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Spatial pricing and competition: A theoretical and empirical analysis of the German raw milk market

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List of abbreviations

AIC	Akaike information criterion
ARDL	autoregressive distributed lag
BSE	bovine spongiform encephalopathy
CAP	Common Agricultural Policy
CMO	common market organisation
EC	European Community
ECM	error correction model
ECU	European currency unit
EGLS	estimated generalised least squares
EU	European Union
FE	fixed effects
FD	first-differences
fob	free on board
FPE	final prediction error
GO	Greenhut-Otha
HS	Hotelling-Smithies
iof	investor-owned firm
irf	impulse-response function
LM	Lagrange multiplier
LR	likelihood ratio
ML	maximum likelihood
od	optimal discriminatory
PM	Price-matching
RE	random effects
RTBR	random-tie breaking rule
SPS	single payment scheme
TSLS	two-stage least squares
TVECM	threshold vector error correction model
ud	uniform delivered
VAR	vector autoregressive
VECM	vector error correction model
ZMP	Zentrale Markt- und Preisberichtsstelle

List of symbols

CS	consumer surplus
d	distance between buyers
d_{ij}	distance between firms i and j
D	density function of sellers
D_t	deterministic trend of a VECM
DI	milk density
e	price elasticity of supply
G	organisational form
i	individual
j	number of lags
K	dimension of a stochastic process or the number of explanatory variables
L	lag operator or backshift operator
m	mill price
MM	processed milk quantity
N	number of units (e.g., firms, individuals and households)
NC	number of competitors
p	seller's net price
p_t	time series of the producer price
P_t	vector of the producer price (p_t) and wholesale price (w_t)
P	producer price of raw milk
PS	producer surplus
q	supply function
Q	total supply of the input
r	a unit of distance
R	market area or market boundary
s	absolute importance of space
S	absolute importance of space
t	time (as index) or time trend (as variable)
T	number of time periods
w	net sales price
w_{ij}	element of the spatial weight matrix

w_t	time series of the wholesale price
W	spatial weight matrix
Wp	sales price (= price of the processed product)
WS	national average selling price of milk
α	loading matrix of a VECM
β	cointegrating coefficient or cointegration vector of a VECM
γ	proportion of the transport costs
Γ	matrix of short-run relationship coefficients
δ	production costs
θ	conjectural reaction
λ	spatial error coefficient
λ_t	unobservable individual-invariant effects
μ_i	unobservable time-invariant effects
υ	threshold parameter of a TVECM
π	profit
Π	matrix of long-run and speed of adjustment coefficients
ρ	spatial lag coefficient
τ	transportation costs
$\hat{\varphi}$	FE estimator
ϕ	cointegration vector of a TVECM
ψ	rank of Π
ω_{t-1}	threshold variable of a TVECM
Ω	welfare

1. Introduction

Space is an important dimension in agricultural markets. This is particularly true for the raw milk market with production at the farm level being scattered in space and processing being concentrated in relatively few dairies. In addition, the product is bulky and perishable with a low product value per unit weight or volume. These characteristics cause high costs of shipping, and a low market radius for the raw product. Together with a small number of processors, this implies an oligopsonistic market structure, i.e., processors can exert market power (Eaton and Lipsey, 1977; Rogers and Sexton, 1994), which is even aggravated given the increasing concentration of the processing sector in the last decades. For example, the number of dairies decreased by 26% in Germany from 1997 to 2006 (ZMP, 2007 and 2008). Therefore, incorporating the spatial dimension is important to any analysis of the raw milk market as well as many other agricultural markets.

A great number of studies analyse spatial market power towards demanders of good. Spatial monopolies have been investigated in regard to three different spatial pricing strategies, i.e., free on board (fob) pricing, uniform delivered (ud) pricing and optimal discriminatory (od) pricing. In addition, many studies examine spatial oligopolies by analysing the three most well-known competition strategies: Löschian competition, Hotelling-Smithies (HS) competition and Greenhut-Otha (GO) competition. Thereby, various researchers analyse possible combinations of spatial pricing strategies and spatial competition strategies. With regard to spatial pricing strategies, fob pricing is discussed, for example, in Beckmann (1976), Capozza and van Order (1978), Hobbs (1986), Greenhut et al. (1987, p. 19 ff.), Thisse and Vives (1988), Anderson et al. (1989) and Schöler (2005, p. 83 ff.). While ud pricing is analysed in Beckmann (1976), Gronberg and Meyer (1981), Schuler and Hobbs (1982), Greenhut et al. (1987 p. 101 ff.), Anderson et al. (1989), Kats and Thisse (1993) and Schöler (2005, p. 84 ff.). Furthermore, od pricing is presented in Beckmann (1976), Norman (1981), Hobbs (1986), Greenhut et al. (1987, p. 101 ff.), Schöler (1988), Thisse and Vives (1988), Sanner and Schöler (1998) and Schöler (2005, p. 87 ff.). Analysing spatial competition strategies, Löschian competition is investigated, for example, in Capozza and van Order (1978), Gronberg and Meyer (1981), Norman (1981), Greenhut et al. (1987, p. 19 ff.) and Schöler (2005, p. 94 ff.). Whereas, Capozza and van Order (1978), Gronberg and Meyer (1981), Schuler and Hobbs (1982), Hobbs (1986), Greenhut et al. (1987, p. 19 ff.), Kats and Thisse (1993) and Schöler (2005, p. 94 ff.) analyse HS competition and Capozza and van Order (1978), Norman (1981), Greenhut et al. (1987, p. 19 ff.) and Schöler (2005, p. 94 ff.)

examine GO competition.

In contrast, only few studies examine spatial market power towards input suppliers, i.e., spatial monopsonies and oligopsonies. Löfgren (1986) theoretically investigates a spatial monopsony under ud, fob and od pricing. Furthermore, Löfgren (1985) empirically examines the Swedish pulpwood market, which is a spatial monopsony, with respect to spatial pricing strategies. Notable papers on spatial oligoposonies include Alvarez et al.'s (2000) and Zhang and Sexton's (2001). Alvarez et al. (2000) theoretically analyse a spatial duopsony under ud pricing and with a specific form of Löschian competition, so called Price-matching (PM) competition. The authors test their theoretical results for the case of the raw milk market in a region in Spain. Zhang and Sexton (2001) theoretically examine a processor's decision regarding spatial pricing strategy, i.e., fob or ud pricing, in a duopsony situation. Graubner (2010) analyses spatial pricing strategies and the nature of spatial competition using an agent-based simulation model. Additionally, the author studies a firm's location decision and its pricing strategy simultaneously in a spatial duopsony and a spatial oligopsony. While these studies investigate spatial competition between investor-owned firms (iof), Huck et al. (2005) look at competition between cooperatives and Sexton (1990), Tribl (2009) and Fousekis (2011) analyse mixed markets of iof and cooperatives.

A number of studies analyse different important aspects of the raw milk market. For example, Serra and Goodwill (2003) and Perekhozuk and Grings (2007) examine price transmission and market power in the Spanish and the Ukrainian raw milk market, respectively. Other papers address economic policy issues. For example, Coterill (2006) evaluates a price policy and a potential reform in the northeastern USA. Several studies examine the impact of removing the milk quota system on the European Union's (EU) raw milk market and different ways in which the abolishment is introduced (e.g., Isermeyer, 2007; Bouamra-Mechemache et al., 2008). In addition, some scholars analyse pricing schemes that depend on the fat content of milk (Xia and Sexton, 2009) or on milk components, e.g., butter-fat, non-fat solids and water (Gillmeister, 1996).

Several studies describe the German raw milk market (e.g., Gerlach et al., 2006; Weindlmaier and Betz, 2009; Bundeskartellamt, 2009). Furthermore, Weindlmaier and Huber (2001) and Weindlmaier (2005) describe the factors determining the milk producer prices, e.g., enactments of agricultural policy within the EU, enterprise size of a dairy and marketing size of a dairy. Additionally, the researchers empirically test some of their results using surveys among dairies. In one notable study Cramon-Taubadel and Gloy (1991) empirically analyse the relationship between milk producer prices and product range of dairies in a northern region of Germany (Schleswig-Holstein). Additionally, the authors derive the factors determining the variance of milk producer prices.

Moreover, some scholars analyse the raw milk market by focusing on the spatial aspects of the market. For example, Nubern and Kilmer (1997) investigate the "impact of spatial price discrimination within Florida dairy cooperatives", i.e. the impact of spatial price discrimination on average revenue and blend price. Bakucs and Fertő (2008) study spatial market integration in the Hungarian milk sector. Bouamra-Mechemache et al. (2002) investigate the impact of EU dairy policy reforms and future WTO negotiations based on a spatial equilibrium model.

However, very few studies address spatial pricing and/or spatial competition in the raw milk market empirically. One well-known paper by Alvarez et al. (2000) analyses a spatial duopsony under ud pricing and PM competition in the Asturian[1] raw milk market. Huck et al. (2005) use an extension of Alvarez et al.'s (2000) to model a spatial oligopsony competition of the cooperatives in the northern part of Germany (Schleswig-Holstein).

The research objective of this doctoral thesis is to investigate whether, how and to what extend space influences the milk producer prices in the German raw milk market and the competition among German dairies. To do so, we first derive analytical results for different spatial pricing and competition strategies for the monopsonistic as well as the oligopsonistic situation. Afterwards we test some of our theoretical results empirically for data of the German raw milk market. In particular, we formulate four research questions in regard to spatial pricing and spatial competition. The questions are: (Q1) Which combinations of spatial pricing and spatial competition are theoretically possible in input markets? (Q2) Which type of spatial competition exists between German dairies? (Q3) Which spatial and non-spatial factors influence the German milk producer price? (Q4) Do dairies have an impact on price competition and milk producer price of spatial neighbouring competitors in the German raw milk market?

To achieve these objectives, we organise the study into a theoretical section and an empirical section.

In section 2, we present the theory of spatial pricing and competition. First, we derive results for all different combinations of spatial pricing (fob, ud and od) and spatial competition (Löschian, HS and GO), that may exist. Second, we compare the results with respect to their optimal prices and profits (see section 2.1 – 2.3). In section 2.4, we illustrate two specific spatial models and several spatial hypotheses in regard to the raw milk market. The first

[1] Asturia is a northwestern region of Spain.

model by Graubner et al. (2011) examines spatial competition in the presence of sellers' marketing cooperatives. By doing so, the researchers analyse non-cooperative HS competition and cooperative PM competition. The second model by Alvarez et al. (2000) assumes that PM competition exists and analyses a duopsony market with different degrees of overlap. Additionally, some spatial hypotheses are derived regarding the German raw milk market. Section 3 describes the German milk market in detail. Section 4 includes an empirical analysis of the German raw milk market. In section 4.1, we empirically analyse Graubner et al.'s (2011) theoretical model. Thereby, we investigate which type of spatial competition, i.e., HS competition or PM competition exists between dairies. As a structural model is not applicable because of data limitations (e.g., cost structure of the dairies), we utilise time series methods to investigate the price transmission behaviours under HS and PM competition. If PM competition exists, then the price transmission is theoretically equal to or less than 0.5. In contrast, HS competition has a perfect price transmission and, therefore, equal to one. Utilising a vector error correction model (VECM), we can derive the price transmission in the German raw milk market. In section 4.2, we utilise panel data and a panel model with fixed effects to analyse empirically the influence of the absolute importance of space on the producer price in the German raw milk market. Additionally, we empirically study the impact of the selling price of processed milk, the number of competitors, the quantity of processed milk and the milk density on the German producer price. In section 4.3, we determine further spatial and non-spatial factors that influence the raw milk price like the organisational form or milk density utilising cross-section data and a spatial lag model. Additionally, we analyse how and to which extent spatial competition among dairies affects the raw milk price. In section 5, we summarise the results and draw our conclusions.

2. The theory of spatial pricing and competition

The theoretical part of this doctoral thesis discusses the models of spatial monopsony and oligopsony markets. Before we model spatial market power, we discuss three common spatial pricing strategies in section 2.1. The next section (2.2) introduces a spatial monopsony model and applies it to the three aforementioned pricing strategies. We examine the more sophisticated oligopsony market in section 2.3. We describe three common spatial competition behaviours and investigate the different combinations of spatial pricing strategies and competition behaviours that may exist within an oligopsony model. Finally, we analyse two spatial models that address the raw milk market and formulate several hypotheses regarding the German raw milk market (section 2.4).

2.1 Spatial pricing strategies

In the spatial context, the full price of one unit paid by the buyer[2] and received by the seller consists of the mill price minus some proportion of the transport costs, which depend on distance. Therefore, we can generally formulate the pricing strategies as:

$$p(r) = m - \gamma \tau r \tag{2.1}$$

where p is the seller's net price[3], m is the mill price, γ is the proportion of the transport costs $(\gamma \in [0,1])$, τ is the transport costs per unit input and distance and r is the distance between the buyer and the seller (Norman, 1981).

As explained above, the three most common spatial pricing strategies are fob (also called mill pricing), ud and od pricing (Löfgren, 1986; Greenhut et al., 1987, p. 116; Schöler, 2005, p. 83 ff.).

A fob pricing policy implies that all sellers receive the same mill price regardless of their locations at the buyer's factory gate. The transport costs are the only part of the net price that depend on the seller's location and vary for each seller. The seller completely absorbs the transport costs, i.e., $\gamma = 1$. Therefore, seller's net price under fob pricing is:

$$p_{fob}(r) = m - \tau r \tag{2.2}$$

In a ud pricing policy, all sellers have the same mill price. In comparison with fob pricing, the

[2] In this context, we also call the buyer a 'firm'.

[3] For the sake of simplicity, we simply call the seller's net price the 'net price'.

net price under ud pricing matches the mill price and the buyer absorbs the transport costs, i.e., $\gamma = 0$. Hence, all sellers receive the same net price regardless of the distance between the seller and the buyer:

$$p_{ud}(r) = m = \text{ constant} \tag{2.3}$$

However, under an od pricing strategy, the sellers receive different prices. In contrast to fob and ud pricing schemes, the buyer sets the mill price such that the profits are maximised at each location. Therefore, the sellers receive different mill prices depending on their location, i.e., the mill price is a function *m(r)* of the distance *r* between the buyer and the seller. Thus, the difference between the mill prices does not equal the transport costs.

$$p_{od}(r) = m(r) - \tau r \tag{2.4}$$

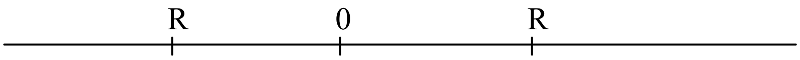
If we want to compare equation (2.4) with the generalisation of spatial pricing (see equation (2.1)), we have to rewrite (2.4) such that $p_{od}(r) = (m - (\gamma - 1)\tau r) - \tau r$. Therefore, the net price under od pricing implies that the buyer pays a variable mill price ($m(r) = (m - (\gamma - 1)\tau r)$) minus the full transport costs (Norman, 1981).
The three pricing strategies differ at a crucial point, which is discrimination. According to Phlips (1983, p. 6), a price is nondiscriminatory if a buyer pays two different sellers for two different versions of a product at the same net price. The net price is defined as the seller's price adjusted for the costs, e.g., the costs of transportation, storage and product design, which differentiate the product. Spatial price discrimination exists if the difference in the net price between the sellers is not equal to the total of their different transport costs (Schöler, 2005, p. 81). With regard to spatial price discrimination, the price difference between the net price and the mill price can be higher or lower than the transport costs between the seller and the buyer. A higher price difference is called 'phantom freight', and a lower price difference is known as 'freight absorption'. Among the three pricing strategies, only the fob price is nondiscriminatory.

2.2. Spatial monopsony

Spatial monopsonies are usually based on the following assumptions, which are also valid for oligopsonies[4] as discussed in section 2.3 (Löfgren, 1986 and Schöler, 2005, p. 82 f.):

Assumption 1: In a linear market, one homogeneous product exists. A single buyer of the input product resells the processed product at a constant price *Wp*. The net sales price *w* is *Wp* minus constant production costs δ ($w = Wp - \delta$) and is the constant marginal revenue product of the input in the processed product form.

Assumption 2: In a linear market, the monopsony is located at point 0. In each direction from the monopsony's location, the market area ranges from 0 to the market boundary *R*. Therefore, the total market area is 2*R*.[5]



Assumption 3: The sellers are continuously distributed over space *r*. The corresponding density function *D(r)* is greater than or equal to zero for all *r* and greater than zero for at least one *r*.

Assumption 4: The supply function $q = q(p)$ is identical for all sellers. Therefore, *q* is the supply, and *p* is the net price received by the seller. Furthermore, the supply curve is twice continuously differentiable, $q'(p) > 0$ and $q(0) = 0$.

Assumption 5: The transportation cost τ per unit input and distance is constant at every point *r* in the market.

Assumption 6: The buyer's goal is profit maximisation.

Assumption 7: The dimension of the linear market is restricted by the price that the buyer pays. Therefore, the market area *R* is endogenous.

Assumption 8: This analysis only applies to short-term phenomena. Firms do not relocate, and new firms do not enter the market.

We based the following analysis on Löfgren's (1986) model. In contrast to Löfgren's (1986) model, which analyses a linear market with a market area extending in only one direction, we consider a firm located in a linear market with a market area that extends in both directions. Similar to Löfgren (1986), we derive the general properties of the monopsony's profit, market area and mill price under fob, ud and od pricing. Additionally, Löfgren (1986) analyses monopsonies under a uniform density or a linear supply curve or a nonlinear supply curve or an exogenous market area. We combine two of these four features and derive the optimal price, market area, quantity, profit and welfare by implementing a linear supply curve and a

[4] Spatial perfect competition cannot exist, as transport costs exist; therefore, the product is not homogeneous (Pindyck and Rubinfeld, 2005, p. 365 ff.).

[5] Adjacent to the market area of the monopsony no competitor exists. Several firms may exist in the whole market, but these competitors must not be located in the monopsony's market area. Hence, a spatial monopsony exists if the market area is spatially isolated.

uniform density.

2.2.1. Free on board pricing

In the case of fob pricing, we derive the monopsony's profit through the following:

$$\pi_{fob} = 2\int_0^R (w-m)q(m-\tau r)D(r)dr = 2(w-m)\int_0^R q(m-\tau r)D(r)dr \qquad (2.5)$$

We define the monopsony's profit as unit profit multiplied by the total supply. Hence, equation (2.5) can be written as:

$$\pi_{fob} = 2(w-m)Q \qquad (2.6)$$

where $Q = 2\int_0^R q(m-\tau r)D(r)dr$ and represents the total supply of the input.

Maximising the profit with respect to m and R yields the following first-order conditions:

$$\frac{\partial \pi_{fob}}{\partial m} = (w-m)\frac{\partial Q}{\partial m} - Q(m,R,\tau) = 0 \qquad \text{and} \qquad (2.7)$$

$$\frac{\partial \pi_{fob}}{\partial R} = (w-m)\frac{\partial Q}{\partial R} = 0 \qquad (2.8)$$

Equation (2.8) can be simplified and written as:

$$(w-m)q(m-\tau R)D(R) = 0 \qquad (2.9)$$

Given that an interior maximum requires that $(w - m)D(R) \neq 0$ the other term $q(m - \tau R)$ must be equal to zero. $q(m - \tau R) = 0$ implies that the size of the market is limited by a function of the mill price and the transport costs. Hence, the market boundary is set at the point at which the seller receives a net price of zero. The condition $q(m - \tau R) = 0$ and assumption 4 (i.e., $q(0) = 0$) determine that $m - \tau R = 0$. The market area is given by $R = m/\tau$, and the partial derivates are $\partial R / \partial m = 1/\tau > 0$ and $\partial R / \partial \tau = -m/\tau^2 < 0$.

The optimal market area R is limited by the mill price in relation to the transport costs. Therefore, R is positive depending on m and negative depending on τ. If the mill price increases (or the transport costs decrease), then the market area will expand. For the optimal mill price, we substitute the function $R = m/\tau$ into equation (2.7). We can solve the equation as $w\frac{\partial Q}{\partial m} = m\frac{\partial Q}{\partial m} - Q(m,R,\tau)$, which we interpret as follows: given the optimal market boundary R, the marginal revenue from an increase in price ($w\frac{\partial Q}{\partial m}$) is equal to the marginal outlay ($m\frac{\partial Q}{\partial m} - Q(m,R,\tau)$).

Substituting $R = m/\tau$ into the profit function, we can write π_{fob} as dependent on w and τ:

$$\pi_{fob}(\tau,w) = \max_{m,R} \;\; 2(w-m)\int_0^R q(m-\tau r)D(r)dr = 2[w-m(w,\tau)]Q(w,\tau) \tag{2.10}$$

Maximising the profit with respect to τ and w and using the envelope theorem yields the following first-order conditions:

$$\frac{\partial \pi_{fob}}{\partial \tau} = -2(w-m)\int_0^R q'(\cdot)rD(r)dr < 0 \tag{2.11}$$

$$\frac{\partial \pi_{fob}}{\partial w} = 2\int_0^R q(\cdot)D(r)dr = 2Q\{R[m(w,\tau),\tau],m(w,\tau),\tau\} = 2Q(w,\tau) > 0 \tag{2.12}$$

The transport costs have a negative effect on the monopsony's profit, but the net sales price has a positive influence on the profit. Both findings are logical, as increasing the transport costs reduces the market area and the total supply and thus, the profit. Ceteris paribus, increasing the net sales prices induces rising profits.

We can explain these results in more detail by implementing some assumptions concerning the supply and density function. In the following, we assume that a linear supply curve and a density of one exist. We define the linear supply function as $q(p) = bp$ with $b > 0$. Therefore, we can rewrite the profit function as follows:

$$\pi^*_{fob} = 2\int_0^R (w-m)b(m-\tau r)dr = 2b(w-m)(mR - 1/2\tau R^2) \tag{2.13}$$

Maximising the profit with respect to m and R, we find that the first-order conditions are as follows:

$$\frac{\partial \pi^*_{fob}}{\partial m}: \quad m' = \frac{w + 1/2\tau R}{2} \tag{2.14}$$

$$\frac{\partial \pi^*_{fob}}{\partial R}: \quad R' = \frac{m}{\tau} \tag{2.15}$$

Insertion of *m'* into equation (2.15) and *R'* into equation (2.14) yields the optimal mill price m^*_{fob} and the market area R^*_{fob}:

$$m^*_{fob} = 2/3w \tag{2.16}$$

$$R^*_{fob} = \frac{2w}{3\tau} \tag{2.17}$$

The optimal mill price and the market boundary are positive depending on the net sales price ($\partial m^*_{fob} / \partial w = 2/3 > 0$ and $\partial R^*_{fob} / \partial w = 2/3\tau > 0$). Additionally, *R* is negative depending on the transport costs ($\partial R^*_{fob} / \partial \tau = -2w/3\tau^2 < 0$).

