearranged to yield

$$p^f\left(1 + \frac{\Theta^p}{\varepsilon^f}\right) = \frac{R_i^p(p^p, x^f, x_k^z(x^f, p^p, z_k^p), t^p)}{\partial x^f} \qquad (4)$$

where the observed raw milk price plus a relative mark-down equals its marginal revenue value, $\Theta^p = \frac{1}{n}\sum_{i=1}^n \frac{\partial x^f}{\partial x_i^f}\frac{x_i^f}{x^f}$ represents the average input conjectural variation (CV) of the processing industry in the raw milk market, and $\varepsilon^f = \frac{\partial x^f}{\partial S^{f^{-1}}}\frac{S^{f^{-1}}}{x^f} = \frac{\partial x^f}{\partial p^f}\frac{p^f}{x^f}$ the market price elasticity of raw milk supply. The input conjectural variation measures the response in total industry input quantity to a change in the i^{th} processor's input level. Since we assume that aggregation is achieved by averaging over all processors' marginal product, it can be interpreted as an industry average (Muth and Wohlgenant 1999). The conjectural variation can take values from 0 to 1. A value of 0 would indicate that the market is of competitive nature, while a value of 1 would stand for monopsony, or a cartel that acts like a monopsony. Values that lie between 0 and 1 denote varying degrees of oligopsonistic market structures (Bresnahan 1989). The ratio $\frac{\Theta^p}{\varepsilon^f}$ shows the ability of the processing industry to mark-down the price of raw milk (Weidegebriel 2004).

The downstream market for the dairy output is modelled in a similar fashion as the upstream raw milk market model. On the dairy output market dairies are assumed to be price takers and sell all their products to a possible oligopsony of retailers. The dairy output supply function is derived by differentiating the industry's profit function with respect to the dairy product price p^p,

$$\frac{\partial \pi^p(p^p, p^f, z_k^p, x^f, x_k^{z*}(x^f, p^p, z_k^p), t^p)}{\partial p^p} = x^p \qquad (5)$$

where y^p is the quantity of dairy product supply to the downstream market. Given the supply of dairy products, the j^{th} retailer's demand can be derived. Profit maximization behavior implies that j^{th} retailer's cost function differentiated with respect to the choice of dairy product level as a specialized input as well as keeping the quantities of the m nonspecialized inputs again at their optimal quantity $x_m^{z*} = x_m^z(x_j^p, p^p, z_m^r)$ conditional on the j^{th} retailer's chosen level of the dairy product input x_j^p, yields

$$\frac{\partial c^r{}_j\left(x_j^p, p^p, x_{mj}^z(x_j^p, p^p, z_m^r), z_m^r, t^r\right)}{\partial x_j^p} = p^p + \Theta^r{}_i \frac{\partial S^{p^{-1}}}{\partial x_j^p} x_j^p \qquad (6)$$

where the marginal factor cost of the dairy product equals the dairy output price plus an absolute mark-down, z_m^r is a vector of the nonspecialized input prices and t^r stands for the technological change at the retail level. Aggregating across all retailers trough averaging across all retailers' marginal costs gives us

$$\frac{\partial c^r(x^p, p^p, x_m^z(x^p, p^p, z_m^r), z_m^r, t^r)}{\partial x^p} = p^p \left(1 + \frac{\Theta^r}{\varepsilon^p}\right) \qquad (7)$$

where $\Theta^r = \frac{1}{n}\sum_{j=1}^{n} \frac{\partial y^p}{\partial y_j^p} \frac{y_j^p}{y^p}$ is the average input conjectural variation of the retail sector regarding the dairy output and $\varepsilon^p = \frac{\partial y^p}{\partial S^{p^{-1}}} \frac{S^{p^{-1}}}{y^p} = \frac{\partial y^p}{\partial p^p} \frac{p^p}{y^p}$ the price elasticity of dairy product input supply. The interpretation of the values of Θ^r is according to those of Θ^p and the ratio of $\frac{\Theta^r}{\varepsilon^p}$ represents here the retailers' ability to mark-down the price of the dairy output.

The equations for raw milk supply (1), processors' demand for raw milk (4), dairy product supply (5), and retailers' demand for dairy output (7) form a system of equation, which allows determining the simultaneous equilibria on the upstream and downstream market. After rearrangement of the equations and several substitutions we can derive explicit solutions for the endogenous variables (p^p, p^f, x^f, and x^p), where none of the endogenous variables depend on any other endogenous variable, but only on the prices of nonspecialized inputs throughout the transformation process of the agricultural product along the supply chain, technical change at all stages, and the average conjectural input variations of dairies and retailers.

By solving the explicit solution of p^p once for one of the nonspecialized input prices at the dairy level and once at the retail level as well as substituting these solutions into the partial equilibrium equation of p^f permits us to derive two price equations, denoted in the rest of the paper as farm- processor equation (8), from which the retail level specific variables are excluded, and as processor- retail equation (9), from which the farm specific variables are excluded. When the parameters of the previous derived supply, (1) and (5), and demand relations, (4) and (7), are merged to one parameter β per variable, the following linear representations of the price equations are obtained,

$$p^f = \beta(\Theta^p)_0 + \beta(\Theta^p)_1 p^p + \beta(\Theta^p)_2 z_h^f + \beta(\Theta^p)_3 z_k^p + \beta(\Theta^p)_4 t^f + \beta(\Theta^p)_5 t^p \quad (8)$$

$$p^f = \left[\beta(\Theta^r)_0 + \beta(\Theta^r)_1 p^p + \beta(\Theta^r)_4 z_k^p + \beta(\Theta^r)_4 z_m^r + \beta(\Theta^r)_5 t^p + \beta(\Theta^r)_6 t^r\right]$$
$$(1 + \Omega(\Theta^p)) \quad (9)$$

where βs depend on the respective conjectural variation and $\Omega(\Theta^p)$ incorporates the effect of dairies' oligopsony power on the processer-retailer equation and also depends on parameters of the derived supply and demand equations (see Appendix (A9)). Gollop and Roberts (1979) argued that conjectural variations are not fixed constants, but rather vary with time. The reason is that unlike the parameters of technology, the conjectural variations are directly formed and influenced by the firms' behavior through procedure of adaptive expectations. Consequently, we allow the conjectural variations, and thus also indirectly the β parameters, to vary over time, which is denoted in the rest of the paper with the subscript *t*. Through the assumption of time-variation the β parameters can be split into a constant and a non-constant component (for the exact formulation of the price equations with split coefficients see in the Appendix (A8) and (A9)),

$$\beta_t(\Theta_t) = \delta_o + \delta_\lambda \lambda_t(\Theta_t) \quad (10)$$

where the δs are constant parameters and λ_t is a non-constant factor, whose time-variation is solely due to changes in the market power conduct. The estimation procedure, which allows the identification of the conjectural variations is described in the following section.