Using the optimal mill price and market area, we find that the total supply and the monopsony's profit are as follows:

$$Q^*_{fob} = \frac{4bw^2}{9\tau} \tag{2.18}$$

$$\pi^*_{fob} = \frac{4bw^3}{27\tau} \tag{2.19}$$

As previously shown, the total quantity and the profit are also positive depending on the net sales price and negative depending on the transport costs ($\partial Q^*_{fob} / \partial w = 8bw/9\tau > 0$ and $\partial Q^*_{fob} / \partial \tau = -4bw^2 / 9\tau^2 < 0$; $\partial \pi^*_{fob} / \partial w = 12bw^2 / 27\tau > 0$ and $\partial \pi^*_{fob} / \partial \tau = -4bw^3 / 27\tau^2 < 0$).

Finally, we calculate the total welfare, which is defined as the consumer surplus *CS* plus the producer surplus *PS*. We can measure the consumer surplus as the profit[6] π^*_{fob}. We estimate the producer surplus as one-half of the product of the total supply and the net price[7]:

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[6] In a monopsony, the consumer surplus is defined as the monopsony's profit (Löfgren, 1986). Similarly, a monopoly's profit is defined as the producer surplus (e.g., Schöler, 2005, p. 90).

[7] Assuming that a monopsony and a linear supply function $q(p) = bp$ exist, we define producer surplus as the half of the rectangle, which we measure as the product of the optimal total supply and the optimal net price. In the spatial context, we must integrate the product of the total supply and net price over the whole market area.

$$PS_{fob} = 1/2\left[2\int_0^R b(m-\tau r)(m-\tau r)dr\right] = \int_0^R b(m-\tau r)^2\,dr \tag{2.20}$$

Inserting m^*_{fob} and R^*_{fob}, we write the producer surplus as follows:

$$PS_{fob} = \frac{8bw^3}{81\tau} \tag{2.21}$$

Now we can determine the welfare:

$$\Omega_{fob} = PS_{fob} + CS_{fob} = \frac{8bw^3}{81\tau} + \frac{4bw^3}{27\tau} = \frac{20bw^3}{81\tau} \tag{2.22}$$

2.2.2. Uniform delivered pricing

Under ud pricing, we estimate the monopsony's profit as:

$$\pi_{ud} = 2\int_0^R (w-m-\tau r)q(m)D(r)dr \tag{2.23}$$

where the mill price *m* is constant for all sellers.

Maximising the profit function with respect to *m* and *R* yields the following first-order conditions:

$$\frac{\partial \pi_{ud}}{\partial m} = -\int_0^R q(m)D(r)dr + \int_0^R (w-m-\tau r)q'(m)D(r)dr = 0 \qquad \text{and} \tag{2.24}$$

$$\frac{\partial \pi_{ud}}{\partial R} = (w-m-\tau R)q(m)D(R) = 0\,. \tag{2.25}$$

For an internal maximum the single supply *q(m)* and the density function *D(r)* must be different from zero. Hence, the term $(w - m - \tau R)$ equals zero.

$$R = \frac{w-m}{\tau} \tag{2.26}$$

Therefore, the optimal market area *R* is positive depending on the net sales price *w* ($\partial R/\partial w = 1/\tau > 0$) and negative depending on the mill price *m* and the transport costs τ ($\partial R/\partial m = -1/\tau < 0$

and $\partial R/\partial \tau = -(w - m)/\tau^2 < 0$).

Substituting the optimal market boundary R and the average distance of the sellers[8] into the profit function, we derive a new first-order condition for $\partial\pi/\partial m$:

$$\frac{\partial \pi_{ud}}{\partial m} = (w - m - \tau \bar{r})q'(m) - q(m) = 0 \qquad (2.27)$$

With respect to the optimal ud price the result shows that the marginal revenue from an increase in price ($wq'(m)$) is equal to the marginal outlay at the average distance of the sellers ($(m + \tau \bar{r})q'(m) - q(m)$).

To analyse the impact of the net sales price and the transport costs on the profit, we use the profit function, which depends on the following variables:

$$\pi_{ud}(w,\tau) = \max_{m,R} \; 2\int_0^R (w - m - \tau r)q(m)D(r)dr \qquad (2.28)$$

Using the envelope theorem, we find that the first-order conditions are as follows:

$$\frac{\partial \pi_{ud}}{\partial w} = 2q(m)\int_0^R D(r)dr > 0 \qquad (2.29)$$

$$\frac{\partial \pi_{ud}}{\partial \tau} = -2q(m)\int_0^R rD(r)dr < 0 \qquad (2.30)$$

Similar to fob pricing, the net sales price has a positive impact on the profit under ud pricing. Additionally, the transport costs have a negative impact on the firm's profit.

To derive more detailed results, we analyse a spatial monopsony with a linear supply curve $q = bp$ (with $b > 0$) and a density of one.

We can express the profit function as:

$$\pi^*_{ud} = 2\int_0^R \big((w - m - \tau r)bm\big)dr = 2bm(wR - mR - 1/2\tau R^2) \qquad (2.31)$$

[8] The average distance of the sellers is $\bar{r} = \int_0^R rD(r)dr \div \int_0^R D(r)dr$. We define the density of the sellers at a distance r as $f(r) = D(r) \div \int_0^R D(r)dr$

Maximising the profit with respect to *m* and *R* we obtain the following first-order conditions:

$$\frac{\partial \pi^*_{ud}}{\partial m}: \quad m' = \frac{w - 1/2\tau R}{2} \tag{2.32}$$

$$\frac{\partial \pi^*_{ud}}{\partial R}: \quad R' = \frac{w - m}{\tau} \tag{2.33}$$

Substituting equation (2.33) into our calculations for the mill price and equation (2.32) into our calculations for the market area, we estimate that the optimal mill price and market area are:

$$m^*_{ud} = 1/3w \tag{2.34}$$

$$R^*_{ud} = \frac{2w}{3\tau} \tag{2.35}$$

Hence, the optimal mill price and the market area depend positively on the net sales price ($\partial m^*_{ud} / \partial w = 1/3 > 0$ and $\partial R^*_{ud} / \partial w = 2/3\tau > 0$). Furthermore, the market area decreases if the transport costs rise ($\partial R^*_{ud} / \partial \tau = -2w/3\tau^2 < 0$).

Inserting m^*_{ud} and R^*_{ud} in equation (2.31), we find that the total supply and profit are:

$$Q^*_{ud} = \frac{4bw^2}{9\tau} \tag{2.36}$$

$$\pi^*_{ud} = \frac{4bw^3}{27\tau} \tag{2.37}$$

Equations (2.36) and (2.37) show that the total supply and the profit increase if the net sales price rises and decrease if the transport costs increase ($\partial Q^*_{ud} / \partial w = 8bw/9\tau > 0$ and $\partial Q^*_{ud} / \partial \tau = -4bw^2 / 9\tau^2 < 0$; $\partial \pi^*_{ud} / \partial w = 12bw^2 / 27\tau > 0$ and $\partial \pi^*_{ud} / \partial \tau = -4bw^3 / 27\tau^2 < 0$).

Finally, we analyse the welfare, i.e., the producer surplus plus the consumer surplus. The consumer surplus is equal to the monopsony's profit. We can write the producer surplus under ud pricing as:

$$PS_{ud} = 1/2\left[2\int_0^R m(bm)dr\right] = \int_0^R bm^2 dr \tag{2.38}$$

$$PS_{ud} = \frac{2bw^3}{27\tau} \tag{2.39}$$

Therefore, we determine the welfare under ud pricing as follows:

$$\Omega_{ud} = PS_{ud} + CS_{ud} = \frac{2bw^3}{27\tau} + \frac{4bw^3}{27\tau} = \frac{6bw^3}{27\tau} \tag{2.40}$$

2.2.3. Optimal discriminatory pricing

We define the monopsony's profit function under the od pricing scheme as:

$$\pi_{od} = 2\int_0^R (w-m)q(m-\tau r)D(r)dr \tag{2.41}$$

Under od pricing, we must solve a variational problem, as we must determine the optimal price path from the firm to the market boundary in an endogenous market area.

We can define a variational problem (Meyberg and Vachenauer, 2003, p. 409) as:

$$I(y) := \int_{x_o}^{x_1} F(x, y(x))dx = Extr! \tag{2.42}$$

where F is a functional, and x and y are variables that are functions themselves. We must maximise $I(y)$ and determine the extremal value of F. We maximise $I(y)$ with respect to y using the Euler equation (Meyberg and Vachenauer, 2003, p. 409 and 414):

$$\frac{\partial F}{\partial y}(x, y) = 0 \tag{2.43}$$

Hence, we determine the optimal mill price by using the Euler equation. We can rewrite equation (2.41) as:

$$\pi_{od} = 2\int_0^R F(r, m(r))dr = Extr! \tag{2.44}$$

where $F(r, m(r)) = 2(w - m(r))q(m(r) - \tau r)D(r)$

The Euler equation for the variational problem (2.44) is:

$$2[(w-m)q'(m-\tau r) - q(m-\tau r)]D(r) = 0 \tag{2.45}$$

We derive the optimal market area with the aid of the transversality condition[9]:

$$2[w - m(R)]q[m(R) - \tau R]D(R) = 0 \tag{2.46}$$

Equation (2.45) shows that the optimal price path depends on space, the marginal revenue, and the transport costs:

$$m^* = m^*(r, w, \tau) \tag{2.47}$$

If the density is greater than zero for all *r*, then the od pricing is independent of the distribution of the sellers. Furthermore, the optimal price path is independent of the largeness of the market area and positive, depending on the net sales price.
We now introduce a linear supply function $q = bp$ and a density $D(r) = 1$.
In this case, we can describe the profit function as:

$$\pi_{od}^* = 2\int_0^R (w - m)b(m - \tau r)dr \tag{2.48}$$

Because the monopsonist maximises the price at each location, we define the gross profit at location *r* as:

$$\pi_{od}^g = (w - m)b(m - \tau r) \tag{2.49}$$

The first-order condition for maximising the gross profit at location *r* with respect to *m* is the following:

$$(w - m)b - b(m - \tau r) = 0 \tag{2.50}$$

Therefore, the optimal mill price is:

$$m^* = \frac{w + \tau r}{2} \tag{2.51}$$

Equation (2.51) shows that the freight rate is absorbed by half of the transport costs carried by the seller.
To obtain the optimal market area we substitute $m*$ into equation (2.48) and maximising the

[9] We use the transversality condition if there is no boundary condition. Here, the terminal value *m*(*R*) is not fixed. The transversality condition avoids the problem of an Euler equation with undefined quantities, i.e., the Euler equation is satisfied (see the following for further details: Sydsæter et al. (2008, p. 300 ff.); Meyberg and Vachenau (2003, p. 420 f.)).

profit with respect to R:[10]

$$R^*_{od} = \frac{w}{\tau} \tag{2.52}$$

Inserting the optimal mill price and the market area in equation (2.48), we obtain the optimal profit and total supply under od pricing:

$$\pi^*_{od} = \frac{bw^3}{6\tau} \tag{2.53}$$

$$Q^*_{od} = \frac{bw^2}{2\tau} \tag{2.54}$$

Similar to fob and ud pricing, under od pricing, the optimal market area, the profit and the total quantity are also positive, depending on the net sales price and negative, depending on the transport costs ($\partial R^*_{od} / \partial w = 1/\tau > 0$ and $\partial R^*_{od} / \partial \tau = -1/\tau^2 < 0$; $\partial Q^*_{od} / \partial w = bw/\tau > 0$ and $\partial Q^*_{od} / \partial \tau = -2bw^2/\tau^2 < 0$; $\partial \pi^*_{od} / \partial w = bw^2/\tau > 0$ and $\partial \pi^*_{od} / \partial \tau = -bw^3/2\tau^2 < 0$).

Finally, we calculate the producer surplus and the welfare which is equal to the producer surplus plus the consumer surplus (= profit). Equations (2.55) and (2.56) present the producer surplus generally under od pricing and in detail for a linear supply and a density of one, respectively:

$$PS_{od} = 1/2\left[2\int_0^R b(m-\tau r)(m-\tau r)dr\right] = \int_0^R b(m-\tau r)^2\, dr \tag{2.55}$$

$$PS_{od} = \frac{bw^3}{12\tau} \tag{2.56}$$

In addition, we can calculate the welfare as follows:

$$\Omega_{od} = PS_{od} + CS_{od} = \frac{bw^3}{6\tau} + \frac{bw^3}{12\tau} = \frac{bw^3}{4\tau} \tag{2.57}$$

[10] Schöler (2005, p. 87 f.)

2.2.4. Comparison of spatial pricing strategies

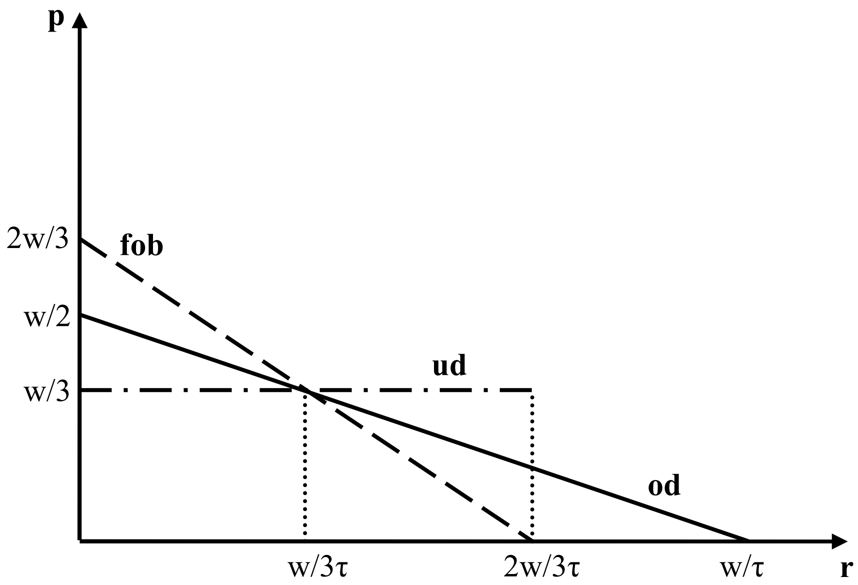
Table 1 summarises the results of the three different pricing strategies.

Table 1: Comparative statistics of the three pricing strategies (with a linear supply function and a uniform density of one)

	FOB	UD	OD
m^*	$\frac{2w}{3}$	$\frac{w}{3}$	$\frac{w+\tau r}{2}$
p^*	$\frac{2}{3}w-\tau r$	$\frac{1}{3}w$	$\frac{1}{2}w-\frac{1}{2}\tau r$
R^*	$\frac{2w}{3\tau}$	$\frac{2w}{3\tau}$	$\frac{w}{\tau}$
Q^*	$\frac{4bw^2}{9\tau}$	$\frac{4bw^2}{9\tau}$	$\frac{bw^2}{2\tau}$
π^*	$\frac{4bw^3}{27\tau}$	$\frac{4bw^3}{27\tau}$	$\frac{bw^3}{6\tau}$
Ω	$\frac{20bw^3}{81\tau}$	$\frac{6bw^3}{27\tau}$	$\frac{bw^3}{4\tau}$

The optimal mill price is higher under fob pricing than under ud pricing. These results cannot be compared with the mill price under od pricing, as this price is dependent on the distance r. To clarify this point, we depict the net price in Figure 1. Under fob and od pricing, the net price for the seller at each point in the market is different. In contrast, under ud pricing, the net price does not vary over space. Hence, we can illustrate the net price p as a function of the distance r (see Figure 1). Therefore, under ud pricing, complete freight absorption (i.e., the seller carries no transport costs) occurs. Under od pricing, half of the transport costs is absorbed, and under fob pricing, there is no freight absorption, i.e., the seller carries all of the transport costs. If the seller is near the buyer’s location, then the fob price represents the highest price for the seller. However, if the seller is located far away from the buyer, then the ud price provides the highest price. The od pricing is always the mean of the ud and fob price within the market area of $2w/3\tau$. Additionally, Figure 1 and Table 1 display the market area, which is the same under fob and ud pricing. Od pricing leads to a greater market area than the other two price strategies.

Figure 1: Curve of the net price p with the three price strategies:
Dependence of the net price p on the distance r



Source: Own illustration modelled after Schöler (2005, p. 89) and Anderson et al. (1992, p. 323)

Furthermore, the total supply and the monopsony's profit are equivalent under ud and fob pricing, whereas od pricing induces the highest quantity and profit. Hence, a single firm would prefer od pricing over the other pricing schemes under the following three conditions (Schöler, 2005, p. 88):

a) the aforementioned price strategy must not be forbidden by the competition laws,

b) od pricing must be seen as a fair price strategy by the public and the sellers and

c) the costs of finding the optimal price at each location cannot be higher than $bw^3/54\tau$ (i.e., the profit under od pricing is $bw^3/54\tau$ higher than the profit under ud or fob pricing).

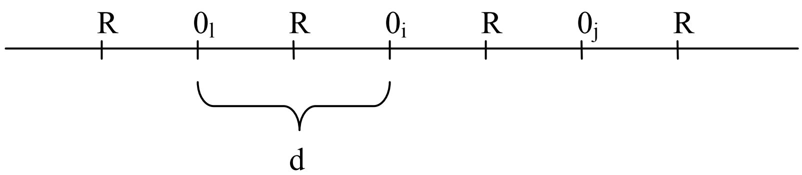
Finally, we need to analyse the welfare, i.e., the producer surplus plus the consumer surplus. As the consumer surplus is equal to the monopsony's profit, the highest consumer surplus occurs under od pricing. Ud and fob pricing achieve the same consumer surplus. Additionally, the highest producer surplus is realised under fob pricing, and the lowest producer surplus occurs under ud pricing. However, we must analyse the whole welfare of the market. Table 1 shows the results of this analysis. Hence, the highest welfare exists under od pricing, and the lowest welfare exists under ud pricing. As Schöler (2005, p. 90 f.) argues, one must consider the fact that the market area is different under the three pricing strategies. Thus, we can also calculate the welfare by estimating the welfare per capita. The welfare per capita is equal to the welfare divided by the whole market area $2R^*$. Note that the density is one in this case. We obtain the following results: $\Omega^c_{fob} = \frac{5bw^2}{27}$, $\Omega^c_{ud} = \frac{bw^3}{6}$ and $\Omega^c_{od} = \frac{bw^2}{8}$. Now the highest welfare per capita exists under fob pricing, and the lowest welfare per capita exists under od pricing. Moreover, the producer surplus per capita yields new results. Specifically, the producer surplus per capita under fob pricing is the highest, and the lowest producer surplus per capita exists under od pricing ($PS^c_{fob} = \frac{2bw^2}{27}$, $PS^c_{ud} = \frac{bw^2}{18}$ and $PS^c_{od} = \frac{bw^2}{24}$).[11]

Therefore, we can conclude that no definite answer exists regarding the effects of welfare. The sellers prefer fob pricing, and the buyers prefer od pricing. However, from a macroeconomic perspective, fob pricing is the best solution for the welfare per capita, whereas od pricing is the optimal solution for the whole welfare. At the same time, from each perspective, the fob pricing is preferable to ud pricing.

2.3. Spatial competition between buyers

Compared with the buyer's market area in a spatial monopsony, the buyer's market area within an oligopsony is not isolated. Instead, the market areas have shared boundaries. Compared with the assumptions underlying the monopsony, only three assumptions are modified in the case of the oligopsony (Schöler 2005, p. 92 ff.):

Assumption 2: In a linear market, a firm is always located at point 0. Its market area ranges in each direction from 0 to the boundary *R*. The market area of firm *i* is connected to the market areas of *i*'s competitors (e.g., *j* and *l*). No monopsony exists, and each market area has two neighbours. Additionally, we assume that there are no overlapping market areas.[12] The distance between two competitors is *d*.



Assumption 6: The buyers' goals are to maximise their profits. The production costs and the structure of the supply are identical for all buyers. Therefore, we use the concept of a representative firm. By doing so, we can analyse a duopsony without risking the loss of information.

[11] There is no consumer surplus per capita, as only one buyer exists.
[12] We will provide a model with overlapping market areas in section 2.4.

Assumption 8: This analysis only applies to the short-term phenomena. Firms do not relocate, and new firms do not enter the market.

In addition, we introduce one new assumption:

Assumption 9: Input sellers maximise their profits and sell their products to the firm, which buys their products at their location for the highest net price $m - \tau r$. As the distance between the competitors, e.g., firm i and j, is d, we define the market area R of firm i as:

$$m_i - \tau R = m_j - \tau(d - R) \quad \text{or} \quad R = (m_i - m_j + \tau d)/2\tau \tag{2.58}$$

where m_i is the mill price of firm i, and m_j is the mill price of firm j.

Another important feature of spatial competition is the strategies that explain how a competitor reacts to a change in a buyer's price. If firm i changes its mill price by dm_i, then the firm expects its competitor to change its price by dm_j. A price change dm_j in reaction to a price change dm_i is called the conjectural reaction θ ($\theta = dm_j/dm_i$). As no overlapping market areas exist, the price change and the resulting competition strategy can lead to a change in the market area. We define the change in the market area caused by a change in the mill price by differentiating the market area (see equation (2.58)) with respect to the mill price:

$$\partial R/\partial m_i = (1 - \theta_{ij})/2\tau \qquad \text{where } \theta_{ij} = \partial m_j/\partial m_i \tag{2.59}$$

As we have a representative firm the competition strategy exists not only between firms i and j but also between firms i and l, as well as among all other firms. Hence, the market area always depends on its own mill price and the competitor's mill price, i.e., $R(m_i, m_j)$ and $R(m_i, m_l)$. Additionally, the rival's mill price depends on firm i's mill price, i.e., $m_j(m_i)$ and $m_l(m_i)$.

2.3.1 Nature of spatial competition

Many different conjectural reactions exist. The three most well-known conjectural reactions are the following:

- Löschian competition: each firm assumes that its competitor reacts to an own price change with the same price change in terms of direction and magnitude (Lösch, 1962). For example, if firm i increases its price by five Euros, then its competitor j will also increase its price by five Euros. Hence the conjectural reaction θ_{ij} is equal to one, and the market boundary does not change ($\partial R/\partial m_i$ = 0).[13]

- HS competition: each firm assumes that its competitor does not react to an own price change at all (Hotelling, 1929; Smithies, 1941). For example, if firm *i* increases its price by five Euros, then its competitor *j* will not change its price. Hence, the conjectural reaction θ_{ij} is equal to zero, and the market boundary changes as follows: $\partial R / \partial m_i = \frac{1}{2\tau}$.
- GO competition: each firm assumes that its competitor reacts to an own price change with the same price change but in the opposite direction. Additionally, firms assume that the price at the market boundary is constant (Greenhut and Ohta, 1975). For example, if firm *i* increases its price by five Euros, then its competitor *j* will decrease its price by five Euros. Hence, the conjectural reaction θ_{ij} is equal to minus one and the market boundary changes as follows: $\partial R/\partial m_i = 1/\tau$.

Most scholars illustrate spatial competition in oligopsonies by using the example of duopolies. Therefore, we derive models for spatial oligopsonies, based on spatial oligopolistic models under fob (Schöler, 2005, p. 94 ff.), ud (Gronberg and Meyer, 1981; Schöler, 2005, p. 99ff; Schuler and Hobbs 1982) and od pricing (Hobbs, 1986; Schöler, 1988, p. 222 ff.; Schöler, 2005, p. 101 ff.). By doing so, we analyse the three competition strategies and compare them under every pricing strategy. Furthermore, we assume that the supply function is linear ($q = bp$) and that the density function of the sellers in space is equal to one. The duopsony consists of firm *i* and its neighbouring firm *j*. Based on the concept of a representative firm, we examine the optimal mill price, market area and profit of firm *i*.