4 Methodology

Price series, in particular if vertically or horizontally integrated via markets, are often nonstationary and cointegrated (Hendry and Doornik 2001). Variables are labelled as cointegrated when one or more combinations of these exist that are stationary in the long-run (Juselius 2006). To account for possible non-stationarity in and cointegration among the data series, we embed our theoretical model in a vector autoregressive (VAR) framework. It is assumed that the data can be approximated by a VAR(p) model,

$$y_t = \psi_1 y_{t-1} + \psi_2 y_{t-2} + \ldots + \psi_p y_{t-p} + \varepsilon_t \quad (11)$$

where y_t is the data vector of *n* variables, and ψ_i $(i = 1, \ldots, p)$ $(n \times n)$ are parameter matrices to be estimated by using time series data $(t = 1, \ldots, T)$. The error term ε_t is a $(n \times 1)$ vector of normal and identical distributed disturbances with zero mean and non-diagonal covariance matrix Σ.

In the presence of cointegration relationships, (11) is rearranged to form the error correction model (ECM),

$$\Delta y_t = \alpha\beta_t' y_{t-1} \ + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t = \alpha ECT_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t \qquad (12)$$

Where Δ is the difference operator, $\beta_t' y_{t-1}$ is the cointegration vector, and y_{t-1} comprises all the n covariates $(p^f, p^p, z_h^f,\ z_k^p,\ z_m^r)$ as well as the constant term and the trend term of the price equations (8) and (9). β_t' is a ($n \times r$, where r is the number of cointegration vectors) matrix of the long-run cointegration parameters of the price equations, while α is a $(r \times n)$ coefficient matrix that captures the speed to which deviations ($ECT = \beta_t' y_{t-1}$) from the equilibrium are corrected in each time period. If α possess the value 1, deviations are corrected immediately. While the error correction term (*ECT*) captures the long-run response, the Γ_i parameters measure the short-run response of Δy_t to past shocks (Steen and Salvanes 1999; Llyod et al. 2009).

While it is generally assumed in ECMs that coefficients are constant, we alter this method by allowing the cointegration parameter, which are the βs from the price equations (8) and (9), to be time-variant due to changes in the market conduct of buyers. This is achieved by implementing a Kalman-Filter in Lütkepohl and Krätzig's (2004) simple two-step (S2S) estimation procedure for ECMs. The S2S procedure allows in a first step to estimate via ordinary least squares (OLS) the α matrix by normalizing the cointegration vector. In our case we assume two cointegration relationships, which represent the two price equations (8) and (9), and normalize respectively on one of either the nonspecialized input prices at farm or retail level, the variables that only appear in one of the equations. Therefore, the corresponding cointegration coefficient is set to a value of 1. The β parameters of variables that are excluded from the one of the cointegration vectors are set to 0 (for an explicit formulation of the cointegration matrix see in the Appendix (A6)).

In a second step, the acquired knowledge of the α matrix is used to estimate a transformed equation, again via OLS, to derive the cointegration parameters β (Lütkepohl and Krätzig, 2004). Even though, the S2S approach uses OLS for estimation, its estimator has the asymptotic distribution of a maximum likelihood estimator (Ahn and Reinsel 1990; Reinsel 1993). However, to permit the long-run parameters to vary with time, instead of using standard OLS techniques[1], the Kalman-Filter is applied to the transformed equation (13) and thus allow firms to behave Bayesian and updated their conjectural variations (Perloff et al. 2007). The Kalman-Filter is a recursive procedure in which the estimates of the unknown state, here the parameters, are updated in each time period with new observations on the observable data (Kalman 1960). For the estimation we derive the following observation and state equation for our model,

[1] In case of more than one farm or retail nonspecialized input, the transformed equation is estimated once again via OLS to derive the corresponding constant coefficient and is altered again to only incorporate time-varying parameters (for detail see Appendix (A7)).

$$\Delta y_t{}^* = \beta_t(\Theta_t)' y_{t-1}{}^* + \varepsilon_t{}^* \qquad \text{(observation equation)(13)}$$

$$\beta_t(\Theta_t)' = \beta_{t-1}(\Theta_t)' + \xi_t \qquad \text{(state equation)} \qquad (14)$$

Where, $\Delta y_t{}^*$, $y_{t-1}{}^*$, and $\varepsilon_t{}^*$ are transformations of the corresponding ECM vectors Δy_t, y_{t-1}, and ε_t (see Appendix (A7)), and ξ_t is a $(n \times 1)$ vector of normal and identical distributed disturbances with zero mean and non-diagonal covariance matrix Ω.

As mentioned before in the theory section, the time-varying cointegration parameters can be split into a constant and a non-constant component (see Appendix (A8) and (A9)). To accomplish this a dynamic factor model is applied (Stock and Watson, 2005), which takes a similar form and is estimated in an analogous fashion via the Kalman-Filter and maximum likelihood as the state-space representation of the ECM,

$$\beta_{rt}(\Theta_t) = \delta_{or} + \delta_{\lambda r}\lambda_t(\Theta_t) + \xi_t \qquad \text{(observation equation)(15)}$$

$$\lambda_t(\Theta_t) = \gamma\lambda_{t-1}(\Theta_t) + \tau_t \qquad \text{(state equation)} \qquad (16)$$

Where r is a subscript for the number of estimated time-varying cointegration coefficients and $\lambda_t(\Theta_t)$ a dynamic time-varying factor, which is common to every r parameter equation. The constant coefficient δ_{or} and $\delta_{\lambda r}$ are compounds of the parameters of the derived supply, (1) and (5), and demand equations, (4) and (7), (for detail see the in the Appendix (A8) and (A9)) and differ between the r parameter equations. The state equation coefficient γ measures how past values of the dynamic factor, indirectly the oligopsonistic market conduct, has affected the current value. The error of the observation equation (15), is a vector $(r \times 1)$ of normal and identical distributed disturbances with zero mean and diagonal covariance matrix Φ. The error term of the state equation, τ_t, is Gaussian normally distributed. The dynamic factor analysis is carried out by using the MARSS package in R (Holmes et al., 2012). With the estimates of $\lambda_t(\Theta_t)$, δ_{or}, and $\delta_{\lambda r}$ explicit solutions for $\Theta^p{}_t$ and $\Theta^r{}_t$ can be found (see (A8) and (A9)).

Since $\Theta^p{}_t$ enters the processor-retailer equation through Ω, we first determine $\Theta^p{}_t$ with the described procedure and then use the estimated market conduct parameter in the estimation of the processor-retailer equation and all subsequent steps. In the following sections we apply our approach to the German dairy supply chain. First, we give a brief description of the data and apply standard time series test, e.g. cointegration test and unit root test. Second, we present the results of our empirical application.

5 Data

The analyzed time period spans from January 2000 to March 2011. The frequency of the data series is monthly. If data were only available with a quarterly frequency, the time series were interpolated to a monthly frequency using the x-12-arima procedure in the RATS software (see Table 1). In addition, the data were deflated using the Consumer Price Index. The data include all available relevant input costs for the production and marketing process along the dairy supply chain[2]. Data on capital costs and energy costs would have been a helpful addition to the database and the following estimations. However, these time series were only available with an annual frequency. Nevertheless, even though these cost variables probably would have improved the estimation, their relevance is debatable. In 2011, material costs and labor costs of dairy processors accounted for a total cost share of respectively 68.8% and 6.7%. In contrast, energy consumption only made up 1.9% and capital consumption 1.7% of the overall production costs (BMLEV 2013).