2.3.2 Free on board pricing

We define the profit function of the input buyer *i* as follows:

$$\pi = 2\int_0^R (w - m_i) b(m_i - \tau r) dr \quad \text{or dissolved} \quad \pi = 2bR(w - m_i)(m_i - 1/2\tau R) \qquad (2.60)$$

Maximising the profit with respect to m_i, we obtain the following first-order condition:

$$\frac{\partial \pi}{\partial m_i}: 2bR'(w - m_i)(m_i - 1/2\tau R) - 2bR(m_i - 1/2\tau R) + 2bR(w - m_i)(1 - 1/2\tau R') = 0 \quad (2.61)$$

[13] We derive the alteration of market area R by inserting the value of θ_{ij} in equation (2.59) (analogous to HS and GO competition).

where $R' = \partial R/\partial m_i = (1 - \theta_{ij})/2\tau$.
Simplifying equation (2.61), we obtain:

$$\frac{\partial \pi}{\partial m_i} : R' m_i^2 + m_i (2R - R'w - \tau RR') + w\tau RR' - wR - 1/2\tau R^2 = 0 \quad (2.62)$$

Assuming that θ ≠ 1[14], we generate the following two solutions for the optimal mill price:

1. $m_i^* = 0.5[(-2R + R'w + \tau RR')/R']$
$$+ (1/(2R'))\sqrt{(2R - R'w - \tau RR')^2 - 4(R')^2 Rw\tau + 4wRR' + 2\tau R' R^2} \quad (2.63)$$

2. $m_i^* = 0.5[(-2R + R'w + \tau RR')/R']$
$$- (1/(2R'))\sqrt{(2R - R'w - \tau RR')^2 - 4(R')^2 Rw\tau + 4wRR' + 2\tau R' R^2} \quad (2.64)$$

We can rewrite equations (2.63) and (2.64) such that $R' = (1 - \theta)/2\tau$:

$$m_i^* = (-2R + (1-\theta)w/2\tau + R(1-\theta)/2)\frac{\tau}{(1-\theta)}$$
$$+ \sqrt{(4R^2 + w^2(1-\theta)^2/4\tau^2 + R^2(1-\theta)^2/4 - R^2(1-\theta) - wR(1-\theta)^2/2\tau)/\frac{(1-\theta)^2}{\tau^2}} \quad (2.65)$$

and

$$m_i^* = (-2R + (1-\theta)w/2\tau + R(1-\theta)/2)\frac{\tau}{(1-\theta)}$$
$$- \sqrt{(4R^2 + w^2(1-\theta)^2/4\tau^2 + R^2(1-\theta)^2/4 - R^2(1-\theta) - wR(1-\theta)^2/2\tau)/\frac{(1-\theta)^2}{\tau^2}} \quad (2.66)$$

To maximise the profit, we require a mill price in which the second-order condition is negative. In Appendix A, Appendix B and Appendix C, we derive a proof for the maximum for all of the competition strategies. The results reveal that Löschian, HS and GO competition only have one solution for the mill price, which is also a maximum.
For HS competition ($\theta = 0$), we obtain the following optimal mill price:

$$m_{HS}^* = \tau(w/2\tau - 1.5R) + \sqrt{\tau^2(3.25R^2 + w^2/4\tau^2 - wR/2\tau)} \quad (2.67)$$

For GO competition ($\theta = -1$), we calculate the following optimal mill price:

[14] In the following, we will write θ_{ij} as θ. If $\theta = 1$, then R' is equal to zero, and we obtain another solution for the mill price. This case is applicable for the Löschian competition, as we show later.

$$m_{GO}^{*} = \tau(w/2\tau - 0.5R) + \sqrt{\tau^2(0.75R^2 + w^2/4\tau^2 - wR/2\tau)} \qquad (2.68)$$

For Löschian competition ($\theta = 1$), the derivation of the profit function is shorter, as the market area does not react to a price change ($R' = 0$). In equation (2.61), we can set all R' to zero and solve the equation for the mill price:

$$m_L^{*} = 0.5w + 0.25\tau R \qquad (2.69)$$[15]

The three price curves show that the movement of the mill price depends on the market area. However, the market area cannot be greater than the monopsony's market radius ($R = 2w/3\tau$) if profit maximisation is assumed. To graphically illustrate the three price curves, we assume that w is equal to 40 and that τ is equal to one. Additionally, we calculate an isoprofit curve to compare the mill price and market area under Löschian, HS and GO competition. We define the isoprofit curve as:

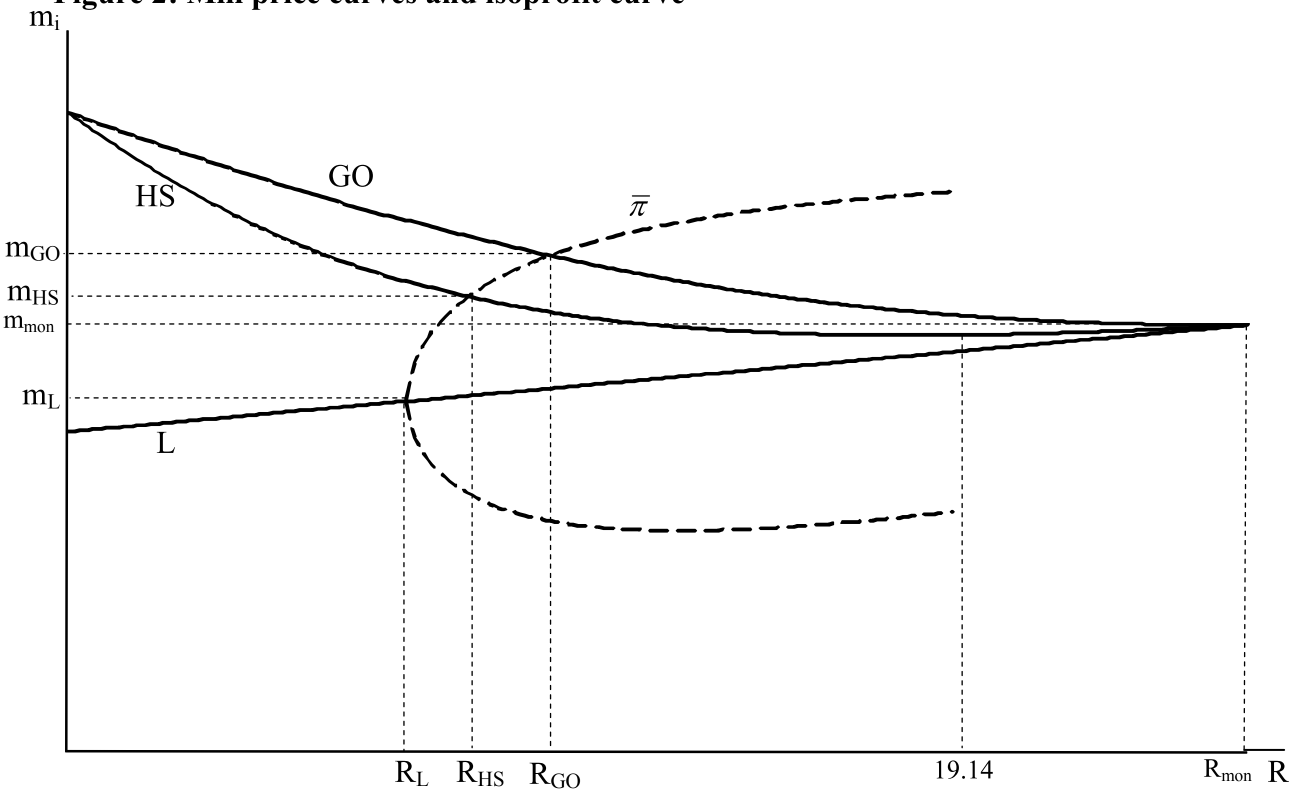
$$2bR(w - m_i)(m_i - 1/2\tau R) = \bar{\pi}_i \qquad (2.70)$$

where $\bar{\pi}_i$ is a fixed profit.

[15] In the following, index L denotes Löschian competition.

Figure 2 shows the price curves of all competition strategies and one representative isoprofit curve.

Figure 2: Mill price curves and isoprofit curve



Source: Own illustration modelled after Schöler (2005, p.98)

The mill price under Löschian competition increases if the market area *R* increases. In contrast, the price curve under GO competition decreases over the space *R*. Under HS competition, the mill price decreases first if the market area R increases. However, between *R* = 19.14 and R_{mon}, the mill price increases marginally if the market area increases. All of the price curves converge at the monopsony's mill price (m_{mon} = 26 ⅔) in the monopsony's market area R_{mon} = 26 ⅔. Economic logic dictates that the mill price decreases if the market area increases, as a larger market area implies a smaller number of competitors and, therefore, a less competitive environment. However, the mill price curve under Löschian competition and partly under HS competition shows the opposite relationship. A possible explanation is that the firms that decrease their mill prices lose few input sellers at the market boundary to their competitors if the competitors react to the firms' price changes with the same price changes in terms of direction. Under Löschian competition, firms lose none of their input sellers to their competitors, as the competitors reacts with the same price change in terms of direction and magnitude. Therefore, a firm can only lose its input sellers because of price elasticity of supply. For example, in the agricultural markets, the price elasticity of supply is often inelastic or low. Hence, a decreasing mill price can imply less supply and a higher profit at the same time if the decreased costs, i.e., the decreased mill price, compensate for the loss in sellers. However, the price elasticity of supply is crucial, determining whether the profit increases or decreases.

Figure 2 illustrates an isoprofit curve that is representative for all isoprofit curves. The curve demonstrates a given profit over a varying market area. The profit is higher if the isoprofit curve lies further to the right. Regardless of the value of the profit, each isoprofit curve illustrates the relationship among the three mill prices and among the three market areas. Given that a profit exists, the mill price is always highest under GO competition and lowest under Löschian competition. Additionally, the smallest market area exists under Löschian competition, and the largest market area exists under GO competition. Under HS competition, the mill price and the market area are located between the respective prices and the areas of Löschian and GO competition.

Finally, we compare the profits under the three pricing strategies. We insert the optimal mill prices m_L^*, m_{HS}^*, m_{GO}^* into the profit function (equation (2.60)):

$$\pi_L^* = 2bR(0.5w - 0.25\tau R)^2 \tag{2.71a}$$

$$\pi_{HS}^* = 2bR\left(0.5w + 1.5\tau R - \sqrt{\tau^2(3.25R^2 + w^2/4\tau^2 - wR/2\tau)}\right)\times \left(0.5w - 2\tau R + \sqrt{\tau^2(3.25R^2 + w^2/4\tau^2 - wR/2\tau)}\right) \tag{2.71b}$$

$$\pi_{GO}^* = 2bR\left(0.5w + 0.5\tau R - \sqrt{\tau^2(0.75R^2 + w^2/4\tau^2 - wR/2\tau)}\right)\times \left(0.5w - \tau R + \sqrt{\tau^2(0.75R^2 + w^2/4\tau^2 - wR/2\tau)}\right) \tag{2.71c}$$

As the profit functions are too complex to compare, we solve this problem numerically by assuming that $b = 1$, $\tau = 1$ and $w = 40$. Therefore, the profits under Löschian, HS and GO competition depend only on the market area R.[16] Table 2 shows that the firm's profit is maximised under Löschian competition and minimised under GO competition. These results are also valid for $R < 1$ and $R > 20$.

[16] Although, we can compare profit functions, which depend on τ or w, we choose to compare the profit functions depending on the market area R, as the spatial factor is more important than the sales price for the purpose of this doctoral thesis.

Table 2: Comparison of the profits under Löschian, GO and HS competition

R	π^*_L	π^*_{HS}	π^*_{GO}
1	780.1	144.5	76.0
2	1521.0	520.8	288.6
3	2223.4	1053.1	615.3
4	2888.0	1680.2	1034.6
5	3515.6	2354.5	1526.5
6	4107.0	3041.1	2072.3
7	4662.9	3715.6	2654.8
8	5184.0	4362.4	3258.3
9	5671.1	4971.8	3869.1
10	6125.0	5539.0	4474.9
11	6546.4	6061.9	5065.5
12	6936.0	6540.4	5632.1
13	7294.6	6975.5	6168.1
14	7623.0	7368.7	6668.0
15	7921.9	7722.0	7128.2
16	8192.0	8037.2	7546.2
17	8434.1	8316.4	7920.7
18	8649.0	8561.3	8251.6
19	8837.4	8773.8	8539.2
20	9000.0	8955.4	8784.6

2.3.3 Uniform delivered pricing

After analysing spatial competition under fob pricing, we examine ud pricing. In this case, the seller's net price is constant over the whole market area. Assuming spatial competition and profit maximisation, we find that the market area of each competitor must be smaller than the monopsony's market area ($R < 2w/3\tau$).

We define the profit function of the buyer i under ud pricing as follows:

$$\pi = 2\int_0^R (w - m_i - \tau r) b m_i dr \quad \text{or dissolved} \quad \pi = 2bm_i(wR - m_i R - 1/2\tau R^2) \qquad (2.72)$$ [17]

In the case of Löschian competition, the market area is fixed, and each firm assumes that its competitors will respond to every one of its price changes with equal adjustments of their own prices. As overlapping markets do not exist (see assumption 2), a price change does not lead to a larger market area but to higher costs as m_i increases. The rational strategy for the firm is to collude with other firms and to split the market into equal halves (Gronberg and Meyer,

[17] This profit function is the same for buyer *j*, as the firms are identical.

1981).[18] Each firm takes its closest half of the distance *d* and regards its market area $\bar{d}/2$ as fixed.[19] Both buyers set the same ud price and maximise their profits (see equation (2.72)) with respect to *m* by holding *R* fixed at $\bar{d}/2$. The optimal mill price is:

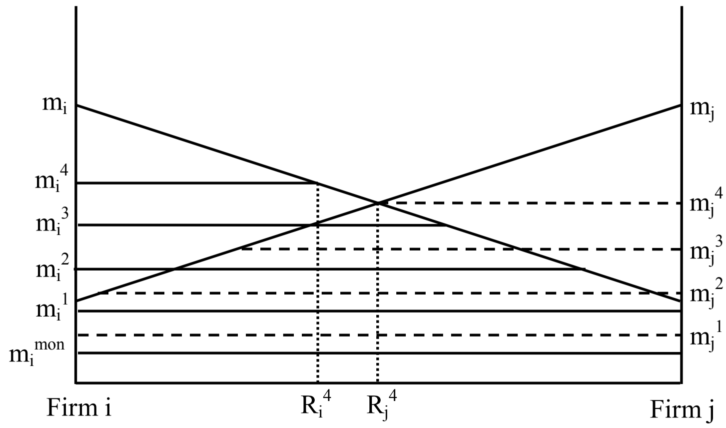
$$m_L^* = 1/2w - 1/8\tau\bar{d} \qquad \text{or} \qquad m_L^* = 1/2w - 1/4\tau R \tag{2.73}$$

which is equal to the monopsony's price.
Inserting the optimal mill price into equation (2.72), we obtain the optimal profit:

$$\pi = b\bar{d}\left(\frac{w}{2} - \frac{1}{8}\tau\bar{d}\right)^2 \qquad \text{or} \qquad \pi = 2bR\left(\frac{w}{2} - \frac{1}{4}\tau R\right)^2 \tag{2.74}$$

As we can see, the profit under Löschian competition and ud pricing is the same as that under Löschian competition and fob pricing if *R* is fixed at $\bar{d}/2$. The long-term equilibrium is realized when the profits are equal to zero. That is, the firms enter the market and adjust $\bar{d}$ until their profits are equal to zero.[20]
Under HS competition, the buyers face two options: an unstable option in pure strategies or a stable equilibrium in mixed strategies. First, we evaluate the unstable alternative (Schuler and Hobbs, 1982; Schöler, 2005, p. 99 ff.), which consists of a dynamic price cycle (see Figure 3).

Figure 3: Undercutting and conceding behaviour



Source: Own illustration modelled after Schuler and Hobs (1982, p. 177)

[18] Collusion allows for territorial arrangements.
[19] As we assumed that the market area is $2R$ and extends in both directions of the firm, the firm will have a fixed market area $\bar{d}/2$ and in its backyard, the firm can act as a monopsony. Given that the duopsony is illustrated as a simplification of spatial competition, we assume that there are also competitors in the backyard of the firm and that the firm will have the fixed market area $\bar{d}/2$ in both directions.
[20] We can realize another outcome of Löschian competition and ud pricing under overlapping markets, which will be explained in section 2.4.

Firms i and j are established at the end of a line and have a market area that extends in only one direction. However, the results are the same, even if there are more competitors in the backyard. The price line of firm i starts at point m_i and then decreases as the market area increases. The same is true for firm j. The price line between points m_i and m_j represents the willingness to act within a market area under ud pricing. In the bidding process, a firm such as buyer i first chooses the monopsony price m_i^{mon}. Next, firm j can overbid firm i by setting price m_j^1 and thereby steal firm i's entire market area. Consequently, firm i overbids its competitor to obtain the entire market area. The overbidding process continues until one firm reaches a price at which it is unwilling to continue operating within the whole territory. Price m_j^2 represents the point at which firm j will no longer serve the whole market area. The overbidding process continues until the firms' profits become equal to zero. However, if the firms are profitable, then the overbidding process will stop at a point at which the market area no longer expands (e.g., price m_j^4). Bidding beyond price m_j^4 leads to price m_i^4. Here, firm i does not obtain a larger market area but instead obtains a smaller market area R_i^4. Hence, additional overbidding results in no further gains. We define the non-negative profit as:

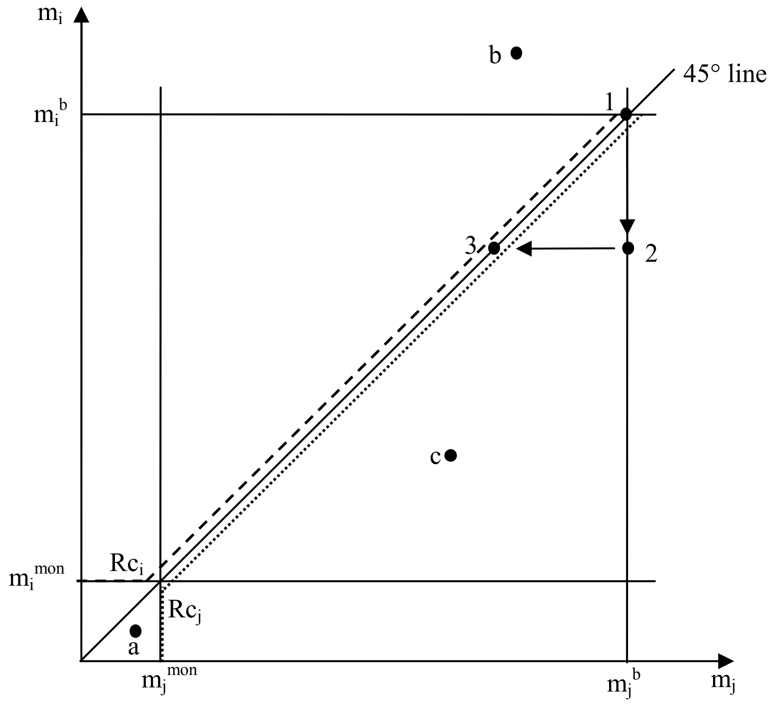
$$2bm_i(wR - m_iR - 1/2\tau R^2) = 0 \tag{2.75}$$

We calculate the upper price limit as:

$$m_i = w - \frac{1}{2}\tau R \tag{2.76}$$

After firm j sets the price at m_j^4, firm i no longer profit from making any more bids. Hence, firm i concedes and prefers to set the corresponding optimal monopsony price (e.g., m_i^2) for the remaining market area $d - R_j^{4\ 2}$. The sellers between firm i and R_j^4 prefer to sell their products to firm j at the higher price, but firm j does not buy outside of its market area R_j^4. As both firms are identical, firm i's decision is also the best decision for firm j. Thus, firm j decreases its price to m_j^3, and the overbidding process starts again. Hence, the pricing behaviour undergoes a dynamic cycle of overbidding and conceding. For a better understanding of this process, Figure 4 illustrates this dynamic pricing behaviour.

Figure 4: Dynamic pricing behaviour



Source: Own simplistic illustration modelled after Schuler and Hobbs (1982, p. 184)

Figure 4 partially illustrates firm *i*'s and firm *j*'s reaction curves. The x- and y- axes of the diagram displays the ud price of firm *j* (m_j) and the ud price of firm *i* (m_i). The point along the m_i-axis m_i^{mon} is the monopsony price of firm *i*, and m_i^b is the price beyond which overbidding no longer allows firm *i* to steal its neighbour's market area. Therefore, overbidding beyond this area leads to lower profits (similarly for firm *j*). Rc_i and Rc_j are the reaction curves of each firm. We only show the reaction curves between m_j^{mon} and m_j^b, as these curves are the important part of the dynamic cycle. Both reaction curves lay on the 45° line. We start from the initial point *a*, where both firms buy the product for a price less than the monopsony price. One firm will overbid until the price matches the monopsony price and the other firm will follow. Both firms will continue to overbid and travel up the 45° line in accordance with their reaction curves. Overbidding will stop when further overbidding no longer allows one firm to steal the other's market area. In the graph, point 1 represents the point at which overbidding ceases to be useful. When firm *j* reaches point 1, firm *i* will initially concedes the bidding war and decreases its price to point 2[21]. As both firms are identical, firm *j* now also lowers its price to point 3. Then the overbidding cycle is thus reinitiated. It is important to see that the dynamic price cycle will eventually exist within the triangle connecting points 1, 2 and 3. If

[21] Point 2 shows the optimal monopsony price for the remaining market area of firm *i*.

the initial price points are *b*, *c* or any other combination, then the price will reach the 45° line and the price cycle will eventually fall within the triangle connecting points 1, 2 and 3. Therefore, a stable equilibrium does not exist.

Another theoretical solution for HS competition would be collusion as already explained for Löschian competition (Schöler, 2005, p. 100 ff.; Schuler and Hobbs, 1982). Collusion will only be present if territorial arrangements are allowed, if the firms know the price cycle and if the price cycle proceeds infinitely fast such that a firm cannot own any temporary advantages by overbidding for a product. As these assumptions are unrealistic, collusion will not occur.

As explained above, no price equilibrium exists in pure strategies. However, an equilibrium exists for ud pricing and HS competition in mixed strategies. For example, Kats and Thisse (1993) analyse a duopoly under ud pricing and HS competition. They establish a two-stage game in which the firms simultaneously choose their locations in the first stage and determine their prices in the second stage. The result of their game suggests that under spatial competition, a unique location equilibrium and a price equilibrium exist in mixed strategies. Another study (Zhang and Sexton, 2001) examines a duopsony under ud pricing and HS competition. These researchers assume that a leader-follower situation exists with respect to the price. The authors find that price equilibrium exists in mixed strategies.[22]

We can show that GO competition under ud pricing is not possible. If a firm under ud pricing increases its price by a small amount, then the firm will obtain the whole market area and, therefore, can steal the competitor's market area. A competitor will not react by decreasing its price, as this reaction does not allow it to regain the market area. The firm will increase its price; however, the price at the boundary will not be the same as before. Hence, a condition of GO competition is broken, and GO competition cannot exist under ud pricing.