Table 1: Descriptive statistics of data

Item	Series	Symbol	Min	Max	Mean	Source	Notes
Milk farm gate price	monthly data	p^f	0.20	0.38	0.30	AMI/ZMP	seasonally adjusted using x12arima
Implied processors' milk price	monthly data for milk powder, butter and Emmentaler cheese	p^p	0.33	0.56	0.43	AMI/ZMP	calculated using technical conversion factors and shares on processing
Feed price	concentrate for milk production, monthly data	z^f	0.14	0.23	0.17	AMI/ZMP	
Average wage food industry	quarterly data on salaries and labour input	z^p	29.59	32.63	30.76	Statistisches Bundesamt	interpolation to monthly data
Average wage retail employee	quarterly data on salaries and labour input	z^R	19.57	20.98	20.31	Statistisches Bundesamt	interpolation to monthly data

Source: own elaboration, based on data from AMI/ZMP.

The next step is to analyze the time series properties of the data. First, we test for stationarity by apply the Augmented Dickey Fuller Test (ADF) to each data series individually (Dickey and Fuller 1981). Using the lag choice provided by the Schwarz Criterion as well as testing for stationarity without additional parameters, with a constant, and with a constant and trend, in only one case, ADF test with constant regarding the

[2] Because only data on one nonspecialized farm and retail input price are used, the 2nd step of S2S method is not applied. Instead, the Kalman-Filter is used directly to estimate the cointegration coefficients, as described in the main text.

milk farm gate price, the hypothesis of stationarity is accepted at the 90% significance level (see Table 2). Consequently, all data series are non-stationary

Table 2: Augmented Dickey Fuller Test results

	Lags[a]	Test statistics		
		[b]	with constant[c]	with constant and trend[d]
Milk farm gate price	2	-0.2661	-2.7125*	-2.9235
Implied processors' milk price	1	-0.3998	-1.7629	-1.4464
Feed price	2	0.2151	-2.0959	-2.5078
Average wage food industry	3	0.4524	-1.9880	-2.4568
Average wage retail employee	2	-0.5250	-1.2991	-2.1532

Source: own elaboration.

Notes:

[a] lag choice according to Schwarz Criterion.

[b] The critical values for accepting the null hypothesis of stationarity at the 1%/5%/10%-level: -2.56/-1.94/-1.62, denoted by ***/**/*.

[c] The critical values for accepting the null hypothesis of stationarity at the 1%/5%/10%-level: -3.43/-2.86/-2.57, denoted by ***/**/*.

[d] The critical values for accepting the null hypothesis of stationarity at the 1%/5%/10%-level: -3.96/-3.41/-3.13, denoted by ***/**/*.

With the result of non-stationarity in all data series, the next step is to test whether a cointegration relationship among the variables exist or not. The Lambda-max test statistics for up to rank 4 are presented in Table 3 (Johansen 1995). The null hypothesis that the variables are cointegrated of rank r against the alternative that a higher rank cointegration exists is tested. The results confirm our theoretical assumption of two cointegration vectors. While the null hypotheses of rank 0 and rank 1 are clearly rejected, the null hypothesis of rank 2 is not rejected.

Table 3: Lambda-max test for cointegration

Cointegration rank	Test statistic	10% significance level	5% significance level
r0	47.8	34.8	37.8
r1	32.5	29.0	31.5
r2	22.2	23.1	25.4
r3	12.1	16.9	19.2
r4	5.2	10.6	12.5

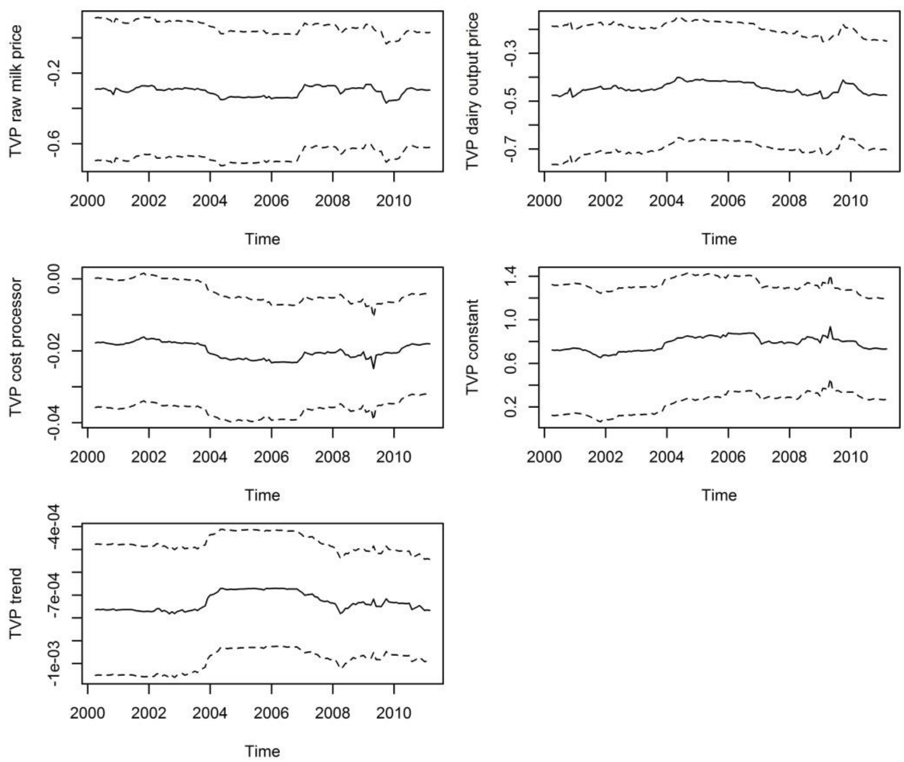
Source: own elaboration.

We proceed with our estimation of the ECM with a lag choice of two provided by the Schwarz-Criterion. The results of the Kalman-Filter and the DFM are presented in the next section.

6 Results

The estimation results of the stable ECM are presented in the Appendix (A10 and A11) and are not further discussed since they are only used as a starting point to derive the transformation equations, which were estimated using the Kalman-Filter. Figure 1 and Figure 2 present the results for time-varying cointegration parameters for the respective price equation.

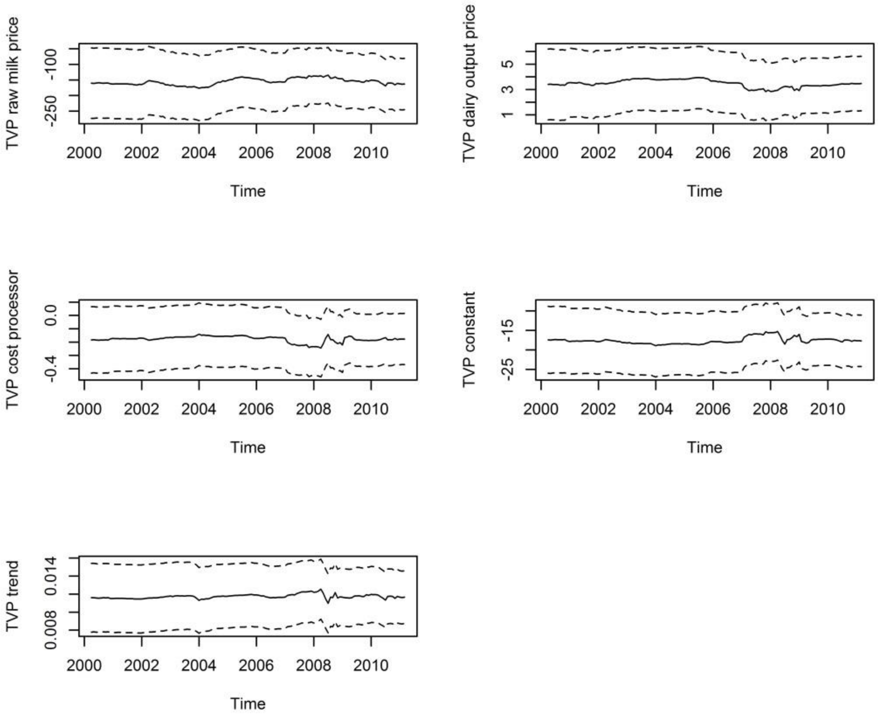
Figure 1: Estimation results of the time-varying cointegration parameters of the farm-processor equation (8) with 95%-confidence intervals



Source: own elaboration.

All of the estimates, of the farm-processor as well of the processor-retailer equation, lie in their 95%-confidence intervals at any point in time. As can be seen from the graphs, the coefficients vary with a significant magnitude over time and some even evolve in similar patterns. While the coefficients of the raw milk price and the non-specialized input at the processing level abruptly drop in value after 2004 only to increase almost as sudden after 2008, the coefficients of the remaining variables are lifted to higher values after 2004 and decline in 2007 quickly with a brief high around 2009. These patterns already indicate how the average input conjectural variation of processors has evolved over the period, since all changes in parameters are due to changes in the conjectural variation. Around 2004, 2007, and 2009/2010 drastic changes in the market behavior of dairies must have taken place.

Figure 2: Estimation results of the time-varying cointegration parameters of the processor-retailer equation (9) with 95%-confidence intervals

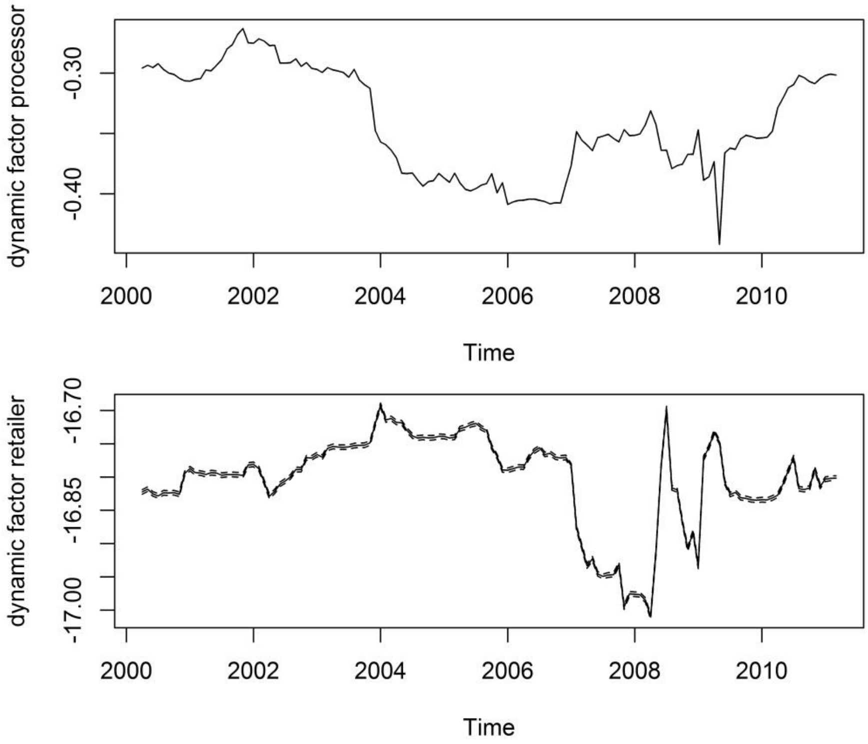


Source: own elaboration.

The coefficients of the processor-retailer cointegration relationship show over the time frame are smoother development. A period of parameter stability until 2007 is followed by a period of larger variation, which in turn is replaced by a period of increased stability after 2010.

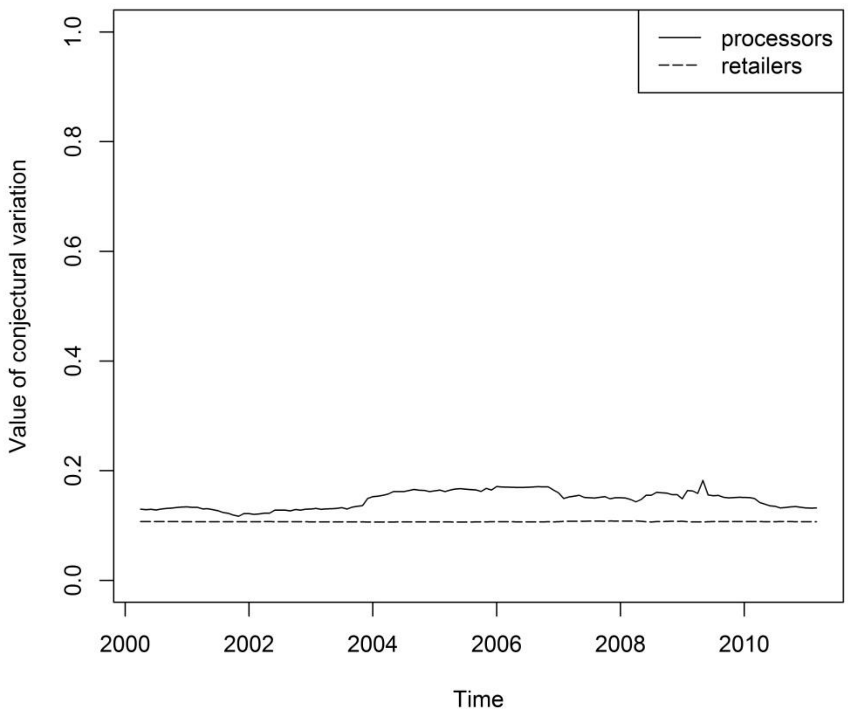
The estimated time-varying cointegration parameters were then used in a DFM to extract a common factor and stable coefficients. The results of the DFM and stable parameter are provided in the Appendix (A12). Figure 4 displays the dynamic factor estimates for the farm-processor, denoted as ‘dynamic factor processor’, since it depends on the oligopsonistic behavior of processors, as well as the processor-retailer equation, denoted as dynamic factor retailers, because it relies on the average input conjectural variations of retailers. The evolution patterns of the respective time-varying parameters can be rediscovered in the dynamic factors. The dynamic factor of the farm-processor equation undergoes significant value changes in 2004, around 2007, and 2009. In contrast, the dynamic factor, which incorporates the market conduct of retailers, evolves rather stable with a period of instability from about 2007 to 2009/2010.