2.3.4 Optimal discriminatory pricing

In contrast to ud pricing, all competition strategies exist under od pricing. As shown previously, we derive oligopsonistic models under Löschian, HS and GO competition, which are based on oligopolistic models under Löschian (Schöler, 1988, p. 222 ff.), GO (Schöler, 1988, p. 225 ff.) and HS competition (Hobbs, 1986; Schöler, 2005, p. 101 ff.).

Under od pricing, the seller maximises the profit at each local market point and not over the whole market area. Because of spatial competition and profit maximisation, each competitor's

[22] Both papers refer to Dasgupta and Maskin's (1986) paper, which proves the existence of equilibrium in discontinuous economic games.

market area must be smaller than the monopsony's market area ($R < w/\tau$). As the seller i maximises the profit at each location, we define the gross profit under od pricing at the location r as follows:

$$\pi_i^g = (w - m_i)b(m_i - \tau r) \quad \text{or} \quad \pi_i^g = (w - p_i - \tau r)bp_i \; ^{23} \tag{2.77}$$

Maximising the gross profit at location r, we obtain the optimal local net price:

$$p_i(r) = (w - \tau r)/2 \tag{2.78}$$

Similarly, for the competing firms j and l, the optimal local net prices are:

$$p_j(r) = (w - \tau r)/2 \quad \text{and}$$

$$p_l(r) = (w - \tau r)/2 \tag{2.79}$$

Given that the competition's boundary lies between firms i and j, which are d units apart from one another, the two firms have the same local net price at the boundary:

$$p_i(R) = p_j(d - R) \quad \text{or} \quad (w - \tau R)/2 = (w - \tau d + \tau R)/2 \tag{2.80}$$

Solving equation (2.80), we define the market area as $d/2$.

Under Löschian competition, a firm assumes that its market area is fixed and that its competitors will respond to every price change with equal adjustments of their own prices. Hence, assuming that the market area R is fixed and that the optimal local price is $p_i(r)$, we calculate the resulting profit:

$$\pi = b/2(w^2 R - w\tau R^2 + 1/3\tau^2 R^3) \quad \text{or}$$

$$\pi = b/4(w^2 d - 1/2 w\tau d^2 + 1/12\tau^2 d^3) \tag{2.81}$$

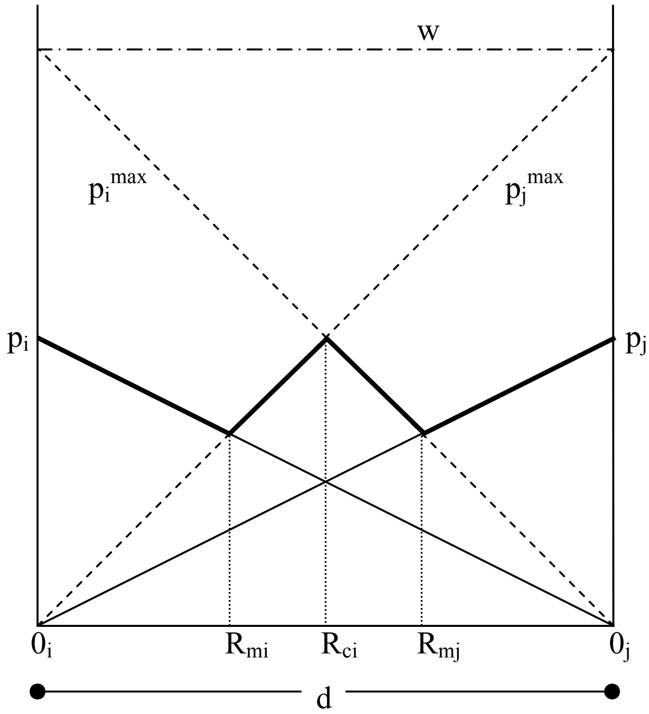
Next, we explain HS competition. Figure 5 shows two competing firms i and j. The two firms are located d units away from each other. The figure depicts the optimal local net prices for firms i and j (see equation (2.78) and (2.79)) as the continuous lines p_i and p_j, respectively. We depict the net sales price w, which is exogenous, as the horizontal dashed line w. We display the maximal local net prices that firms i and j are willing to pay as the dashed line p_i^{max} and p_j^{max}, respectively. We assume that each firm does not pay a mill price, which causes

[23] We replace m_i with $p_i + \tau r$, as under od pricing, $p_i = m_i - \tau r$.

a negative profit. Equation (2.77) shows that the maximal mill price that a firm is willing to pay is equal to the net sales price. A mill price that is greater than the net sales price induces a negative profit. Hence, we define the maximal local net prices p_i^{max} and p_j^{max} as:

$$p_i^{\max} = w - \tau r_i \qquad \text{and} \qquad p_j^{\max} = w - \tau r_j \tag{2.82}$$

Figure 5: HS competition under od pricing



Source: Own illustration modelled after Schöler (2005, p. 102)

Each firm will set the optimal local net price if no competition exists. As firms *i* and *j* both attempt to serve the whole market area between their firms' locations, competition exists. Therefore, each firm wants to expand its market area by raising its local net price and overbidding its competitor. Each firm can raise its price to the maximal local net price. A price higher than the maximal local net price is not profitable for either firm. Additionally, the seller offers its product to the firms, which pays the highest local net price.

Therefore, firm *i*'s market area is partly monopsonistic in that the firm's optimal local net price p_i is greater than firm *j*'s maximal local net price p_j^{max}:

$$(w - \tau r)/2 > w - \tau(d - r) \qquad \text{with} \quad r \in [0, R_{mi}[\tag{2.83}$$

where $R_{mi} = \frac{2}{3}d - \frac{w}{3\tau}$.

Figure 5 portrays firm i's monopolistic market area as the thick continuous line from 0_i to R_{mi}. Similarly, firm j's monopolistic market area is represented by the thick continuous line from 0_j to R_{mj}. At R_{mi}, i.e., the point at which firm i's price line crosses the line of firm j's maximal local net price, firm i marginally raises its price over firm j's maximal local net price. Hence, firm i's price is a little bit higher than firm j's maximal local net price and smaller than its own maximal local net price between R_{mi} and R_{ci}. Firm j will not offer a price that is higher than its maximal local net price (similarly, for firm j in the market area between R_{ci} and R_{mj}). R_{ci} is the market boundary at which the maximal local net prices of both firms are the same.

To estimate the profit of firm i under HS competition and od pricing, we calculate price p_{ci} for the market area $[R_{mi}, R_{ci}]$. Given that the price p_{ci} is a marginal amount ε over firm j's maximal local net price, we define p_{ci} as:

$$p_{ci} = w - \tau(d - r) \tag{2.84}$$

We previously calculated the price p_{mi} for the market area $[0_i, R_{mi}[$ (see equation (2.78)). Thus, we define the profit of firm i as[24]:

$$\pi_i = 2\int_0^{R_{mi}} (w - p_{mi} - \tau r) b p_{mi} dr + 2\int_{R_{mi}}^{R_{ci}} (w - p_{ci} - \tau r) b p_{ci} dr \qquad \text{or}$$

$$\pi_i = 2b \int_0^{\frac{2}{3}d - \frac{w}{3\tau}} \left(\frac{w}{2} - \frac{\tau r}{2}\right)^2 dr + 2b \int_{\frac{2}{3}d - \frac{w}{3\tau}}^{d/2} (\tau d - 2\tau r)(w - \tau d + \tau r) dr \tag{2.85}$$

Solving equation (2.85), we obtain the optimal profit under HS competition and od pricing:

$$\pi_i = b\left(\frac{1}{36}\tau^2 d^3 - \frac{1}{6} w\tau d^2 + \frac{1}{3} w^2 d - \frac{1}{18}\frac{w^3}{\tau}\right) \tag{2.86}$$

Under GO competition the firms assume that the price at the market boundary *p(R)* will be constant. Therefore, each firm aims to change its price in a direction such that the price at the market boundary *p(R)* will be constant. If one firm changes its price, then the other firm can realise the "original" price *p(R)* through a price reaction. The firm returns to the price *p(R)*

[24] In contrast to the author (Schöler, 2005, p. 102), we still define the profit function as price multiplied by quantity minus variable costs multiplied by quantity. Schöler defines the end profit as monopolistic profit plus competitive profit and each profit as price (monopolistic or competitive price) multiplied by quantity. The variable costs are not reduced in his profit function. In this paper, we deduct the variable costs from the revenue.

through an adjustment process in which the exogenous parameters are modified. Because of these modifications, the firm must change its price to the previous value.
As shown previously, we use the optimal local net price:

$$p^*(r) = (w - \tau r)/2 \qquad \forall r \in [0, w/\tau] \tag{2.87}$$

Depending on R, we can describe the optimal local price $p^*(R)$ as subject to R within the interval $[w/2,\ 0]$. We can rewrite equation (2.87) as:

$$p^*(R) = p'w \qquad \text{with } p' \in [1/2,\ 0] \tag{2.88}$$

Inserting equation (2.88) in the optimal local price $p(R) = (w - \tau R)/2$, we define the market area as:

$$R = w(1 - 2p')/\tau \tag{2.89}$$

The profit function of firm i is:[25]

$$\pi_i = 2 \int_0^{w(1-2p')/\tau} (w - p^* - \tau r) b p^* dr \qquad \text{or}$$

$$\pi_i = 2b \int_0^{w(1-2p')/\tau} \left(\frac{w}{2} - \frac{\tau r}{2} \right)^2 dr \tag{2.90}$$

Solving equation (2.90), we obtain the optimal profit under od pricing and GO competition:

$$\pi_i = \frac{b}{6\tau}(w^3 - 8(p')^3 w^3) \tag{2.91}$$

It is important to point out that the optimal profit depends on the price path p'.
Finally, we shall compare the three competition strategies. All of the profit functions rely on the transport costs τ, the parameter b and the net sales price w. The profit under Löschian and HS competition also depends on the distance between the firms d. In contrast, the profit under GO competition is constrained by the price path p'. Thus, we will examine Löschian and HS competition under the alternative distances between firms d. As shown previously, we set the transport costs τ to one, the parameter b to one and the net sales price w to 40. Hence, we can

[25] In contrast to the author (Schöler, 1988, p. 226), we define the profit function as price multiplied by quantity minus variable costs multiplied by quantity. Schöler does not deduct the variable costs from the revenue.

estimate the profit under Löschian competition with $d/2$ as the market area as follows:

$$\pi_L = \frac{1}{48}d^3 - 5d^2 + 400d \tag{2.92}$$

Under HS competition, we can only apply the profit function in equation (2.86) if the distance between the firms is greater than 20. Equation (2.83) shows that the optimal local price is only greater than the competitor's maximal local net price if d is greater than 20. If d is lower than or equal to 20, then firm i sets its price at a minimal amount over the competitor's maximal local net price. Hence the profit for HS competition and $d \in [0,\ 20]$ is:

$$\pi_{HS} = -\frac{5}{12}d^3 + 20d^2 \tag{2.93}$$

The profit for HS competition and $d \in]20,\ \infty[$ is:

$$\pi_{HS} = \frac{1}{36}d^3 - 6\frac{2}{3}d^2 + 533\frac{1}{3}d - 3555\frac{5}{9} \tag{2.94}$$

Table 3 displays the profits achieved under Löschian and HS competition for different values of d. As can be seen, the profit is always greater under Löschian competition than under HS competition.

Table 3: Profits under od pricing for Löschian and HS competition

d	π_L	π_{HS}
0	0	0
2	780	77
4	1521	293
6	2225	630
8	2891	1067
10	3521	1583
12	4116	2160
14	4677	2777
16	5205	3413
18	5702	4050
20	6167	4667
22	6602	5247
24	7008	5788
26	7386	6293
28	7737	6761
30	8063	7194

This result is due to the firm's monopsonistic behaviour under Löschian competition. Under Löschian competition, the firm can set the local net price of a monopsony over the whole market area, whereas under HS competition, the market area is only partially monopsonistic. However, rather fierce competition exists within the remaining market area under HS competition. Therefore, the profits are smaller under HS competition than under Löschian competition.

2.3.5 Comparison of spatial pricing and competition strategies

Under fob and od pricing, all three competition strategies, i.e. Löschian, HS and GO, are possible. In contrast, under ud pricing, GO competition is not feasible, and the other two competition strategies are only available under certain conditions. Ud pricing and Löschian competition exist only if collusion exists. If overlapping market areas exist, then ud pricing and a modified form of Löschian competition called PM competition are available. We will analyse this scenario in section 2.4. Additionally, ud pricing and HS competition exist only in mixed strategies. In section 2.4.1, we examine another alternative in which ud pricing and HS competition are realisable in pure strategies because of the sellers' marketing cooperatives.

Hence, we compare Löschian competition under the three price strategies and compare HS competition under fob and od pricing. To compare the results, we make numerical assumptions regarding the transport costs τ, the parameter b and the net sales price w. Then we compare the profits and mill prices with respect to the different market areas R or the distance between firms d. Although, we can perform the comparisons with respect to τ or w, we use the market area R because of its dependence on space. We do not provide a comparison of GO competition, as the profits can only be analysed under different p' and only for fob and od pricing.

As shown previously, the mill prices for the different pricing strategies under Löschian competition are:

$$m_{fob}^{L} = \frac{1}{2}w + \frac{1}{4}\tau R \tag{2.95a}$$

$$m_{ud}^{L} = \frac{1}{2}w - \frac{1}{4}\tau R \tag{2.95b}$$

$$p_{od}^{L} = \frac{w}{2} - \frac{1}{2}\tau r \qquad \text{or rather} \qquad m_{odp}^{L} = \frac{w}{2} + \frac{1}{2}\tau r \tag{2.95c}$$

The equations show that under ud pricing, the mill price is the lowest. Under fob pricing, the sellers receive a higher mill price than under od pricing if they are near the processing firm. If the sellers are more than half the distance of the market area away from the firm, then they obtain higher mill prices under od pricing. Depending on the distance between the buyer and seller, fob or od pricing provides the highest mill price.
Next, we compare the profits:

$$\pi_{fob}^{L} = 2bR\left(\frac{1}{4}w^2 - \frac{1}{4}w\tau R + \frac{1}{16}\tau^2 R^2\right) \tag{2.96a}$$

$$\pi_{ud}^{L} = 2bR\left(\frac{1}{4}w^2 - \frac{1}{4}w\tau R + \frac{1}{16}\tau^2 R^2\right) \tag{2.96b}$$

$$\pi_{od}^{L} = 2bR\left(\frac{1}{4}w^2 - \frac{1}{4}w\tau R + \frac{1}{12}\tau^2 R^2\right) \tag{2.96c}$$

The profits under fob and ud pricing are the same (see equation (2.96a) and (2.96b)). The equations also provide proof that the profit under od pricing is always greater than the profit under fob or ud pricing if Löschian competition exists. Additionally, we numerically compare the profits, while we assume that $\tau = 1$, $w = 40$ and $b = 1$.

Table 4: Comparison of the profits under Löschian competition for fob, ud and od pricing

R	π_{fob}^{L}	π_{ud}^{L}	π_{od}^{L}
1	780.1	780.1	780.2
2	1521.0	1521.0	1521.3
3	2223.4	2223.4	2224.5
4	2888.0	2888.0	2890.7
5	3515.6	3515.6	3520.8
6	4107.0	4107.0	4116.0
7	4662.9	4662.9	4677.2
8	5184.0	5184.0	5205.3
9	5671.1	5671.1	5701.5
10	6125.0	6125.0	6166.7
11	6546.4	6546.4	6601.8
12	6936.0	6936.0	7008.0
13	7294.6	7294.6	7386.2
14	7623.0	7623.0	7737.3
15	7921.9	7921.9	8062.5
16	8192.0	8192.0	8362.7
17	8434.1	8434.1	8638.8
18	8649.0	8649.0	8892.0
19	8837.4	8837.4	9123.2
20	9000.0	9000.0	9333.3

Table 4 affirms equations (2.96a) – (2.96c) and shows that the profit under od pricing is maximised at all times. We also perform calculations for $R < 1$ and $R > 20$ and find the same results.

Finally, we compare the profits under HS competition. Here, we can only check fob pricing against od pricing because ud pricing and HS competition do not exist under the described conditions. The profit functions under HS competition are:

$$\pi_{fob}^{HS} = 2bR\left(\frac{w}{2} + 1.5\tau R - \sqrt{\tau^2(3.25R^2 + w^2/4\tau^2 - wR/2\tau}\right)\times$$

$$\left(\frac{w}{2} - 2\tau R + \sqrt{\tau^2(3.25R^2 + w^2/4\tau^2 - wR/2\tau}\right) \quad \text{or}$$

$$\pi_{fob}^{HS} = bd\left(\frac{w}{2} + 0.75\tau d - \sqrt{\tau^2(0.8125d^2 + w^2/4\tau^2 - wd/4\tau}\right)\times$$

$$\left(\frac{w}{2} - \tau d + \sqrt{\tau^2(0.8125d^2 + w^2/4\tau^2 - wd/4\tau}\right) \tag{2.97a}$$

$$\pi_{od}^{HS} = b\left(-\frac{5}{12}\tau^2 d^3 + \frac{1}{2}w\tau d^2\right) \qquad \text{if } d \leq 20$$

$$\pi_{od}^{HS} = b\left(\frac{1}{36}\tau^2 d^3 - \frac{1}{6}w\tau d^2 + \frac{1}{3}w^2 d - \frac{1}{18}\frac{w^3}{\tau}\right) \qquad \text{if } d > 20 \tag{2.97b}$$

Because the profit under od pricing depends on the distance between firms (d), we rewrite the profit under fob pricing as being dependent on d. Given that $m_i - R_i = m_j - (d - R_i)$ and that the firms are identical (see the assumptions presented in section 2.3), the mill prices of the two firms at the market boundary are the same. Hence, we can define R_i as $d/2$ and insert R_i into the first part of equation (2.97a).

We can no longer compare equations (2.97a) and (2.97b) because they are too complex. We numerically analyse the profits with different distances between the firms d (assumptions: $\tau = 1$, $b = 1$ and $w = 40$). Table 5 illustrates the results. As shown by the table, the profit under fob pricing is higher than the profit under od pricing if d is smaller than 41.4. If d is greater than or equal to 41.4, then od pricing is more profitable for the firm. We perform the calculations for $d > 48$ and find the same result.

Table 5: Comparison of the profits under HS competition for fob and od pricing

d	π_{fob}^{HS}	π_{od}^{HS}
0	0	0
4	521	293
8	1680	1067
12	3041	2160
16	4362	3413
20	5539	4667
24	6540	5788
28	7369	6761
32	8037	7595
36	8561	8300
40	8955	8889
41	9035	9019
42	**9108**	**9142**
44	9232	9371
48	9403	9756

These results are due to the rather fierce competition that exists under od pricing if the firms are not far away. In this case, the firms have no or only a small partially monopolistic market area. Consequently, the firms have higher profits under fob competition, as the competition is more mild in this case. However, if the distance between the firms is sufficiently large, then the firms have a rather large partially monopolistic market area under od pricing and obtain higher profits than they do under fob pricing.

2.4 Theoretical models and hypotheses concerning the raw milk market

Raw milk markets are often characterised by ud pricing and overlapping market areas. Hence, we discuss two models to account for the characteristics of this market. Graubner et al. (2011) analyse the spatial competition in the presence of sellers' marketing cooperatives. By doing so, the researchers examine non-cooperative HS competition and a modified form of cooperative Löschian competition (i.e., PM competition). The second model by Alvarez et al. (2000) assumes that PM competition exists and analyses a duopsony market with different degrees of overlap. In addition to these two models, we derive some spatial hypotheses regarding the German raw milk market.

2.4.1 Spatial competition in the presence of marketing cooperatives: theoretical model by Graubner et al.

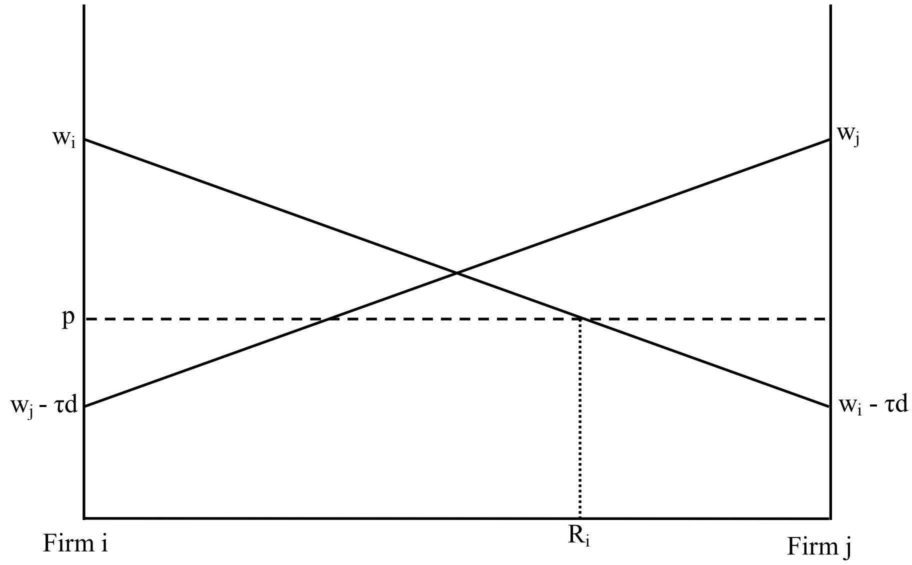
Graubner et al. (2009 and 2011) present a spatial competition model based on most of the assumptions outlined in section 2.3:

- a product with homogenous input exists in a linear market,
- the sellers[26] have a density equal to one and are equally distributed,
- the transportation costs τ per unit input and distance are constant at every point in the market,
- the buyer[27], an iof, pursues profit maximisation,
- the buyer of the input product resells the processed product at a constant price Wp,
- as the production costs δ are constant, the net sales price w is equal to $Wp - \delta$.

In contrast to the previously presented models, this model analyses a duopsony with processors i and j that are located at the endpoints of the line (see Figure 6). Processor i is located at $r = 0$, and processor j is located at $r = d$. The distance between the firms is $d = 1$, and the distance from processor i to a seller is r, whereas the distance from processor j to a seller is $d - r$. The sellers receive the same ud price p at every location r. The supply function is identical for all of the producers and is defined as $q(p) = p^e$, with $e \geq 0$ as the price elasticity of supply. In contrast to the supply function introduced in section 2.3, the supply function here is more flexible and can describe a quota system with $e = 0$ or close to 0, as well as systems with a higher price elasticity of supply, i.e., $e > 0$.

[26] Hereafter, we will also call the seller 'producer'.
[27] In this context, we will also call the buyer 'processor' or 'firm'.

Figure 6: A spatial duopsony in a linear market



Source: Graubner et al. (2011)

Under monopsonistic competition, the firms do not serve at location *r*, where the local profits are negative. That is, because the transport costs *τr* plus the net price *p* cannot exceed the net sales price *w*, the market boundary is defined by zero profits (for a proof, see Appendix D). However, the exogenous restrictions or the characteristics of the market can induce a situation in which the processor cannot choose the optimal market area. For the German raw milk market, this characteristic exists in the form of marketing cooperatives. Farmers cooperate and concentrate their supply of raw milk to increase their market power. These marketing cooperatives follow a type of horizontal integration, are commonly used in the production of some agricultural goods, such as milk or cereals, and exist in many countries (e.g., Rotan, 2001). In 2007, 139 German marketing cooperatives were registered in the raw milk sector (BMELV, 2008). Marketing cooperatives deliver a considerable share of processed milk. For example, marketing cooperatives delivered 34% of the processed milk in Saxony in the year 2005 and 20% of the processed milk in Bavaria in 2008.[28] Additionally, the law supports the formation of marketing cooperatives (Marktstrukturgesetz). Farmers forming a marketing cooperative can receive subsidies in the first 5 years after their cooperative is approved and can apply for investment grants. The members of a marketing cooperative are (arbitrarily) distributed over space. Therefore, processors competing for the marketing cooperatives' supply must partly collect milk from locations in which the local profit is negative; however,

[28] The data are published online at http://www.statistik.sachsen.de, www.lfl.bayern.de, http://www.bayern-meg.de and http://www.interessensgemeinschaft-ige-sachsen.de.

the total profit must be non-negative. If a processor cannot reject the individual members of a marketing cooperative, then the market area *R* is fixed at the distance between the processors *d*. This situation is similar to Kats and Thisse's (1993) and Iozzi's (2004) scenario in which firms do not ration their supply[29] and buy at all locations within the distance *d*. One can only continue to assume that an exogenous market area *R* exists if the transport costs or distances between the neighbouring processors are sufficiently high that spatial monopsonies exist. In the German raw milk market, spatial monopsonies are unlikely to exist, as a relatively great number of processors exist.

Taking into account marketing cooperatives, we analyse a duopsony while assuming that two distinct competition strategies exist: non-cooperative HS competition and cooperative PM competition. PM is a modified form of Löschian competition. The firm expects that the competitor will match any price variation (θ_{ij} = 1) and that the sellers choose the firm randomly. The markets overlap, and the radii depend on the price ($\partial R/\partial p < 0$). In contrast to Löschian competition, where the markets are fixed ($\partial R/\partial p = 0$), market overlaps may exist under ud pricing and PM competition.

Because each firm assumes that every price change will be answered by the same price change from its competitor under PM competition, the rational strategy for each firm is to maximise its cumulative profit over the whole market area. Therefore, both firms set the same ud price. If the sellers have no preferences regarding distance, then they will show the same probability of choosing each processor. Scholars call this assumption the random tie-breaking rule (RTBR) (Iozzi, 2004). We define the cumulative profit under PM as:

$$\pi_{PM} = p^e \int_0^d (w - p - \tau r)dr = p^e d(w - p - \frac{1}{2}d\tau) \tag{2.98}$$

As the sellers will choose any of the processors with equal probability, the processors *i* and *j* equally share the cumulative profit: $\pi_i = \pi_j = \frac{1}{2}\pi_{PM}$. We derive the optimal seller's price by maximising the profit with respect to *p*:

$$p^*_{PM} = \frac{e(2w - \tau d)}{2(1+e)} \tag{2.99}$$

[29] The supply may not be rationed for different reasons, such as the costs of turning down customers in terms of lost-goodwill, damaged reputation or offence caused (Dixon, 1990), production on a winner-take-all basis (Baye and Morgan, 2002); and regulatory requirements (Iozzi, 2004). Hence, marketing cooperatives are only another reason for assuming that no rationing occurs.

The optimal net price depends on the net sales price *w*, the transport costs τ, the distance between firms *d* and the price elasticity *e*. If the supply function is linear, i.e., the price elasticity is equal to one, and if the market area is *R* instead of *d*, then we derive the optimal price of a monopsony (see equation (2.32)).

As discussed in section 2.3.3, under HS competition and ud pricing, no equilibrium exists in pure strategies. However, Iozzi (2004) shows that equilibrium may exist in pure strategies under RTBR. Under HS competition, a firm does not expect its competitor to react to a price change. If one firm increases its seller's price, i.e., the price is higher than the competitor's price, then the firm captures the whole market area. If both firms offer the same net price, then they equally share all of the locations. Therefore, there are three possibilities: the own seller's price is higher (+) than, equal (=) to or lower (-) than the competitor's price. If the competitor's net price is p', then the firm's profit is as follows:

$$\pi_{HS}^{(+)}(p, p') = p^e \int_0^d (w - p - \tau r) dr \qquad \text{if } p > p' \qquad (2.100a)$$

$$\pi_{HS}^{(=)}(p, p') = \frac{1}{2} p^e \int_0^d (w - p - \tau r) dr \qquad \text{if } p = p' \qquad (2.100b)$$

$$\pi_{HS}^{(-)}(p, p') = 0 \qquad \text{if } p < p' \qquad (2.100c)$$

Because of marketing cooperatives and an exogenous market area of $R = d$, no residual market area, and therefore, monopsonistic competition can exist if the competitor's price is higher than its own price. In contrast to the equations introduced in section 2.3.3, equation (2.100c) always equals zero. However significantly higher net prices can induce negative local prices (see Figure 6) and as a result, a distant location can lower the overall profit. Thus, profits under $p > p'$ (equation 2.100a) are always higher than those under $p = p'$ (equation 2.100b) and $p < p'$ (equation 2.100c), unless all of the alternatives are equal to zero. Consequently, if the firm sets a higher price than its competitor, then the competitor increases its price, and the two sides begin a bidding war. The overbidding ends if the profit is equal to zero. Hence, a price equilibrium exists in pure strategies. We define the zero profit function as:

$$\pi_{HS} = p^e \int_0^d (w - p - \tau r) dr = 0 \qquad (2.101)$$

Solving the profit function for p, we derive:

$$p_{HS}^{*} = \frac{1}{2}(2w - \tau d) \tag{2.102}$$

Both processors earn zero profits over the whole market area. The local profits are positive for processor i at locations $r \in [0,\ d/2]$ and negative at $r \in [d/2,\ d]$. For processor j the local profits are negative at locations $r \in [0,\ d/2]$ and positive at $r \in [d/2,\ d]$.

We can compare the results of HS and PM competition (see Table 6). We analyse not only the optimal seller's price and the profit but also the impacts of the sales price w, the price elasticity y and the absolute importance of space s (s = τd) on the net price p. As shown in Table 6, the optimal net price and the profit depend on the price elasticity under PM competition but are independent of y under HS competition. Under HS competition, the optimal seller's net price is always higher, and the profit is always lower. Additionally, the absolute importance of space s, which we defined as τd (Alvarez et al., 2000), has a negative impact on the net price under both HS and PM competition.

Table 6: Summary of the theoretical findings regarding HS and PM competition

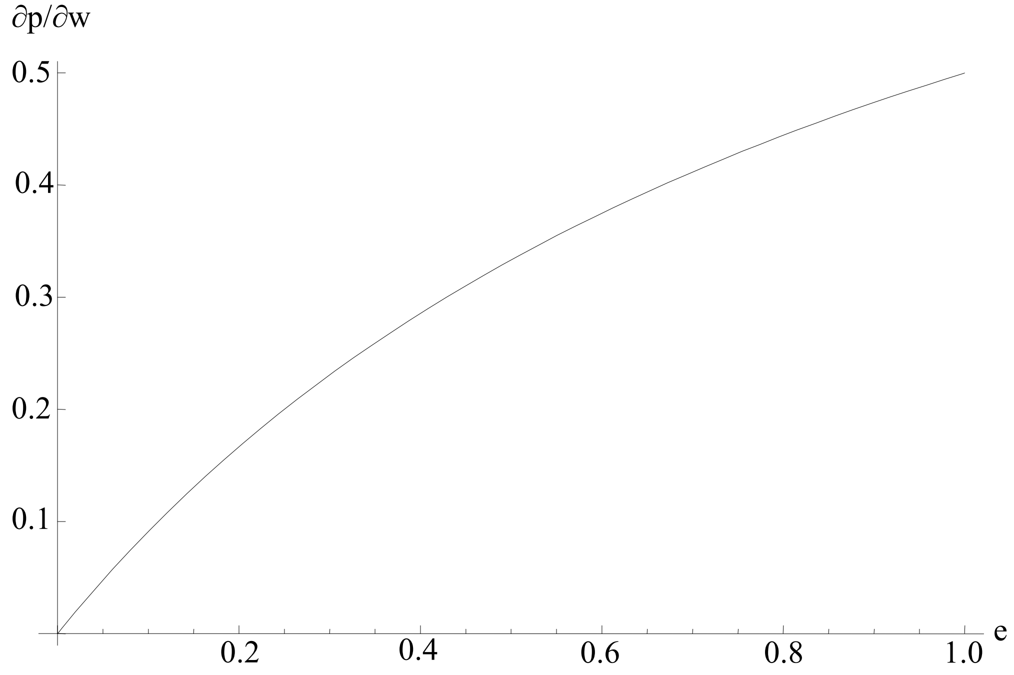
	HS	**PM**
p*	$\frac{1}{2}(2w - \tau d)$	$\frac{e(2w - \tau d)}{2(1+e)}$
π(p*)	0	> 0
∂p/∂w	1	e/(e+1)
∂p/∂y	0	$\frac{2w - s}{2(1+e)^2}$
∂p/∂s	-1/2	$-\frac{e}{2(1+e)}$

Source: Graubner et al. (2011)

Finally, we analyse price transmission, i.e., the impact of the net sales price w on the seller's net price p. Under HS competition, price transmission is always perfect, i.e., $\partial p/\partial w$ = 1.0. In contrast, price transmission under PM competition depends on the price elasticity of supply.

Figure 7 illustrates the relation between the price elasticity of supply *e* and the price transmission *p/w*. Given that a quota system exists in the German raw milk market, we can expect the price elasticity of supply to be quite inelastic. Therefore, the price transmission is less than 0.5 and is imperfect.

Figure 7: The relation between price transmission and the price elasticity of supply e under PM competition



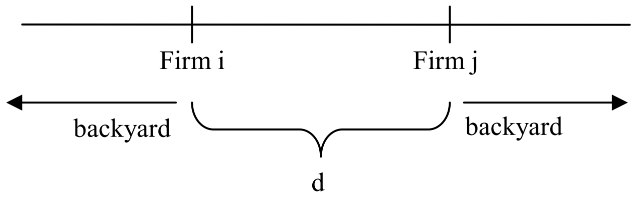
Source: Graubner et al. (2011)

Overall, under HS competition, the firms display non-cooperative behaviour because of more fierce competition, which manifests itself in the form of zero-profits and perfect price transmission. Under PM competition, the firms are more cooperative because the firms maximise their joint profits and exploit their local market power, as shown by the positive profits and imperfect price transmission from the net sales price *w* to the seller's net price *p*.

2.4.2 Spatial pricing under Price-matching competition and uniform delivered pricing: theoretical model by Alvarez et al.

Alvarez et al. (2000) analyse a duopsony, which consists of two iofs with PM competition, overlapping markets and ud pricing. In contrast to previous models, firms may also have competition in the backyard as illustrated in Figure 8.

Figure 8: Duopsony with backyard



Source: own illustration

Therefore, the firm only has a competitor in one direction. The other assumptions are the same as those outlined in section 2.3:

- a homogeneous input product exists in a linear market,
- the supply function is linear, i.e., $q = p$, where p is the ud price (= seller's net price),
- the sellers have a density of one and are equally distributed,
- the distance d between the firms is exogenous,
- the buyer pursues profit maximisation,
- the buyer of the input product resells the processed product at the price Wp,
- because the production costs δ are constant, the net sales price w is equal to $Wp - \delta$,
- the transportation costs τ per unit input and distance are constant at every point in the market r,
- the product $s = \tau d$ quantifies the absolute importance of space (Alvarez et al., 2000, p. 351),
- the ratio s/w quantifies the importance of space relative to the net value of the processed product (Alvarez et al., 2000, p. 351).

Assuming that PM competition exists, we find that the net prices and the market areas must be equal among the firms in an equilibrium, i.e., $p_i^* = p_j^* = p^*$ and $R_i^* = R_j^* = R^*$. Therefore, we define the optimal market area as $R^* = (w - p^*)/\tau$ (for a proof, see section 2.2.2). There are three possible cases concerning the degree of competition and market overlap:

a) there is no overlap, and the firms act as a spatial monopsonist (see section 2.2.2),
b) the markets only overlap between the firms (see Figure 9),
c) the markets overlap between the firms and partially in the backyard (see Figure 10).

The degree of market overlap differs in the value of s/w (for a proof, see Appendix E). If $s/w \geq 4/3$, then the firms act as a spatial monopsonist. If $4/7 < s/w < 4/3$, the the market overlap only appears between the firms (see Figure 9; also called "competition en route"). If $0 < s/w \leq 4/7$, then the market overlap occurs between the firms and in the backyard of the competitor (see Figure 10; also called "competition in the backyard"). In the following case, we will analyse cases b) and c), as case a) was already explained in section 2.2.2.

Figure 9: Competition en route

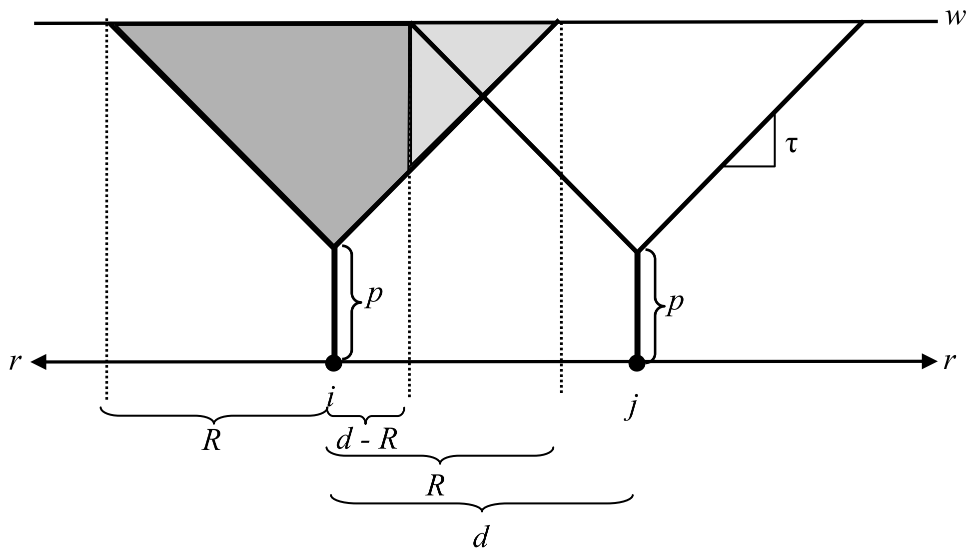
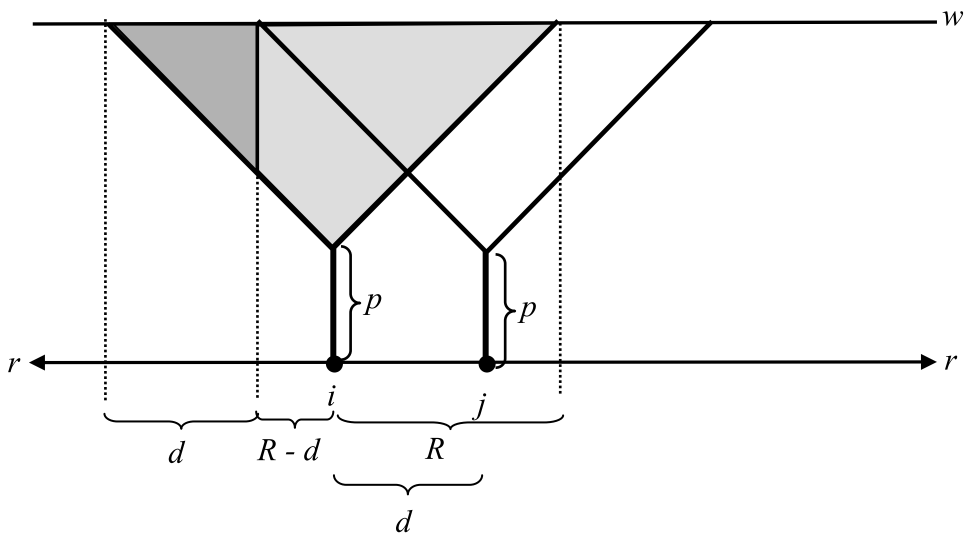


Figure 10: Competition in the backyard



In this instance, we study "competition en route". We divide the profit into three parts and define it as follows:

$$\pi_{Cr} = p\left[\int_{0}^{R}(w-p-\tau r)dr + \int_{0}^{d-R}(w-p-\tau r)dr + \frac{1}{2}\int_{d-R}^{R}(w-p-\tau r)dr\right] \tag{2.103}$$

The first integral represents the profit obtained in the backyard, where the firm has no competition. The second part measures the profit obtained in the area between the firms with no market overlap, and the third integral represents the profit obtained in the area between the firms with market overlap (see light grey region in Figure 9). In the area of market overlap, each firm receives half of the profits, as the sellers have an equal probability of choosing each firm.

Setting the optimal market area R^* in equation (2.103), we calculate the following:

$$\pi_{Cr} = \frac{ps}{\tau}\left(w - p - \frac{s}{4}\right) \tag{2.104}$$

Maximising the profit with respect to p, we obtain the optimal seller's price:

$$p_{Cr}^{*} = \frac{w}{2} - \frac{s}{8} \tag{2.105}$$

Next, we analyse the case with "competition in the backyard". We can express the profit function as:

$$\pi_{Cb} = p\left[\int_{R-d}^{R}(w-p-\tau r)dr + \frac{1}{2}\int_{0}^{R-d}(w-p-\tau r)dr + \frac{1}{2}\int_{0}^{R}(w-p-\tau r)dr\right] \tag{2.106}$$

The first integral represents the profit obtained in the backyard, where the firm has no competition. The second part measures the profit obtained in the backyard with market overlap, and the third integral represents the profit obtained in the area between the firms with market overlap. In the area of market overlap, each firm receives half of the profits, as the sellers have an equal probability of choosing each firm.

Setting the optimal market area R^* in equation (2.106), we estimate the following:

$$\pi_{Cb} = \frac{p}{2\tau}\left((w-p)^2 - \frac{s^2}{2}\right) \tag{2.107}$$

Maximising the profit with respect to p, we generate the following first-order condition:

$$p_{Cb}^{*} = \frac{4w - \sqrt{4w^2 - 6s^2}}{6} \tag{2.108}$$

After deriving the optimal seller's prices, we present the comparative statistics in Table 7.

Table 7: Comparative statistics concerning competition en route and competition in the backyard

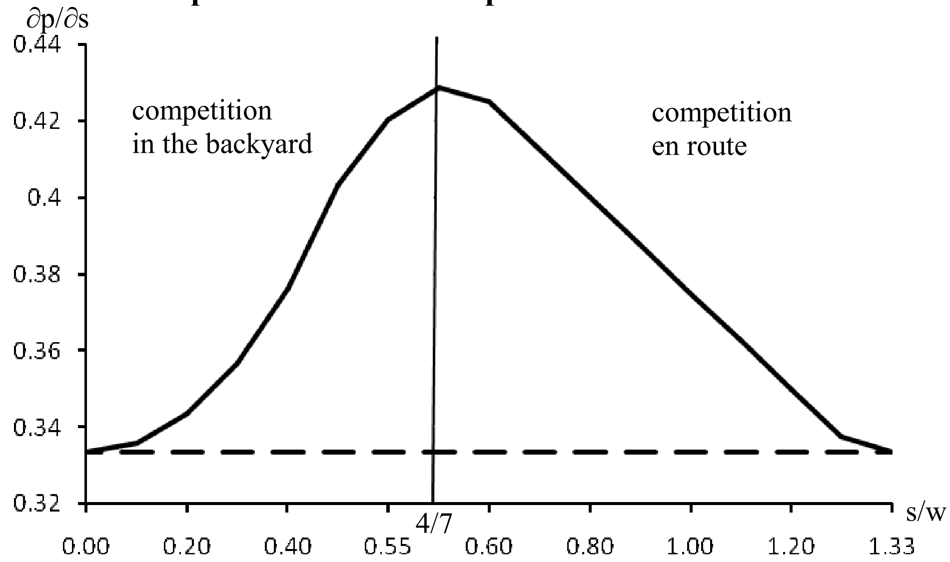
	Competition en route 4/7 < s/w < 4/3	Competition in the backyard 0 < s/w ≤ 4/7	
$\partial p^* / \partial w$	1/2	$\frac{2}{3}\left[1 - \frac{w}{\sqrt{4w^2 - 6s^2}}\right]$	> 0
$\partial p^* / \partial s$	-1/8	$\frac{s}{\sqrt{4w^2 - 6s^2}}$	> 0

We first examine the price transmission $\partial p^* / \partial w$ from the firm to the seller. For both types of market overlap, the price transmission is positive and less than one, i.e., no perfect price transmission exists. This finding is in line with that of Graubner et al.'s (2011) model, where PM competition indicates that cooperative competition and, therefore, imperfect price transmission exist. If $4/7 < s/w < 4/3$, then the price transmission amounts to 1/2, and half of the change in the net sales price is transmitted to the producer. For example, an increase of one cent in the net sales price will result in an increase of 1/2 cent in the seller's net price. However, if space is less important ($0 < s/w \leq 4/7$), then the price transmission $\partial p^* / \partial w$ is not constant and depends on the absolute importance of space s. If $s \rightarrow 0$, then the price transmission is 1/3. If $s \rightarrow 4/7$, then $\partial p^* / \partial w \rightarrow 1/5$. Therefore, the price transmission is between 1/5 and 1/3 and lower under "competition in the backyard" than under "competition en route".

Next, we analyse the influence of the absolute importance of space s on the seller's net price

p. Depending on s/w, the influence can be positive or negative. If space is important ($4/7 < s/w < 4/3$) and if s increases, then the net price p falls by 1/8 because an increasing s implies rising transport costs τ or a larger distance d. In this case, the market area of each firm becomes smaller. Hence, the percentage of overlapping markets decreases, the competition between the firms becomes less fierce, and the seller's price declines. In contrast, if $0 < s/w \leq 4/7$, then s has a positive influence on p, i.e., if the importance of space rises, then the seller's net delivered price p increases. There are two different effects that cause such behaviour where $\partial p^* / \partial s > 0$. The first effect is that, ceteris paribus, increasing the seller's net price above the monopsony level induces falling profits as the monopsony price maximises the profit. The second effect is that the market area R decreases with increasing p. With an increasing p, firm i reduces its market area and, therefore, loses the sellers located in the backyard of its competitor. However, because firm i expects firm j to react to firm i's price change in the same manner under PM competition, firm j also reduces its market area. Then firm i loses the sellers on the right side of firm j and gains the sellers on its left side, i.e., in its own backyard, at the same time, as firm j reduces its market area by conceding this area (see Figure 10). As the transport costs are lower near the firm, the per-unit profit increases considerably. If space becomes more important, then the firms can increase their seller's price above the monopsony level to reduce the market overlap and thus increase the market area in which they can act as spatial monopsonists. This effect only arises under PM competition, ud pricing and competition in the competitor's backyard. Figure 11 graphically illustrates the influence of space on the seller's price. The figure shows that as s increases, the seller's price p rises if market overlap also exists in the competitor's backyard. Therefore, we find the highest ud pricing when the firms are located an average distance away from one another. If the firms are nearby ($s \to 0$), then the previously described effect is not as strong given that the market overlap is almost complete and that the sellers obtained by reducing the market area are located far away from the firm. At s/w = 4/7 where space is less important and the market overlap exists only between the firms, the seller's price decreases. At s/w = 4/3, the firms can act as spatial monopsonies and offer the monopsony price $w/3$, which is displayed as the dashed line in Figure 11.