Figure 3: Estimated dynamic factors of farm-processor and processor-retailer equation



Source: own elaboration.

Figure 4: Derived values if the average input conjectural variations



Source: own elaboration.

With the DFM results for the constant coefficients and the dynamic factors, it was now possible to derive the values of the conjectural variations, which are presented in Figure 4. The values lie in the theoretical consistent range of 0 to 1. While the average input conjectural variation of processors varies between 0.1170 and 0.1824, the one of the retail sector ranges from 0.1063 to 0.1083. The development patterns of conjectural variations are similar to those of the dynamic factors, but with smaller magnitude.

7 Discussion

The estimates for the average input conjectural variations indicate that the markets for raw milk and dairy output are characterized by slightly imperfect competition. The measure for oligopsonistic conduct is larger on the upstream market than on the downstream market, but still far from monopsony level. The obtained measurement of the average input conjectural variation of dairies is comparable in magnitude to previous studies on the raw milk market in other European countries. Hockmann and Vőnecki (2009) find a slight less imperfect market (CV of around 0.1) for raw milk in Hungary over the period 1999 to 2006. Stronger oligopsonistic conduct (CV between 0.22 and 0.30) for the Hungarian milk market from 1993 to 2006 is reported by Perekhozhuk et al. (2013) using firm-level data. Again using firm-level data, but for the Ukrainian raw milk market over the timer period 1996 to 2015, Perekhozhuk et al. (2015) state a conjectural variation of 0.15 for the national and values between 0.09 and 0.32 for the different regional levels.

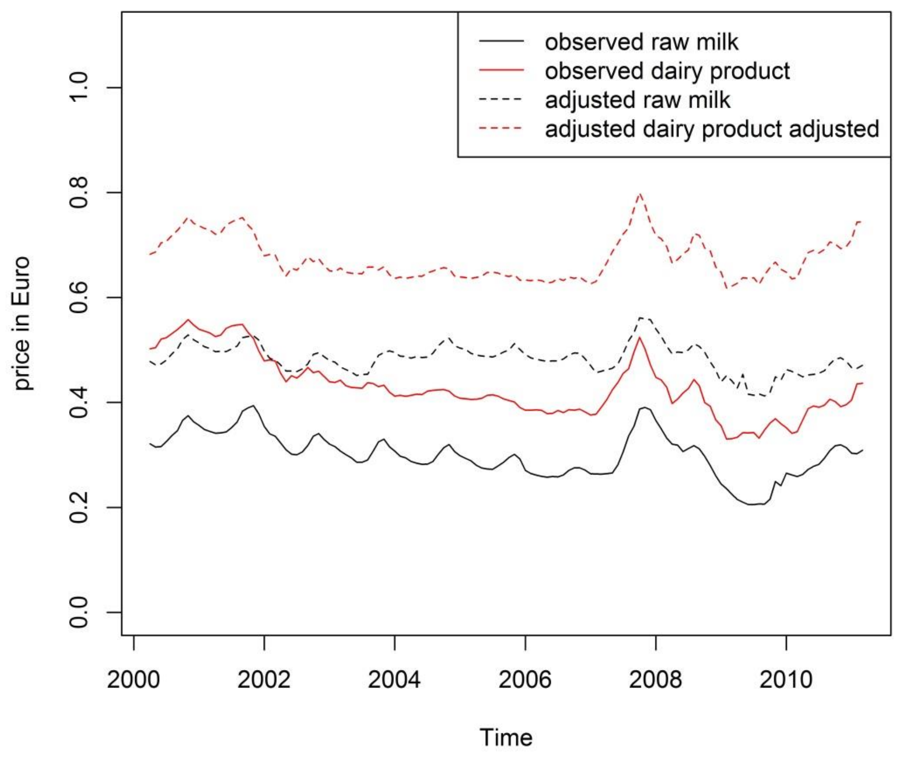
In contrast to the mentioned studies and our own results, Zavelberg et al. (2015) discover large abuse of oligopsonistic market power on the national and regional German raw milk markets from 2001 to 2012. A CV of 0.7483 for the national level and up to 0.7659 for the regional level is reported. The large difference between the estimates of their analysis and our estimation might be due to the fact that Zavelberg et al. (2015) assume a highly inelastic raw milk supply curve, with a supply elasticity of 0.01, while we estimate the supply elasticity to be more than 10 times higher.

The development of the two conjectural variations is rather heterogeneous. After a brief period of decline, the CV of dairies grew steadily from approximately 0.1170 to 0.1706 between 2002 and 2007. After 2007, the oligopsonistic behavior of dairies declined back to its previous level of 2000 with a value of about 0.13. In contrast, the conjectural variation of retailers only varied slightly in magnitude.

The relatively low levels of oligopsony behavior on the raw milk market, even though dairies like the Deutsche Milch Kontor (DMK) accumulate more than 50% of the supply in some German regions, might be due to the strategy of dairies to cost-minimize production and thus keep production capacities fully utilized (Richards et al. 2001). This can only be accomplished by having a guaranteed constant supply flow of raw milk. Consequently, even though exertion of market power provide higher profits in the short-run, the long-run effects, e.g. permanent decline in supply quantity due to low prices and thus less incentives for farmers to invest or produce, might lead to lower profits overall (Crespi et al. 2012).

While mergers, in particular until 2007 might have resulted in a more oligopsonistic market structure (see Figure 4), the market became more competitive after 2007. This trend coincides with price peaks for both products around 2007/2008 (see Figure 5). The price peaks were caused by high global demand for dairy products due to income growth and dietary changes in emerging economies and further fueled by empty public milk powder stocks in the EU and sharp increases in the feed prices due to low global supply and high demand for grains for the production of biofuel (Acosta et al. 2014; Trostle 2008). Dairies, while aiming to expand their output quantities during this period of market growth, might have acted less collusively to secure higher quantities of raw milk supply for their production, what would explain the lower levels of conjectural variation.