Figure 11: The relation between the optimal seller's price p and the absolute importance of space s under PM competition



Source: Own illustration modelled after Alvarez et al. (2000, p. 355); sales net price is assumed as one

2.4.3 Theoretical hypotheses for the German raw milk market

After analysing two theoretical models, we derive additional spatial hypotheses as well as non-spatial hypotheses concerning the German raw milk market. In section 4.3, we will empirically analyse these hypotheses by constructing a spatial econometric model.

The most important hypothesis is concerned with spatial competition, which implies that spatial interactions between spatial units exist (Anselin, 2002). The previous models intensively analysed spatial competition. In this instance, we show which types of spatial interaction exists with respect to the econometric models and illustrate the associated hypotheses. Specifically, we show that two types of spatial interaction may exist (Anselin and Bera, 1998):

a) The spatially neighbouring competitors directly influence the pricing of one dairy (= buyer) and vice versa. This type of spatial dependence is called a spatial lag.
b) With the exclusion of a spatial lag, the firm's pricing is spatially influenced. Hypotheses on the nature of this spatial influence exist, but various problems to confirm these hypotheses exist, e.g., these variables cannot be modelled or measured correctly or there are no data. Later, we will address this spatial influence as a spatial error.

Next, we derive the following four theoretical hypotheses:

1) Spatial competition exists in the German raw milk market, i.e., a spatial lag and/or a spatial error exist.

   The existence of PM or HS competition can justify the existence of a spatial lag. A spatial lag shows how a firm reacts to a price change by its neighbouring competitors. As PM and HS competition identify a firm's expectation of its competitor's reaction to an own price change, a spatial lag can show which type of competition exists. Furthermore, the existence of a spatial lag is supported by surveys from Weindlmaier and Huber (2001) and the German Federal Cartel Office (Bundeskartellamt, 2009). These two surveys show that dairies include the milk prices of their neighbouring dairies or other competitors into their pricing schemes. Von Cramon-Taubadel and Gloy (1991) also account for the pricing of neighbouring competitors while analysing the factors that influence the price of raw milk in Schleswig Holstein[30].

   A spatial error may exist because of spatial dependence among the spatial units, i.e., spatial autocorrelation. As written previously, a spatial error does not explain the type of spatial influence that is present. In the following, we show some of the possible types of spatial influence. Weindlmaier and Huber (2001) define various factors, such as the regional competitive environment and location to sales markets that impact the raw milk price (also see Weindlmaier, 2005). The regional competitive environment can illustrate the dairies' labour costs, i.e., employees costs, which vary over space, as spatial clusters with lower labour costs and higher labour costs exist (i.e., Eastern Germany versus Western Germany, respectively) (Statistisches Bundesamt, 2006). The sales markets for dairies' products are regional, national and international. For example, the sales market for fresh milk is primarily regional and at most national, as few brands exist, and the time of permanency is short in this type of branch. Therefore, spatial influence may exist because the intensities of food retailers and neighbouring dairies vary over space. However, neither factors can be exactly measured, and no data exist. Thus, this influence only appears in the spatial error term and the remaining error term.

2) A higher milk density induces higher producer prices.

   Weindlmaier (2000 and 2005) and Weindlmaier and Betz (2005) justify this hypothesis by assuming that a higher milk density enables the dairy to incur fewer expenses while collecting milk from the producers. As fewer expenses imply higher profits for the dairies, the fewer expenses can result in higher producer prices.

3) Larger quantities of processed milk quantity induce higher producer prices.

[30] Schleswig-Holstein is a northern Land in Germany.

The quantity of milk collected by a dairy can represent the economics of scale and the enterprise size. According to Weindlmaier (2000 and 2005), a rising quantity of processed milk implies decreasing processing costs. Lower processing costs induce higher producer prices. However, the author observes that other variables, such as the quality of management and the employees' qualifications and degree of engagement, influence the relationship between processed quantity and processing costs. Therefore, a larger quantity of processed milk does not automatically imply lower processing costs.

4) The dairy's type of organisation influences the dairy's pricing, i.e., the producer price for a member in a cooperative is lower than the producer price for a seller to an iof.

   Several studies show that unlike iofs, cooperatives produce rather basic milk products (i.e., fresh milk, butter and milk powder) instead of brands. In addition, the cooperatives invest a considerably lesser amount of money in brands than iofs (Peters, 1992; Cook, 1995; Wissenschaftlicher Beirat, 2000; Schramm et al., 2005; Gerlach et al., 2006; Bundeskartellamt, 2009; Steffen et al., 2009). The cooperative's strategy is driven by the Cooperative Societies Act and the resulting problems, such as the free-rider problem and the portfolio problem (Cook, 1995). The free-rider problem means that a new member receives the same producer price as a long-term member. In general, the cooperative is not permitted to differentiate among its members. A rising enterprise value does not imply that the value of the holdings, which the individual members of the cooperative keep, is also rising. Therefore, members of cooperatives are often unwilling to invest in brands. The portfolio problem is due to the members' heterogeneous risk levels. As a result, the investment portfolio does not match the shareholders' individual risk behaviours, and individual members pressure the cooperative to reduce the investment if the risk is too high for them (Cook, 1995; Schramm et al., 2005). In addition, because many members think in short-term rather than the long-term, they favour a higher short-term price from the processor rather than long-term investments (Peters, 1992). Moreover, members, who cease to run their farms in the near future, do not favour investments (Gerlach et al, 2006). However, because investments in brands and a good product portfolio significantly affect the creation of value and the cooperative's competitiveness, they also influence the producer price. Because cooperatives invest only a small amount of money in brands, their members suffer from a deficit in value and face, on average, lower producer prices than the sellers of an investor-owned dairy (Peters, 1992; Schramm et al., 2005; Bundeskartellamt, 2009; Steffen et al, 2009).

3. Description of the German milk sector

After presenting the general theory of spatial pricing and competition concerning oligopsonies and detailed models concerning the German raw milk market, we describe the German raw milk market and its characteristics. In section 3.1, we depict the framework of the German milk market, which consists of the Common Agricultural Policy (CAP) and the common organisation of agricultural markets. In section 3.2, we characterise the dairy farming sector in Germany. Lastly, we describe the structure of the German dairy industry (see section 3.3).

3.1. Common Agricultural Policy and the common organisation of the market in milk and milk products

Similar to all of the milk markets in the EU (previously known as the European Community) the German milk market is heavily influenced by the CAP and the common organisation of agricultural markets (previously known as the common organisation of the market in milk and milk products). Thus, the CAP determines the objectives, the principles and the possible instruments to achieve these objectives and principles. Additionally, common market organisation (CMO) exists for nearly all agricultural products, e.g., cereals, sugar and meat, to specify the details of these agricultural markets and as an instrument to achieve the CAP's objectives.

The CAP aims to increase productivity, ensure a fair standard of living for the agricultural community, stabilise markets, assure the stability of supplies and serve consumers at reasonable prices (Article 33, paragraph 1, Treaty establishing the European Community respectively article 39, paragraph 1, Treaty on the Functioning of the European Union). The three principles that should guide the CAP are as follows (Kay, 1988, p. 15; Ritson, 1997, p. 2; Grant, 1997, p. 68):

- market unity: all of the regulations should be obligatory and the same for all Member States (e.g., common external protection or common agricultural policy with regard to competition)
- community preference: common agricultural products, i.e., the products of the EU are preferred to the agricultural products of third countries
- financial solidarity: common agricultural policy will be financed conjointly

The common organisation of agricultural markets was established to achieve these objectives (Article 34, Paragraph 1, Treaty establishing the European Community). This organisation governs the assessment of uniform prices for agricultural products, the granting of subsidies for agricultural producers, the regulation of quantity and the regulation of trade with third countries. Until 2007, individual CMOs for each agricultural product, e.g., a CMO in milk and milk products, existed. Since 2007, one CMO has governed all 21 agricultural sectors and the individual CMOs should be gradually repealed up to October 2008 (Council Regulation (EC) No 1234/2007 of 22 October 2007).

Three different price regulations exist: target price, threshold price and intervention price. The target price displays the price at which agricultural products should be sold according to the EU authorities. The threshold price is a minimum price at which imported agricultural products can be sold in the EU. Custom duties or similar instruments ensure the threshold price. Finally, the intervention price is a guaranteed minimum price at which an intervention agency buys the agricultural products. The agency places these products in storage and uses them for humanitarian purposes or sells them outside of the EU at the world price. The threshold price is always higher than the intervention price, and the intervention price is normally higher than the world price (Hill, 1984, p. 24 ff. and p. 52; Ritson, 1997, p. 4 ff.).

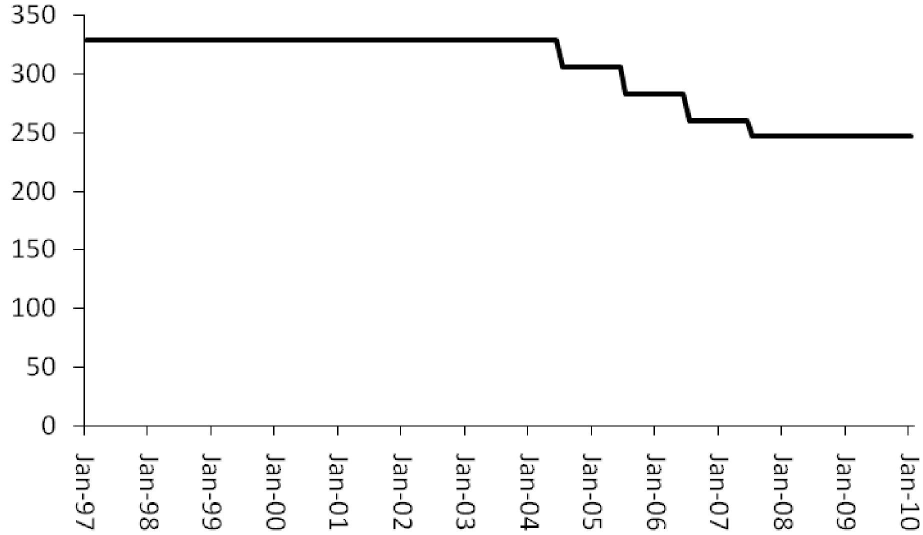
The CMO's second objective is to ensure that subsidies enforce more stable incomes for the agricultural community. For this purpose, many reforms have been passed. Until 2003, farmers mainly received subsidies that were coupled with land or animals. The 2003 reform of the CAP introduced a new system of direct payments; the so-called single payment scheme (SPS). In this system, the payments are decoupled from production and represent the largest part of the subsidies. Using SPS, the EU pays farmers for their land that they own and manage or lease and manage. Additionally the SPS is tied to certain standards, such as animal and plant health, which farmers must meet (i.e, the so-called cross-compliance) (European Commission, Info sheet "Single Payment Scheme – the concept").

Thirdly, the CMO introduced quantity regulation to reduce excess production and lower storage costs. Therefore, quotas define the maximum outputs that are assigned to each agricultural holding. If the farmer exceeds his/her quota, then the farmer has to pay a fine. Additionally each Member State must not produce more than a national guaranteed quantity, as the states will face financial sanctions for exceeding this limit. Furthermore, financial incentives for setting aside land and diversifying non-aliments are implemented (Part II, Council Regulation (EC) No 1234/2007 of 22 October 2007).

Finally, the exports and imports of common agricultural products are similarly well-regulated. Import licences, import quota, import duties and levies can be assigned to imports from third countries. For exports to third countries, the European farmers can receive refunds, e.g.,

intervention prices (Part III, Council Regulation (EC) No 1234/2007 of 22 October 2007).
For the EU milk market, the common organisation of the market in milk and milk products contains the regulations (Council Regulation (EC) No 1255/1999 of 17 May 1999). The common organisation of the market in milk and milk products operated from 1999 to 2007. From the first regulation in 1968 to 1999, the proceedings were fragmented. Since 2007, the common organisation of agricultural markets (Council Regulation (EC) No 1234/2007 of 22 October 2007) has regulated milk and milk products. Therefore, the regulations are different for the domestic market, i.e., the market of the EU, and for trade with third countries.
The CMO primarily use target prices and intervention prices to govern public intervention in agricultural markets. The target price for milk containing 3.7% fat is the price that is aimed for producers. Therefore, the target price is only a benchmark and not a binding figure (European Commission, info sheet “The milk sector”; Ritson, 1997, p. 4). Form February 1995 to June 2004, the target price was constant at 30.98 ECU (European currency unit) or Euro per 100 kilogram (ZMP, 2003). The CMO abolished the target price in July 2004. The intervention price, a guaranteed minimum price, exists only for butter and skimmed milk powder. If the prices for butter decrease in one or more Member States to a level lower than 92% of the fixed intervention price for a representative period, then an intervention agency buys in at a price no less than 90% of the intervention price. As soon as the market price for butter is equal to or higher than 92% of the intervention price for a representative period, the agency suspends its buy-in activities (Article 6, Council Regulation (EC) No 1255/1999 of 17 May 1999). With the passage of Council Regulation (EC) No 1787/2003 of 29 September 2003 (Article 1), some changes regarding the intervention price and the associated procedure have been enacted and valid since 1 March 2004. Since then, agencies must purchase at a price that is exactly 90% of the intervention price, and buy-in activities can only occur during the period from 1 March to 31 August. Additionally, the quantities offered for intervention must not exceed the quantities defined by the Council during this period. Otherwise, the Commission may suspend intervention buying. Figure 12 shows the development of the intervention price from January 1997 to January 2010. As shown by the figure, the intervention price has declined four times since 2004. Since July 2007, the intervention price for butter has been 246.39 Euro for 100 kg.

Figure 12: Monthly intervention price for butter in Euro (previously ECU) per 100 kg



Source: ZMP (2008; p. 193); Intervention price for butter from pasteurised cream, with a minimum butterfat content of 82% by weight and a maximum water content, of 16% by weight (further conditions are necessary for intervention buying; defined by Article 6, Council Regulation (EC) No 1255/1999 of 17 May 1999.

Additionally, Table 8 shows the maximum quantities allowed for the intervention buying of butter. In 2004, the Council introduced an upper limit for intervention buying. The upper limit was 70,000 tonnes in 2004 and decreased to 30,000 tonnes in 2008.

Table 8: Maximum quantities of butter offered for intervention buying

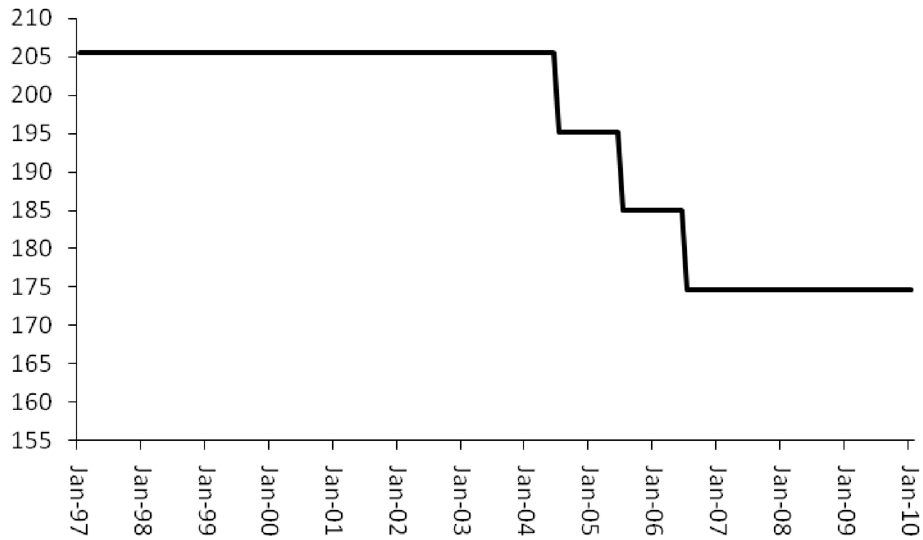
Year	Maximum quantities
2004	70,000t
2005	60,000t
2006	50,000t
2007	40,000t
From 2008	30,000t

Source: Article 6, Paragraph 1, Council Regulation (EC) No 1255/1999 of 17 May 1999, modified by Council Regulation (EC) No 1787/2003 of 29 September 2003

The intervention buying of skimmed milk powder differs from the regulations regarding butter. From 1 March to 31 August, the intervention agencies can buy top-quality skimmed milk powder produced by the spray process at the full intervention price. However, the quantities offered for intervention cannot exceed 109,000 tonnes during this period. Otherwise, the Commission may suspend intervention buying (Article 7, Council Regulation (EC) No 1255/1999 of 17 May 1999 respectively Article 8, 16 and 32 Council Regulation

(EC) No 1234/2007 of 22 October 2007). Figure 13 illustrates the development of the intervention price for skimmed milk powder. The intervention price of skimmed milk powder has declined three times since 2004. Since July 2006, the intervention price of skimmed milk powder has been 174.69 Euro for 100 kg.

Figure 13: Monthly intervention price of skimmed milk powder in Euro (previously ECU) per 100 kg



Source: ZMP (2008, p. 193); Intervention price of top-quality skimmed milk powder produced by the spray process and a minimum fat content of 35.6% by weight of the non-fatty dry extract (additional conditions are necessary for intervention buying; defined by Article 7, Council Regulation (EC) No 1255/1999 of 17 May 1999.

Furthermore, the Council may grant private storage aid for skimmed milk powder or certain cheeses if the price development indicates an imbalance in the market, which may be reduced or extinguished by seasonal storages (Article 7 and 8, Council Regulation (EC) No 1255/1999 of 17 May 1999 respectively Article 31. 35 and 36, Council Regulation (EC) No 1234/2007 of 22 October 2007).

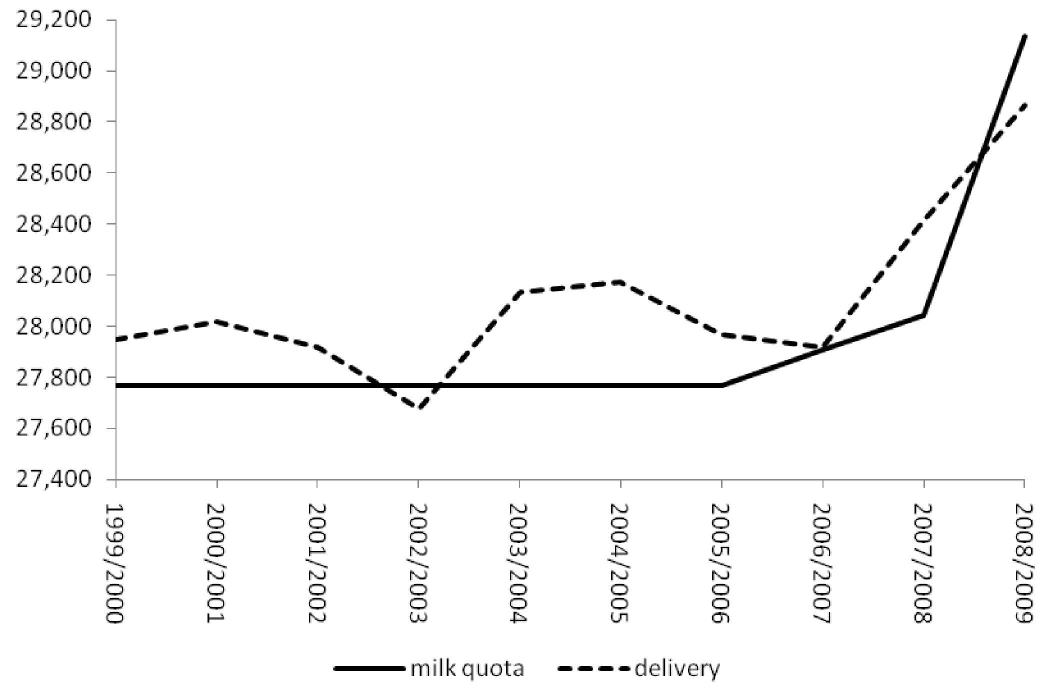
The second important regulation regarding the domestic market refers to the total quantity of raw milk guaranteed for each Member State. Because of the policy of price support, milk production escalated, and the production of milk exceeded milk consumption by late 1970s. As the expenditures for storage and export subsidies for milk products increased dramatically and as increased export quantities disrupted the world market, the Council implemented a milk quota system in 1984. If a Member State delivers more milk than the guaranteed quantity allows, then the state must pay a so-called "super levy". Thus, the milk quota system simultaneously supports producer prices and controls production and expenditures (Kommission der Europäischen Gemeinschaft, 2002, p. 8 f.).

In the milk quota system, the Council determines the guaranteed total quantity of milk or milk equivalent produced by the Community. The Council splits the total quantity into reference quantities for each Member State (Article 1, Council Regulation (ECC) No 856/84 of 31 March 1984). The Council determines the reference quantity by year (i.e., from April to March of the next year), by fat content and by tonne (Köhler, 1997, p. 137 f.). Next, the reference quantity of each Member State is divided among the producers (i.e., production quota) or among the dairies (i.e., procession quota). Hence, each farmer is assigned a production quota or each dairy is assigned a maximum milk quantity. In Germany, the production quota system was chosen (Milchindustrie-Verband e.V., info sheet "Milchquote").

If a Member State exceeds its reference quantity, then the Member State must pay a super levy. The super levy is divided among the producers that over-delivered the product (Köhler, 1997, p. 137 f.). Until 2004, the super levy was equal to 115% of the target price (Kommission der Europäischen Gemeinschaft, 2002, p. 9). With the abolishment of the target price, the Council defines the super levy each year (European Commission, info sheet "The milk sector"). The Council allows the Member States to balance their overall production by using the underproduction of certain producers to compensate for the overproduction of other producers (Köhler, 1997). The milk quota system will be terminated in 2015 (Isermeyer, 2007, p. 1).

Figure 14 shows the milk quota and quantities delivered in Germany from 1999 to 2008. Until 2005, the reference quantity for Germany was constant. However, the quantity increased in the following years. Until 2006, with the exception of 2002/2003, Germany constantly over-delivered its milk products. In 2006/2007, quantity delivered was equal to the quota, but the next year, the country over-delivered once again. In 2008/2009, Germany significantly exceeded its quota by 273,000 tonnes.

Figure 14: Milk quota and quantity delivered in 1,000t for Germany



Source: ZMP (2003 and 2008); for 2008/2009 data from Milch & Markt (http://www.milchindustrie.de/de/eu/agrarpolitik/quote/)

Moreover, financial aids for skimmed milk and skimmed milk powder that are used as animal feed or processed into casein or caseinates exist. In addition, the Community provides aid for school milk and milk products (Article 11, 12 and 14, Council Regulation (EC) No 1255/1999 of 17 May 1999 and Article 99 and 102, Council Regulation (EC) No 1234/2007 of 22 October 2007).

The last regulation concerning the domestic market is direct payments for milk producers, which the Council introduced in 2004. Because of falling intervention prices, the producers receive a dairy premium (European Commission, info sheet "The milk sector"). The Council grants a dairy premium for each calendar year, holding and tonne of individual reference quantity that is suitable for serving as a premium and available at the holding. Additionally, premium supplements exist (Article 16 and 18, Council Regulation (EC) No 1255/1999 of 17 May 1999). The Council paid dairy premiums and the premium supplements from 2004 to 2007. Afterwards, the dairy premium was decoupled and integrated into the single payment scheme (European Commission, info sheet "The milk sector").

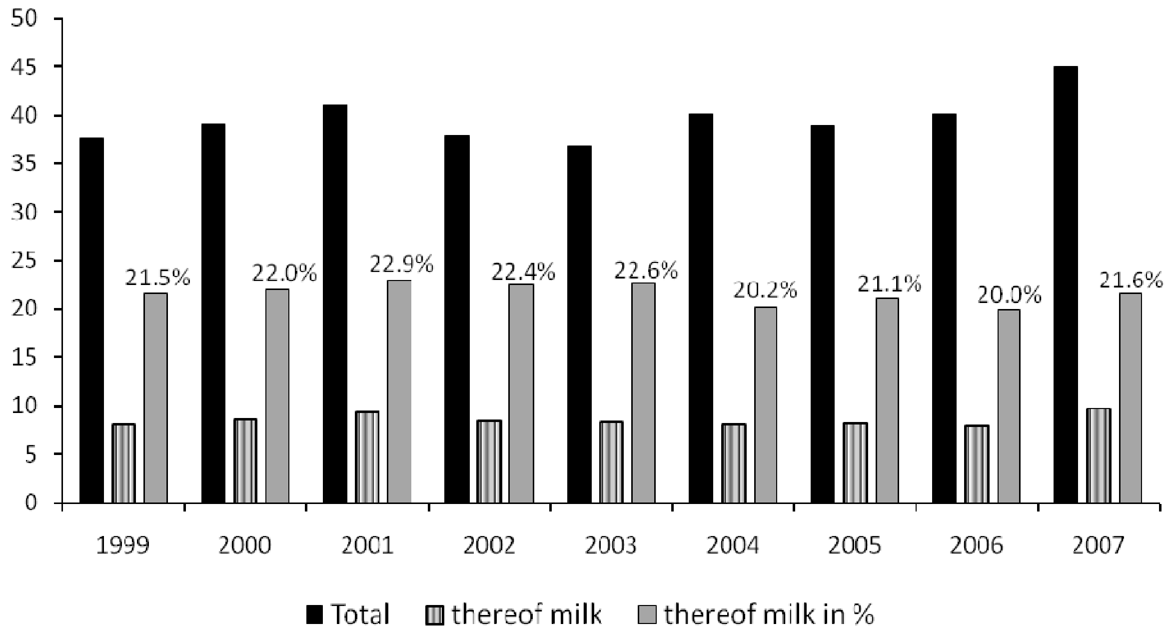
The remaining regulations refer to trade with third countries. Import licences for imports into the European Community are required. In contrast, export licences for exports from the Community may not be required. Furthermore, tariff-rate quotas, additional duties and export refunds can be introduced under certain conditions (Article 26, 28 and 29, Council Regulation

(EC) No 1255/1999 of 17 May 1999 and Article 130, 141, 144, 161 and 162, Council Regulation (EC) No 1234/2007 of 22 October 2007).

3.2 Dairy farmers in Germany

The milk industry is an important branch of the agricultural sector in Germany, as this industry accounts for at least 20% of the country's agricultural production. Figure 15 shows the agricultural production values and the production values of milk from 1999 to 2007. The production value of milk varies between 8 and 9.7 billion Euros. Its percentage of total agricultural production value ranges from 20% to 22.9%.

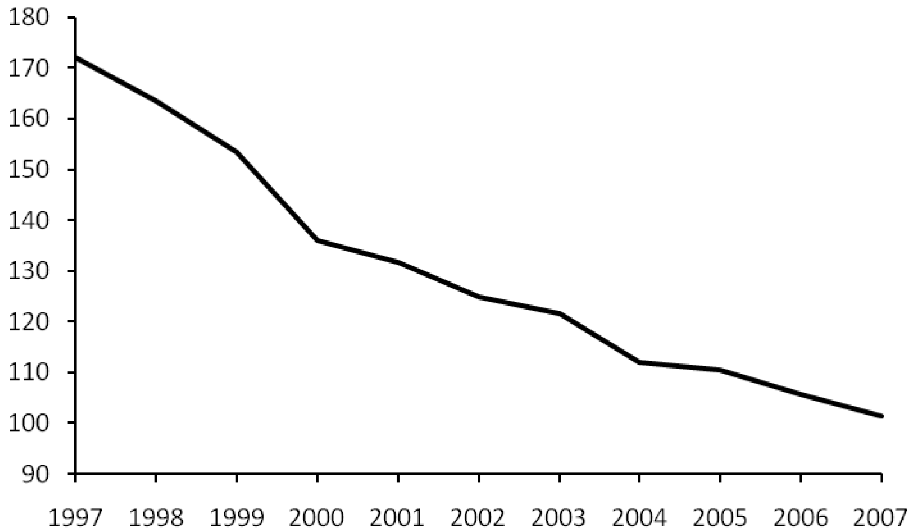
Figure 15: Agricultural production value at producer prices (without value added tax; in billion Euros)



Source: ZMP (2005 and 2008)

We can also show the importance of milk production by depicting the large share of dairy farms in agricultural holdings. From 1997 to 2007, 31.5% of agricultural holdings were dairy farms on average (ZMP 2008, 2007, 2005, 2003, 2001 and 1999), although the number of dairy farms has declined rapidly in the last few years (see Figure 16). The number of dairy farms decreased by 41% from 1997 to 2007 and was 101,300 in 2007.

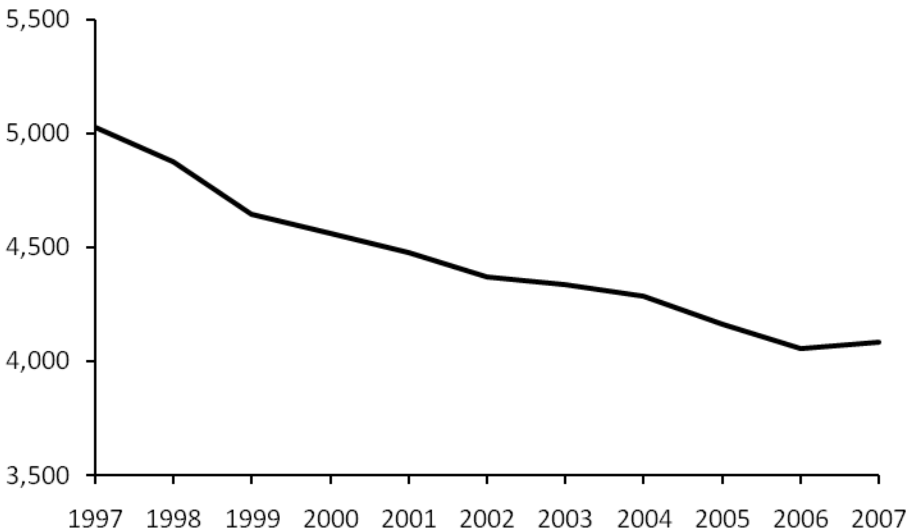
Figure 16: Number of dairy farms (in 1,000)



Source: ZMP (2001, 2003, 2005, 2007 and 2008)

During the same period, the number of dairy cows dropped by 19% (see Figure 17). Hence, the remaining agricultural holdings have constantly increased their number of cows. In 2007, German dairy farms had 4,087,000 dairy cows.

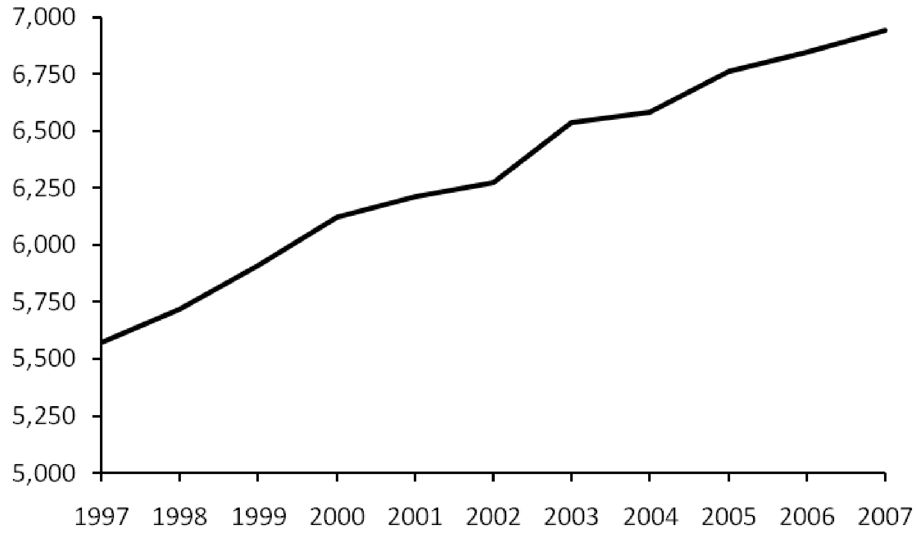
Figure 17: Number of dairy cows (in 1,000)



Source: ZMP (2003, 2005, 2007 and 2008)

In contrast, the milk yield per cow and year has increased constantly since 1997. Figure 18 shows how this yield has increased from 5,575 kg in 1997 to 6,944 kg in 2007. Hence, the milk yield per cow and year has increased by 25% within this 11-year periods.

Figure 18: Milk yield per cow (in kilogram)



Source: ZMP (2003, 2005, 2007 and 2008)

Despite the decreasing number of dairy farms and cows, the production of milk remained mostly constant from 1997 to 2007. That is, milk production was approximately 28,300,000 tonnes on average, with some fluctuations. In 2002, the production of milk reached its lowest level. Nevertheless, the annual change in the production of milk was no larger than 3%.

Figure 19: Milk production (in 1,000 tonnes)

Source: ZMP (2003, 2005, 2007 and 2008)

Table 9 illustrates the spatial pattern of milk production. The table reveals a strong east-west divide and a weak south-north divide. The largest share of milk production occurs in the south with Bavaria being the biggest milk producer (accounting for 27% of the total milk production). Baden-Württemberg, which also lies in the southern of Germany, produces the fifth largest total of milk. Both Laender[31] account for one-third of the total milk production. In the north Lower Saxony, North Rhine-Westphalia and Schleswig-Holstein are the second, third and fourth biggest milk producers, respectively, and are responsible for 36 % of Germany's total milk production. Located in Eastern Germany, the New Laender (i.e., Brandenburg, Mecklenburg-West Pomerania, Saxony, Saxony-Anhalt and Thuringia) are responsible for 22% of the total milk production.

Additionally, 60% of all dairy farms are located in the south (i.e., in Bavaria and Baden-Württemberg). In contrast, only 4% of all dairy farms are located in the New Laender. However, a dairy farm in Bavaria kept 25.4 cows on average, which is the lowest average in Germany, whereas each dairy farm in the New Laender had 184.7 cows on average in 2007. The dairy farms in northwestern Germany (i.e., Lower Saxony, North Rhine-Westphalia and Schleswig-Holstein) lie somewhere between these two extremes. These farms are responsible for 36% of the total milk production and represent 28% of all dairy farms. They also had 49 cows per dairy farm in 2007.

Table 9: Milk production (in 1,000 tonnes) in German Laender

	Milk production (in 1,000t)				
	1999	**2001**	**2003**	**2005**	**2007**
Baden-Württemberg	2,253	2,282	2,288	2,233	2,212
Bavaria	7,566	7,623	7,683	7,553	7,696
Brandenburg	1,349	1,345	1,365	1,385	1,341
Hamburg, Bremen, Berlin	35	32	33	32	32
Hesse	1,047	1,053	1,010	1,034	1,014
Mecklenburg-West Pomerania	1,323	1,338	1,360	1,383	1,409
Lower Saxony	5,316	5,133	5,180	5,165	5,152
North Rhine-Westphalia	2,707	2,668	2,721	2,749	2,750
Rhineland-Palatinate	783	773	789	797	767
Saarland	90	89	91	90	88
Saxony	1,483	1,522	1,572	1,597	1,587
Saxony-Anhalt	1,084	1,061	1,058	1,083	1,033
Schleswig-Holstein	2,358	2,333	2,455	2,393	2,377
Thuringia	943	940	927	958	943

[31] Germany is split up into 16 federal states that are called "Laender".

Germany	28,334	28,191	28,533	28,453	28,403
Old Laender	22,152	21,986	22,252	22,048	22,089
New Laender	6,182	6,205	6,282	6,406	6,314

Source: ZMP (2001, 2003, 2005, 2007 and 2008)

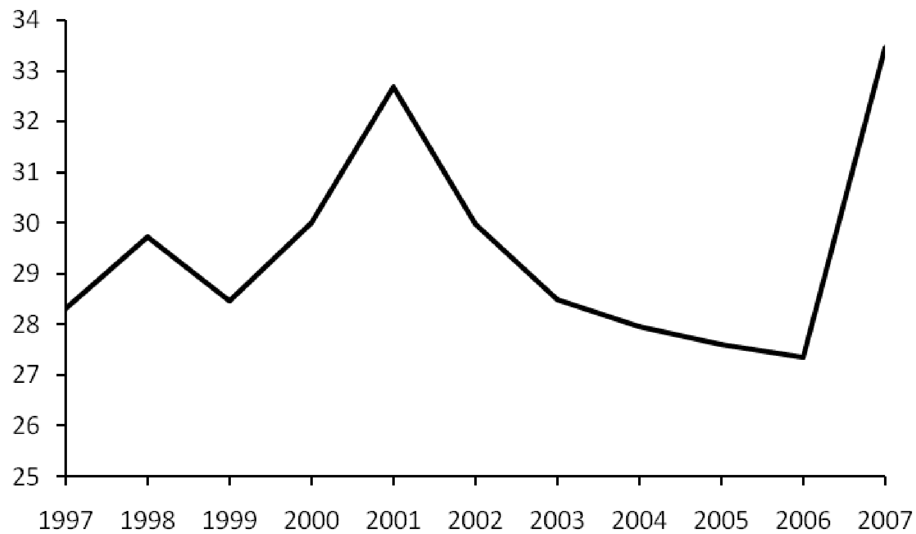
Table 10: Number of dairy farms (in 1,000) and number of dairy cows per farmer (in 1,000) in German Laender

	Number of dairy farms (in 1,000)					Number of dairy cows per farmer (in 1,000)				
	1999	2001	2003	2005	2007	1999	2001	2003	2005	2007
Baden-Württemberg	22.6	18.5	16.4	14.4	12.7	19.4	22.6	24.3	26.7	28.5
Bavaria	68.1	61	56.7	51.9	48.5	21.2	23.0	23.4	24.6	25.4
Brandenburg	1.1	0.9	0.9	0.8	0.7	186.5	218.2	201.9	210.1	222.4
Hesse	7.8	6.3	5.6	5.0	4.5	22.0	26.9	28.8	31.4	33.7
Mecklenburg-West Pomerania	1.2	1.1	1.0	0.9	0.8	162.1	172.2	178.8	199.7	204.5
Lower Saxony	22.6	18.9	17.2	15.8	14.2	35.6	40.3	43.4	46.4	49.9
North Rhine-Westphalia	13.9	11.4	10.5	9.4	8.7	30.6	35.8	37.3	40.7	42.9
Rhineland-Palatinate	4.1	3.6	3.3	3.0	2.7	32.6	37.1	38.9	41.1	43.0
Saarland	0.5	0.4	0.3	0.3	0.3	34.1	44.4	43.9	47.4	50.2
Saxony	1.8	1.7	1.5	1.4	1.3	121.6	128.7	138.1	144.4	149.6
Saxony-Anhalt	1.0	0.9	0.9	0.8	0.7	156.6	162.8	167.3	182.0	192.1
Schleswig-Holstein	7.6	6.6	6.3	5.9	5.4	50.5	54.8	57.1	58.7	62.4
Thuringia	1.1	0.8	0.9	0.7	0.7	124.3	142.7	149.4	165.6	177.9
Germany	153.5	131.8	121.5	110.4	101.2	30.7	34.3	36.0	38.4	40.2
Old Laender	147.3	126.4	116.4	105.7	97	25.8	27.9	30.2	32.3	34.0
New Laender	6.2	5.4	5.1	4.6	4.2	146.9	156.9	161.1	176.4	187.4

Source: ZMP (2001, 2003, 2005, 2007 and 2008)

Figure 20 displays the development of the producer price for raw milk from 1997 to 2007. In 1997, the producer milk price was 28.32 Euro per 100 kg raw milk. The producer price increased by a small amount before dropping again. By 2001, the producer milk price reached one of its two peaks at 32.69 Euro per 100 kg. This peak was due to the dynamic domestic demand for milk products, the strong sales in the world market and the low supply. The supply of milk declined because of the bovine spongiform encephalopathy (BSE) crisis, which forced farmers to slaughter their milk cows and, therefore, produce less milk (MUGV, 2010 and ZMP, 2001, p. 20). Afterwards the producer price dropped sharply because of the poor demand for milk products and the rather high supply of milk (ZMP, 2003, p. 22 and ZMP, 2005, pp. 20 f.). The producer price reached a nadir in 2006 at 27.35 Euro per 100 kg. In 2007, the producer price reached a second peak at 33.46 Euro per 100 kg raw milk because the demand for milk exceeded the supply. There are many possible explanations for why the demand far exceeded the supply. In the years prior to 2007, demand increased faster than production. Hence, in 2007, inventories were depleted all over the world. Additionally, the supply in Australia and South America decreased because of unfavourable weather conditions. The limited supply induced a worldwide price increase (ZMP, 2007, p. 14).

Figure 20: Producer milk price (in Euro per 100 kg)



Source: ZMP (2007 and 2008); milk with 3.7% fat and 3.4% protein, without value added tax

3.3 German dairy industry

Similar to the raw milk sector, the dairy industry is an important part of the German agribusiness sector. Germany is the largest milk processor in the EU, whereas France is the second largest milk processor. Table 11 shows total quantities of milk processed in the EU and in Germany. On average Germany processed over 27 million tonnes of milk and 24% of the total quantity of milk processed in the EU-15 (21% of the total quantity of milk processed in the EU-25 milk processing and 20% of the total quantity of milk processed in the EU-27).

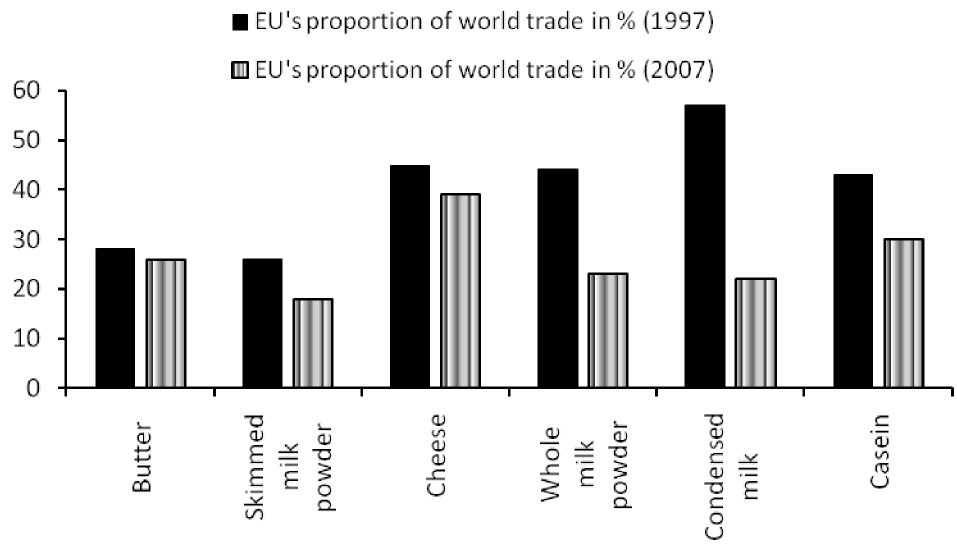
Table 11: Quantity of milk processed in the EU and Germany (in 1,000 tonnes)

Year	EU-27	EU-25	EU-15	Germany
1997			113,634	26,986
1998			113,563	26,752
1999			114,948	26,783
2000			114,690	26,984
2001			115,254	26,883
2002			115,670	26,621
2003			116,741	27,563
2004		131,124	115,332	27,283
2005		132,721	115,952	27,663
2006	133,566	131,670	115,021	27,162
2007	133,924	132,023	115,162	27,619

Source: ZMP (2001, 2005 and 2008)

Figure 21 presents the EU's share of the world trade in dairy products, whereas Figure 22 illustrates Germany's share of the EU's total exports. For example, in 2007, the EU's share of the world trade in cheese was 39%. The figures also show that the EU's trade with the rest of the world (not within the EU) proportionally declined from 1997 to 2007 for all categories. For example, in 1997, the EU accounted for 57 % of the world trade in condensed milk; however, in 2007, the EU held only 22% of the world trade in this product category.

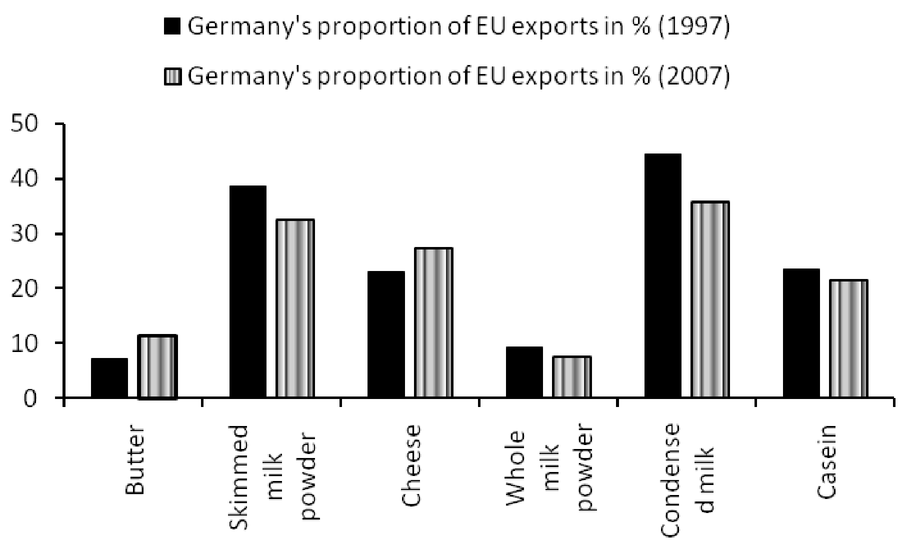
Figure 21: EU's proportion of world trade in dairy products



Source: ZMP (2003 and 2008)

Depending on the dairy product, Germany provides between 7% and 45% of the EU's exports[32]. In both relative and absolute terms, the main export products are condensed milk, skimmed milk powder and cheese. For example, Germany provided 35.8% of the EU's exports of condensed milk (260,000 tonnes) and 27.4% of the EU's exports of cheese (879,900 tonnes) in 2007. From 1997 to 2007, German exports of butter and cheese increased, whereas German exports of milk powder and condensed milk decreased. German exports of casein declined relatively but not absolutely (ZMP, 2003 and 2008).