Figure 5: Observed and adjusted (added the absolute mark-down due to oligopsonistic behavior) prices for raw milk and dairy output in Germany from 2000 to 2011

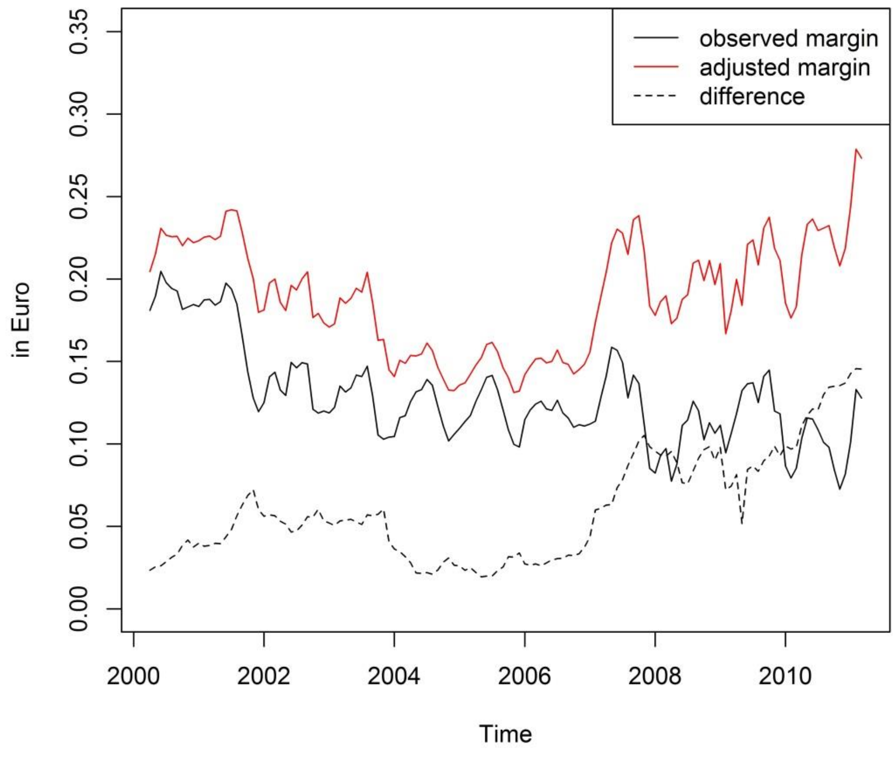


Source: own elaboration.

The low and stable levels of oligopsony on the dairy output market are most likely result of the fierce competition at the retail level. Even though, concentration at the retail stage has increased drastically throughout the analyzed period, from 8 to only 4 dominant firms, and the thread of buyer's market power seems to be imminent, German retailers are generally characterized as highly competitive, also in input markets (Anders 2008). As with diaries, retailers seem to prefer a constant and stable supply of dairy products, an important and frequently purchased product category by consumers, to the possible short-run profits by abusing their bargaining power.

While the levels of oligopsonistic behavior are rather low, we are able to measure the effect of the oligopsonistic market behavior on the prices by adding the realized markdown to the observed values. The results of the procedure are presented in Figure 5. Due to rather inelastic price elasticity of raw milk and dairy product supply the effects of oligopsony in both markets are significant. While the observed, deflated prices for raw milk range between 0.20 and 0.38 € per liter, the adjusted raw milk price lies 0.15 to 0.20 € higher. The difference between observed and adjusted dairy output prices is even higher. While at the beginning of the analyzed period the difference as well ranges from 0.15 to 0.20 €, it increases to approximately 0.30 € after 2007/2008.

Figure 6: Margins between the raw milk and dairy output price for observed and adjusted values in Germany from 2000 to 2011.



Source: own elaboration.

Figure 6 tells a similar story. Here, the price margins between raw milk and dairy output price, observed and adjusted, and the difference between the observed and adjusted margin are displayed. While the margin, in case of no oligopsony power at either stage, would have been at maximum 0.07 € higher between 2000 and 2007, the difference increases to approximately 0.13 € at the end of the investigated period. Consequently, even though the retailers' average input conjectural variation almost remained constant, the growing inelasticity of dairy output supply, caused the dairy output price to be more drastically marked-down after 2007/2008. The decreasing elasticity of dairy supply is a result of fully utilized processing capacities, due to the growth in raw milk supply as a result of gradual lifting the milk quota since 2006 (BMLEV 2013).

With the abolishment of the quota we expect the raw milk supply of farmers to grow further (Graubner et al. 2011). Since many dairies as cooperatives are obliged to process any milk delivered by its members, we expect the supply of dairy output to expand as well and the elasticity of dairy product supply to decrease further. The excessive supply of dairy outputs will boost the bargaining position of the retail sector and its ability to mark-down the diary product price. Apart from this, retailers have developed marketing strategies, such as own private labels, to gain further control over the price transmission along the chain (Loy et al. 2016). On the raw milk market a growing supply might at a first glance strengthen the bargaining position of dairies, but due to the stated obligations of processing all delivered milk, dairies have to fully utilize their capacities, if not expanded in time. This in turn lowers the ability of collusive behavior among dairies, since the thread of increasing procurement can hardly be sustained, and lowers entry barriers as well (Reynolds 1991; Hockmann and Vőneki 2009). Thus the average input conjectural variation of processors is likely to continue decline. The trend in dairies' CV after 2008 might already have been a result of this development, since the gradual abolishment has already been started in 2006 by the EU.

8 Conclusions

In this paper a supply chain approach to the estimation of market power is developed. On the foundations of NEIO theory a structural model of two subsequent markets incorporating buyers' market power on the input as well as output market is established. After deriving the supply equations for the input and output good as well as the corresponding demand equations, a system of equations is formed that gives the explicit solutions for the endogenous variables. Rearranging the price equations permits to cancel quantity variables and estimate the model solely with price data.

For estimation, error correction representations of the two price equations are deduced, in which the long-run coefficients equal the parameters of the price equations. In contrast to standard error correction model assumptions and estimation procedures, we permit the long-run parameters to vary over time. The source of these variations is assumed to be due to changes in the buyers' market conduct. Applying time series estimation techniques such as Kalman-Filter and dynamic factor model to the transformed error correction representation of the price equations allows extracting common time-varying factors, which are the foundation of the calculations of the conjectural variations.

The developed model is applied to the German dairy supply chain over the period January 2000 to March 2011. The estimates of the average input conjectural variations for the dairy industry as well as retailing sectors reveal oligopsonistic market conduct on the raw milk as well as on the dairy product market. However, the values are closer to perfect competition and far from monopsony level, implying smaller than rather larger market distortions. Nevertheless, using these estimates to calculate the absolute mark-down, prices without oligopsony distortion are obtained. The differences between observed and oligopsony unaffected prices are great, due to rather inelastic price elasticity of raw milk and dairy output supply. While the prices for raw milk would be up to 0.20 € per liter more expensive at certain points in the time over the analyzed period, the dairy output price could have been raised by approximately 0.30 € at times.

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Appendix

(A1) Derived inverse supply function of raw milk:

$$p^f = \frac{\partial C(x^f, z_h^f, t^f)}{\partial x^f} = \rho^x + \sum_{i=1}^{h} \rho_i^{zx} z_i^f + \rho^{tx} t^f + \rho^{xx} x^f$$

(A2) Aggregated revenue function of the processing industry:

$$\begin{aligned} R^p = {} & \varphi^0 + \varphi^p p^p + \varphi^{pp} \frac{{p^p}^2}{2} + \varphi^x x^f + \varphi^{xx} \frac{{x^f}^2}{2} + \sum_{j=1}^{k} \varphi_j^z z_j^p + \sum_{j=1}^{k} \varphi_j^{zz} \frac{{z_j^p}^2}{2} + \varphi^t t^p \\ & + \varphi^{tt} \frac{{t^p}^2}{2} + \varphi^{px} p^p x^f + \sum_{j=1}^{k} \varphi_j^{pz} z_j^p \, p^p + \varphi^{pt} p^p t^p + \sum_{j=1}^{k} \varphi_j^{xz} z_j^p \, x^f \\ & + \varphi^{xt} x^f t^p + \sum_{\substack{i=1 \\ i \neq j}}^{k} \sum_{j=1}^{k} \varphi_{ij}^{zz} z_i^p z_j^p + \sum_{j=1}^{k} \varphi_j^{zt} z_j^p \, t^p \end{aligned}$$

(A3) Derived demand function for raw milk:

$$p^f + \rho^{xx} x^f {\Theta^p}_t = \varphi^x + \varphi^{px} p^p + \varphi^{xx} x^f + \sum_{j=1}^{k} \varphi_j^{xz} z_j^p + \varphi^{xt} t^p$$

(A4) Derived inverse supply function of dairy output:

$$p^p = -\frac{-y^p + \varphi^p + \varphi^{px} x^f + \sum_{j=1}^{k} \varphi_j^{pz} z_j^p + \varphi^{pt} t^p}{\varphi^{pp}}$$

(A5) Derived demand function for dairy output:

$$p^p + \frac{y^p {\Theta^r}_t}{\varphi^{pp}} = \vartheta^y + \vartheta^{yy} y^p + \sum_{k=1}^{m} \vartheta_k^{zy} z_k^r + \vartheta^{ty} t^r$$

(A6) The ECTs of the ECM with two cointegration relationships:

$$\begin{pmatrix} ECT_{{\Theta^p}_t} \\ ECT_{{\Theta^r}_t} \end{pmatrix} = \begin{pmatrix} 1 & 0 & \beta_{1t}^{p^f} & \beta_{1t}^{p^p} & \beta_1^{z_h^f} & \beta_{1t}^{z_k^p} & 0 & \beta_{1t}^t & \beta_{1t}^c \\ 0 & 1 & \beta_{2t}^{p^f} & \beta_{2t}^{p^p} & 0 & \beta_{2t}^{z_k^p} & \beta_2^{z_m^r} & \beta_{2t}^t & \beta_{2t}^c \end{pmatrix}' \times \begin{pmatrix} z_1^f & z_1^r & p^f & p^p & z_h^f & z_k^p & z_m^r & t & c \end{pmatrix}$$

(A7) Transformation of dependent variable after first step of S2S procedure:

$$\begin{pmatrix} {\Delta y_{1t}}^* \\ {\Delta y_{2t}}^* \end{pmatrix} = (\alpha' \Sigma^{-1} \alpha) \alpha' \Sigma^{-1} \left(\Delta y_t - \begin{pmatrix} \alpha_{z^f} \\ \alpha_{z^r} \end{pmatrix} \left(z_1^f + \sum_{i=2}^{h} \underbrace{\frac{\rho_i^{zx}}{\rho_1^{zx}}}_{\beta_1^{z_i^f}} z_i^f \quad z_1^r + \sum_{k=2}^{m} \underbrace{\frac{\vartheta_k^{zy}}{\vartheta_1^{zy}}}_{\beta_2^{z_k^r}} z_k^r \right) \right)$$

(A8) Farm-processor price equation:

$$\Delta y_{1t}{}^{*}M = \underbrace{\left(\overbrace{\left(\frac{\varphi^{xx}-\rho^{xx}}{\rho_1^{zx}\varphi^{xx}}\right)}^{\omega^{p^f}{}_0} + \lambda^p{}_t\right)}_{\beta_{1t}^{p^f}} p^f M + \underbrace{\left(\overbrace{\left(\frac{\rho^{xx}\varphi^{px}}{\rho_1^{zx}\varphi^{xx}}\right)}^{\omega^{p^p}{}_0} + \overbrace{(-\varphi^{px})}^{\omega^{p^p}{}_1}\lambda^p{}_t\right)}_{\beta_{1t}^{p^p}} p^p M + \sum_{j=1}^{k}\underbrace{\left(\overbrace{\left(\frac{\rho^{xx}\varphi_j^{xz}}{\rho_1^{zx}\varphi^{xx}}\right)}^{\omega^{z^p{}_j}{}_0} + \overbrace{(-\varphi_j^{xz})}^{\omega^{z^p{}_j}{}_1}\lambda^p{}_t\right)}_{\beta_{1t}^{z_j^p}} z_j^p M$$

$$+\underbrace{\left(\overbrace{\left(\frac{\rho^{xx}\varphi^{xt}-\varphi^{xx}\rho^{tx}}{\rho_1^{zx}\varphi^{xx}}\right)}^{\omega^t{}_0} + \overbrace{(-\varphi^{xt})}^{\omega^t{}_1}\lambda^p{}_t\right)}_{\beta_{1t}^{t}} tM + \underbrace{\left(\overbrace{\left(\frac{\rho^{xx}\varphi^{x}-\varphi^{xx}\rho^{x}}{\rho_1^{zx}\varphi^{xx}}\right)}^{\omega^c{}_0} + \overbrace{(-\varphi^{x})}^{\omega^c{}_1}\lambda^p{}_t\right)}_{\beta_{1t}^{c}} M + \varepsilon_{1t}{}^{*}$$

where $M = I - \Delta y_{t-i}{}'(y_{t-i}\Delta y_{t-i}{}')\Delta y_{t-i}$ includes the effect of the past differences, $\lambda^p{}_t = \frac{\Theta^p{}_t\rho^{xx}}{\rho_1^{zx}\varphi^{xx}(\Theta^p{}_t-\frac{\varphi^{xx}}{\rho^{xx}})}$ is the dynamic factor, $\Theta^p{}_t = -\frac{\lambda^p{}_t\frac{\omega^{p^f}{}_0\omega^{p^p}{}_1}{\omega^{p^p}{}_0}-\lambda^p{}_t}{\frac{\omega^{p^p}{}_0}{\omega^{p^p}{}_1}+\lambda^p{}_t}$ is the average input conjectural variation of processors, and $\varepsilon_t{}^{*} = (\alpha'\Sigma^{-1}\alpha)\alpha'\Sigma^{-1}\varepsilon_t$ is the transformed error term of the original ECM.

(A8) Processor-retailer price equation:

$$\Delta {y_{2t}}^* = \underbrace{\left(\overbrace{\left(\frac{\vartheta^{yy}}{\vartheta_1^{zy}}\right)}^{{\delta^{\Omega}}_0} + {\lambda^r}_t \right)}_{\beta_{2t}^{p^f}} \left[\Omega \left(p^f - \varphi^{px} p^p - \sum_{j=1}^{k} \varphi_j^{xz} z_j^p - \varphi^{xt} t - \varphi^x \right) \right] M + \underbrace{\left(\overbrace{\left(\frac{1 - \varphi^{pp}\vartheta^{yy}}{\vartheta_1^{zy}}\right)}^{{\delta^{p^p}}_0} + \overbrace{(-\varphi^{pp})}^{{\delta^{p^p}}_1} {\lambda^r}_t \right)}_{\beta_{2t}^{p^p}} p^p M$$

$$+ \sum_{j=1}^{k} \underbrace{\left(\overbrace{\left(\frac{-\varphi_j^{pz}\vartheta^{yy}}{\vartheta_1^{zy}}\right)}^{{\delta^{z_j^p}}_0} + \overbrace{\left(-\varphi_j^{pz}\right)}^{{\delta^{z_j^p}}_1} {\lambda^r}_t \right)}_{\beta_{2t}^{z_j^p}} z_j^p\, M + \underbrace{\left(\overbrace{\left(\frac{-\varphi^{pt}\vartheta^{yy} - \vartheta_{ty}}{\vartheta_1^{zy}}\right)}^{{\delta^t}_0} + \overbrace{(-\varphi^{pt})}^{{\delta^t}_1} {\lambda^r}_t \right)}_{\beta_{2t}^{t}} tM$$

$$+ \underbrace{\left(\overbrace{\left(\frac{-\varphi^{p}\vartheta^{yy} - \vartheta^{y}}{\vartheta_1^{zy}}\right)}^{{\delta^c}_0} + \overbrace{(-\varphi^{p})}^{{\delta^c}_1} {\lambda^r}_t \right)}_{\beta_{2t}^{c}} \mathrm{M} + {\varepsilon_{2t}}^*$$

where the effect of ${\Theta^p}_t$ is incorporated in $\Omega = \frac{\varphi^{px}}{({\Theta^p}_t \rho^{xx} - \varphi^{xx})} = \frac{\omega {{p^p}_1}^2 {\lambda^p}_t}{\omega {p^p}_0 {\Theta^p}_t}$, $M = I - \Delta {y_{t-i}}'({y_{t-i}}\Delta {y_{t-i}}')\Delta y_{t-i}$ includes the effect of the past differences, ${\lambda^r}_t = \frac{-{\Theta^r}_t}{\varphi^{pp}\vartheta_1^{zy}}$ is the dynamic factor, ${\Theta^r}_t = -{\lambda^r}_t \frac{{\delta^{p^p}}_1}{{\delta^{p^{f\Omega}}}_0 {\delta^{p^p}}_1 - {\delta^{p^p}}_0}$ is the average input conjectural variation of retailers, and ${\varepsilon_t}^* = (\alpha' \Sigma^{-1} \alpha) \alpha' \Sigma^{-1} \varepsilon_t$ is the transformed error term of the original ECM.

(A10) ECM estimation results for constant α and Γ parameter matrices:

$$\Delta y_t = \begin{bmatrix} -0.086 & -0.002 \\ 0.028 & -0.085 \\ 2.064 & 0.175 \\ -0.016 & 0.002 \\ 0.078 & -0.002 \end{bmatrix} \begin{pmatrix} ECT_{\Theta^p}{}_t \\ ECT_{\Theta^r}{}_t \end{pmatrix}$$

$$+ \begin{bmatrix} 0.335 & -0.000 & -0.003 & 0.063 & -0.016 \\ -2.200 & 0.006 & -0.151 & -0.876 & -0.820 \\ -6.028 & -0.881 & 0.492 & 1.454 & -2.216 \\ 0.246 & 0.004 & -0.010 & 0.087 & 0.063 \\ 0.384 & 0.001 & -0.000 & 0.046 & 0.428 \end{bmatrix} \Delta y_{t-1}$$

$$+ \begin{bmatrix} 0.083 & -0.003 & -0.000 & 0.049 & -0.017 \\ -2.836 & 0.043 & 0.102 & -0.913 & 1.768 \\ -3.393 & 0.411 & 0.032 & -1.475 & 1.497 \\ -0.024 & -0.006 & -0.003 & 0.295 & -0.014 \\ -0.298 & 0.002 & -0.006 & 0.260 & -0.065 \end{bmatrix} \Delta y_{t-2} + \varepsilon_t$$

where $y_t = (z^f \quad z^p \quad z^r \quad p^f \quad p^p)$ is the data vector of the price series.

(A11) Standard errors for constant α and Γ parameter matrices of (A10):

$$\Delta y_t = \begin{bmatrix} 0.028 & 0.002 \\ 0.549 & 0.041 \\ 0.989 & 0.074 \\ 0.037 & 0.003 \\ 0.073 & 0.005 \end{bmatrix} \begin{pmatrix} ECT_{\Theta^p}{}_t \\ ECT_{\Theta^r}{}_t \end{pmatrix} + \begin{bmatrix} 0.087 & 0.005 & 0.002 & 0.065 & 0.038 \\ 1.715 & 0.093 & 0.047 & 1.274 & 0.748 \\ 3.087 & 0.167 & 0.084 & 2.294 & 1.347 \\ 0.116 & 0.006 & 0.003 & 0.086 & 0.051 \\ 0.228 & 0.012 & 0.006 & 0.169 & 0.099 \end{bmatrix} \Delta y_{t-1}$$

$$+ \begin{bmatrix} 0.091 & 0.005 & 0.003 & 0.061 & 0.040 \\ 1.789 & 0.098 & 0.054 & 1.198 & 0.788 \\ 3.220 & 0.176 & 0.097 & 2.155 & 1.418 \\ 0.121 & 0.007 & 0.004 & 0.081 & 0.053 \\ 0.273 & 0.013 & 0.007 & 0.159 & 0.105 \end{bmatrix} \Delta y_{t-2} + \varepsilon_t$$

where $y_t = (z^f \quad z^p \quad z^r \quad p^f \quad p^p)$ is the data vector of the price series.

(A12) DFM estimation results and standard errors of the constant parameters:

Parameter	Value	Standard Error	Parameter	Value	Standard Error
$\omega^{p^f}{}_0$	0.0368	0.252	$\delta^{\Omega}{}_0$	-134	6.75999
$\omega^{p^p}{}_{0_0}$	-0.537	0.0671	$\delta^{p^p}{}_0$	6.42	4.02288
$\omega^{z^p}{}_0$	-0.00327	0.0120	$\delta^{z^p}{}_0$	1.10	0.47647
$\omega^{c}{}_0$	0.290	0.353	$\delta^{c}{}_0$	-24.2	4.65217
$\omega^{t}{}_0$	-0.000992	0.000189	$\delta^{t}{}_0$	1.14	0.09896
$\omega^{p^p}{}_1$	-0.265	0.0461	$\delta^{p^p}{}_1$	0.126	0.20813
$\omega^{z^p}{}_1$	0.0490	0.00483	$\delta^{z^p}{}_1$	0.0545	0.003583
$\omega^{c}{}_1$	-1.44	0.142	$\delta^{c}{}_1$	-0.283	0.09039
$\omega^{t}{}_1$	-0.000768	0.0000844	$\delta^{t}{}_1$	0.0482	0.01480
γ	0.999	0.225	γ	1.00	0.00390

Source: own elaboration.