Figure 22: Germany's proportion of EU exports in dairy products

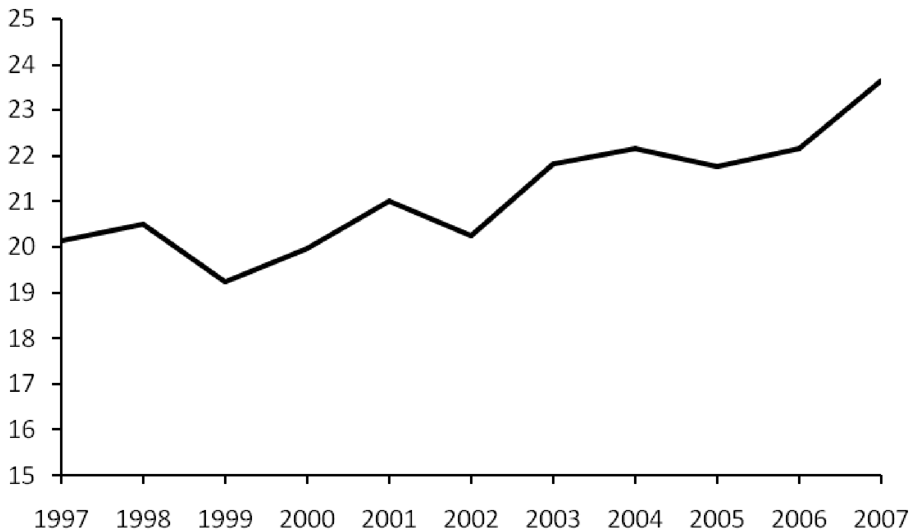


Source: ZMP (2003 and 2008)

[32] The exports are within and outside of the EU.

Measured by turnover, the dairy industry is also an important branch of the German food industry and generates 17% of the turnover in the entire food industry (ZMP 2001, 2003, 2005, 2007 and 2008). As is shown in Figure 23, the turnover of the dairy industry was 20.14 bn Euro in 1997. In most of the following years, the turnover increased and was 23.64 bn Euro in 2007.

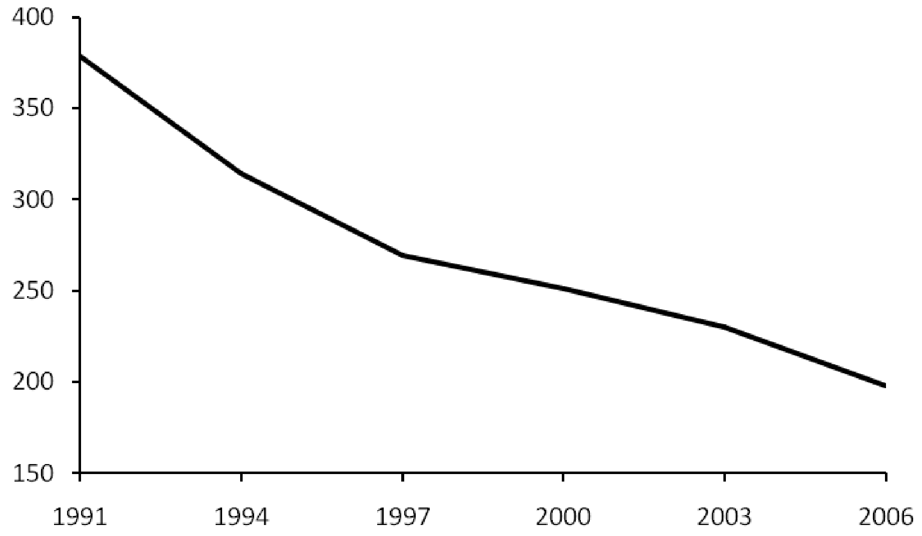
Figure 23: Turnover of the dairy industry in Germany (in bn Euros)



Source: ZMP (2001, 2003, 2005, 2007 and 2008)

According to Figure 24, the number of dairies declined considerably over the last several years and dropped by 48% in total from 1997 to 2006. The increasing number of mergers, acquisitions and shut-downs have resulted in consilidation and concentration of this sector. In addition, the biggest dairies became responsible for an increasing proportion of the total quantity of milk processed and the turnovers (see Table 12 and Table 13).

Figure 24: Number of dairies (only milk-producing companies)



Source: ZMP (2007 and 2008)

In 2007 the five biggest dairies accounted 41.2% of the the total quantity of milk processed in Germany and were responsible for 33.4% of the total turnover. The next five largest dairies accounted approximately 14.8% of the total quantity of milk processed and the turnovers. This finding shows that a few big dairies and many small dairies compete with each other. Compared with the dairies in other countries, German dairies are relatively small. In 2007, only one German dairy was ranked among the 20 biggest dairies worldwide by turnover, i.e., the dairy was ranked 19th (Soßna, 2007).

Table 12: Total quantity of milk processed in the 40 biggest dairies in Germany (2007)

Concentration ratio	Million kg	% of milk processing
CR5	11,181	41.2
CR10	15,193	56.0
CR15	18,505	68.2
CR20	20,995	77.4
CR25	22,935	84.5
CR30	24,572	90.6
CR35	25,842	95.2
CR40	26,937	99.3

Source: Soßna (2007); CR5 covers the five biggest dairies, CR10 the ten biggest dairies, and so on.

Table 13: Cumulative turnovers of the 40 biggest dairies in Germany (2007)

Concentration ratio	Million Euro	% of the dairy industry's turnover
CR5	7,011	33.4
CR10	10,474	49.9
CR15	12,792	61.0
CR20	14,431	68.8
CR25	15,781	75.3
CR30	16,732	79.8
CR35	17,508	83.5
CR40	18,203	86.8

Source: Soßna (2007); CR5 covers the five biggest dairies, CR10 the ten biggest dairies, and so on.

Table 14 illustrates the production of different dairy products and their development from 1997 to 2007. From a quantitative perspective, the industry produced the most drinking milk, sour milk drinks, milkshake products and cheese. From 1997 to 2007, the production of cheese (of every kind), sour milk drinks and milkshake products increased sharply (i.e., between 22% and 31%). In contrast, the production of condensed milk and both milk powders decreased considerably (i.e., by 21% and 31%, respectively). The production of drinking milk, cream products, butter and sour milk quark remained relatively constant.

Table 14: Production of dairy products (in 1,000 tonnes)

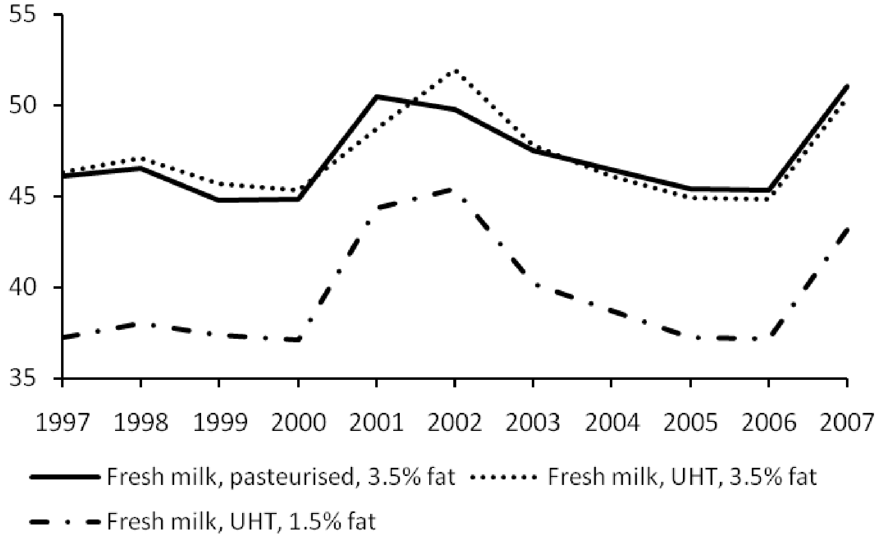
	1997	1999	2001	2003	2005	2007
Drinking milk	5,722	5,612	5,693	6,049	6,010	6,068
Cream products	549	548	572	540	550	561
Sour milk drinks and milkshake products	2,443	2,671	2,691	2,809	2,956	3,056
Butter	442.3	427.0	420.2	451.8	450.0	443.3
Hard cheese, soft cheese, sliced cheese and curdled milk cheese	839.4	845.6	911.0	913.0	994.0	1,035.7
Cream cheese	750.7	748.4	856.1	903.3	935.7	982.8
Processed cheese	150.1	160.5	175.5	167.3	177.1	183.2
Sour milk quark	29.5	28.8	30.3	27.2	29.6	28.7
Condensed milk	566.0	563.8	588.0	491.8	457.8	446.1
Skimmed milk powder	333.8	330.7	289.9	302.0	231.9	231.8
Other milk powder	201.2	200.3	167.2	154.2	153.7	139.1

Source: ZMP (2003, 2005, 2007 and 2008)

Finally, we discuss the average selling prices of drinking milk at the dairy level and the consumer level for the selected dairy products.

Figure 25 depicts the selling price of pasteurised fresh milk and ultra-heat-treated (UHT) milk. As shown by the figure, the pasteurised fresh milk and the UHT milk with 3.5% fat content have similar prices. In contrast, the UHT milk with only 1.5% fat content has a clearly lower price. The development of the three milk prices is similar during the depicted time period. The price of pasteurised fresh milk peaked in 2001, and the price of UHT milk peaked in 2002. These peaks are due to the dynamic domestic demand for dairy products, good sales in the world market and the BSE crisis (ZMP, 2001, p. 20 and MUGV, 2010).

Figure 25: Selling price of drinking milk at a dairy in Euro per 100 litre



Source: ZMP (1999, 2001, 2003, 2005, 2007 and 2008)

Table 15 shows the consumer prices of milk, cheese, butter, yoghurt and quark from 2004 to 2007. Within this four-year period, the consumer price of whole milk increased by 14%, which was the largest increase in price among these products. The prices of natural soft cheese, UHT milk, butter and yoghurt increased moderately (i.e., from 7% to 12%). The consumer prices of young Gouda cheese and quark only changed slightly.

Table 15: Consumer prices of select dairy products (in Euro per unit)

	2004	2005	2006	2007
Whole milk, 3.5% fat, carton 1 litre	0.57	0.57	0.58	0.65
UHT - milk, 3.5% fat, carton 1 litre	0.56	0.56	0.56	0.62
Natural yoghurt, 1.9%-3.5% fat, 150 grams	0.15	0.14	0.15	0.16
Butter, 250 grams	0.86	0.80	0.76	0.93
Young Gouda cheese, piece, self service, 1 kg	4.35	4.22	4.14	4.45
Quark (= curd cheese), 40% fat and more, 250 grams	0.43	0.41	0.39	0.43
Natural soft cheese, 1 kg	5.99	6.06	6.33	6.73

Source: ZMP (2007 and 2008); on the basis of the GfK - household panel

4. Econometric estimations of spatial competition and pricing in the German raw milk market

After describing the German raw milk market, we empirically analyse the spatial pricing and competition in this market. Specifically, we construct three empirical models to analyse the spatial price competition behaviour in the German raw milk market and to determine which factors influence the milk producer price. In section 4.1 we determine whether PM or HS competition exists by utilising a VECM. In sections 4.2 and 4.3, we analyse the spatial and non-spatial factors, such as the absolute importance of space or the organisational forms of dairies, to determine whether and to what extent the factors affect the producer price. To study these factors, we utilise a panel model with fixed effects and a spatial lag model. Additionally, we analyse in section 4.3 how and to which extent spatial competition among dairies affects the raw milk price.

4.1 Empirical analysis of spatial price competition behaviour[33]

In the following section, we empirically analyse Graubner et al.'s (2011) theoretical model, as presented in section 2.4.1. Specifically, we analyse the German raw milk market to determine whether HS competition (non-cooperative behaviour) or PM competition (cooperative behaviour) exists. As a structural model is not applicable because of data limitations (e.g., cost structure of the dairies), we utilise time series methods to investigate the price transmission behaviours under HS and PM competition. If PM competition exists, then the price transmission is equal to or less than 0.5 ($\partial p / \partial w \leq 0.5$). In contrast, HS competition is rather competitive and, therefore, has a perfect price transmission ($\partial p / \partial w = 1.0$). Hence, we empirically determine the price transmission behaviour in the German milk sector. Many different price transmission models exist. These models are differentiated by their characteristics, e.g., symmetry, linearity or interaction among price series. Linear symmetric price transmission models include error correction models (ECM), VECM and autoregressive distributed lag (ARDL) models (e.g., Lütkephol, 2007, p. 237 ff.; Hamilton, 1994, p. 291 ff. and p. 571 ff.). One can also categorise these models as asymmetric models (Frey and Manera, 2007). In contrast, threshold vector error correction models (TVECM) and smooth transition vector error correction models are examples of nonlinear price transmission models

[33] This section is an extended version of Graubner, M., Koller, I., Salhofer, K. and Balman, A.'s article (2011): "Cooperative vs. non-cooperative spatial competition for milk". The author of this doctoral thesis wrote the empirical part of the above-named article.

(Dijk et al., 2002; Ben-Kaabia and Gil, 2007).
Based on the different tests described later, we decide that a VECM best represents the German raw milk market.

4.1.1 A price transmission model: vector error correction model

A VECM is a differenced vector autoregressive (VAR) model with nonstationary cointegrated series. As a result, this model accounts for the interdependences among the variables in both directions. In addition, the model analyses both the long-run relationship and the short-run dynamics among the variables.

Before deriving the VECM, we must provide some definitions. As we address multivariate time series, we summarise the variables' observations in a $(K \times 1)$ vector y_t:

$$y_t = (y_{1t}, y_{2t}, ..., y_{Kt})', \qquad t = 0,\ 1,\ 2, \ldots, T$$

where K is the dimension of the vector; t is the time or the period; and T is the period's length of the vector. The vector y_t is a stochastic process that consists of a sequence of random variables indexed by time (Wooldridge, 2003, p. 846). Later, vector y_t presents K endogenous variables indexed by time, and in sections 4.1.2 and 4.1.3, y_t consists of two price time series (i.e., producer price p_t and wholesale price w_t).

As stated above, the variables of a VECM are nonstationary at their level. Therefore, we provide the definitions of stationary in the following (Wooldridge, 2003, p. 361 f.; Lütkepohl, 2007, p. 24).

Definition 1 (Strict stationarity)

A stochastic process $\{y_t : t = 0,\ 1,\ 2, \ldots\}$ is stationary if the joint distribution of $(y_{t_1}, y_{t_2}, \ldots, y_{t_K})$ is the same as the joint distribution of $(y_{t_1+h}, y_{t_2+h}, \ldots, y_{t_K+h})$ for every set of time indices $\{t_1, t_2, \ldots, t_K\}$ and for all integers $h \geq 0$.

Definition 2 (Weak stationarity)

A stochastic process $\{y_t : t = 0,\ 1,\ 2,\ldots\}$ is stationary if its first and second moments are time-invariant.

$$E(y_t) = \mu \qquad \text{for all } t \qquad (3.1)$$

$$E\left[(y_t - \mu)(y_{t-h} - \mu)'\right] = \Lambda_y(h) = \Lambda_y(-h)' \qquad \text{for all } t \text{ and } h = 0, 1, 2, \ldots \qquad (3.2)$$

Definition 2 shows that the mean and the variance of a weak stationary process are constant. Additionally, the autocovariances of the process do not depend on *t* but only on the time period *h*.

If the time series in their level are stationary, then they are integrated of order 0, i.e., $y_t \sim I(0)$. If the time series in their level are nonstationary, then they can be integrated of order *f* to become stationary again (Lütkepohl, 2007, p. 22 and p. 242).

Definition 3 (Integration)

A process y_t is integrated of order *f*. That is, $y_t \sim I(f)$, if $\Delta^f y_t = (1-L)^f y_t$, where *L* is the lag operator or backshift operator. *L* is defined such that $Ly_t = y_{t-1}$, i.e., the lag operator shifts backs the time index by one period.[34]

Hence, a nonstationary time series can be integrated, which means that the time series are differentiated. In this case, the differentiated times series are stationary, but the time series at their level are nonstationary.

A VAR model can have stationary time series, $y_t \sim I(0)$, and nonstationary time series of the same integrated order, $y_t \sim I(f)$ with $f \geq 1$. A VAR with time series integrated of order 0 is a VAR in level. In contrast, a VAR with nonstationary time series of *I(f)* can be a VAR in difference if the time series are differenced *f* times and are not cointegrated (Hamilton, 1994, p. 549 ff.).

[34] L^2 means that the lag operator shifts backs the time index by two periods, L^3 by three periods, L^4 by four periods, and so on.

Definition 4 (Cointegration)

The variables in a K-dimensional process y_t are designated cointegrated of order (f, b), i.e., $y_t \sim CI(f, b)$, if all of the variables of y_t are $I(f)$ and if linear combination $v_t := \beta' y_t$ with $\beta = (\beta_1, \ldots, \beta_K)' \neq 0$ exists such that v_t is $I(f - b)$.

For example, if all of the variables of y_t are $I(1)$ and if $\beta' y_t$ is stationary ($I(0)$), then y_t is cointegrated of order (1, 1). The process that includes cointegrated variables is called a cointegrated process, and the vector β is the cointegrating vector or a cointegration vector (Lütkepohl, 2007, p. 245).

If the process y_t is nonstationary and if a linear combination v_t exists, then a VAR is not the correct model because of inconsistency issues (Hamilton, 1994, p. 579). Instead, we must estimate a VECM that includes these characteristics. In the following, we derive a VECM model from an unstable VAR model[35] with cointegration.

We assume that a K-dimensional VAR with j lags exists:

$$y_t = A_1 y_{t-1} + \ldots + A_j y_{t-j} + \varepsilon_t \tag{3.3}$$

where A_j are $(K \times K)$ coefficient matrices, and ε_t is a $(K \times 1)$ white noise or innovation process.

The K-dimensional VAR shall be cointegrated of rank ψ. That is, we estimate:

$$\Pi := -(I_K - A_1 - \cdots A_j) \qquad \text{(with } I_K \text{ as identity matrix)} \tag{3.4}$$

The VAR model has rank ψ. Thus, we can write matrix Π as a matrix product $\alpha\beta'$, with α and β of dimension $(K \times \psi)$ and of rank ψ, respectively. If $\psi = 0$, then Δy_t has a stable VAR($j - 1$) process, i.e., a VAR in difference. If $\psi = K$, $\left| I_K - A_1 - \cdots A_j \right| = \left| -\Pi \right| \neq 0$, then y_t is a stable VAR(j) process, i.e., a VAR in level. For any ψ between 0 and K, we can rewrite equation (3.3) in VECM representation:

$$\Delta y_t = \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + \Pi y_{t-1} + \varepsilon_t \tag{3.5}$$

35 A stable process is always stationary. In contrast, an unstable process does not have to be nonstationary (Lütkepohl, 2007, p. 25). Here we assume that the unstable VAR is also nonstationary, as we are not interested in unstable stationary processes in the following sections.

where Δy_t is a ($K \times 1$) vector of the first differences of the K endogenous variables; Γ is a ($K \times K$) matrix of the coefficients representing the short-run relationships among the variables; Π is a ($K \times K$) matrix of the long-run and speed of adjustment coefficients; y_{t-1} is a ($K \times 1$) vector of the once-lagged variables at their level; and ε_t is a white noise process. As explained previously, we can write Π as a matrix product $\alpha\beta'$. Specifically, we call matrix α the 'loading matrix', and this matrix determines the speed of adjustment, i.e., the coefficient indicates the rapidity with which variables move back to the long-run relationship after a shock or a change in the equilibrium. We label matrix β, which represents the long-run relationship, the 'cointegrating matrix' or 'cointegration matrix' (Johansen, 1995, p. 70 ff.; Lütkepohl, 2007, p. 244 ff.).

We can use many different methods to estimate VECM. The best-known estimators are the Engle-Granger two-step ordinary least squares (OLS) estimation (Engle and Granger, 1987) and Johansen's (1988, 1995) maximum likelihood (ML) regression. Additional VECM estimation methods include the following:

- Nonlinear least squares regression (Stock, 1987)
- Nonparametric parameters (Phillips, 1991)
- Estimation based on principal components (Stock and Watson, 1998)
- Estimation based on canonical correlations (Bossaerts, 1988)
- Bayesian estimation (Lütkepohl, 2007, p. 309 ff.)
- Estimated generalised least squares (EGLS) regression (Lütkepohl, 2007, p. 291 ff.)
- Instrumental variables (Hansen and Phillips, 1990)

In the following, we will explain only the ML estimation, which we apply to the German raw milk market. We choose Johansen's ML estimator because the estimator is superior to the other estimators in small samples (Gonzalo, 1994). In comparison with the estimation methods of Engle and Granger (1987), Stock (1987), Stock and Watson (1988) and Bossaerts (1988) Johansen's ML estimator is the best approach as this method is the only one that incorporates all prior knowledge of the presence of unit roots and the full system estimation and that can capture the dynamics of the system (Gonzalo, 1994). Based on these characteristics, we conclude that the ML estimator is more efficient and that it eliminates median bias, part of the nuisance parameter dependencies and the simultaneous equation bias.

To illustrate Johansens's ML estimator (Johansen, 1988 and 1995; Lütkepohl, 2007, p. 294 ff.) in a more convenient way, we rewrite the VECM (equation 3.5)) in matrix notation:

$$\Delta Y = \Gamma \Delta X + \Pi Y_{-1} + \mathrm{E} \qquad (3.6)$$

where

$\Delta Y := [\Delta y_1, \Delta y_2, \ldots, \Delta y_T]$ with T as the number of the sample's periods

$Y_{-1} := [y_0, y_1, \ldots, y_{T-1}]$

$\Delta X := [\Delta X_0, \Delta X_1, \ldots, \Delta X_{T-1}]$ with $\Delta X_{t-1} := \begin{bmatrix} \Delta y_{t-1} \\ \Delta y_{t-2} \\ \vdots \\ \Delta y_{t-p+1} \end{bmatrix}$

$\Gamma := [\Gamma_1, \Gamma_2, \ldots, \Gamma_{p-1}]$

$\mathrm{E} := [\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_T]$

For estimating equation (3.6) via the ML regression, the process y_t must have a Gaussian distribution or ε_t must be normally distributed with a mean of zero and a covariance matrix Σ_ε ($\varepsilon_t \sim N(0, \Sigma_\varepsilon)$). We dot normalise the matrix β[36], but we assume that the rank *rk* of Π is equal to ψ, i.e., $\Pi = \alpha\beta'$ with rk(α) = rk (β) = ψ. The log-likelihood function of a VECM for a sample size of T is:

$$\ln l = -\frac{KT}{2}\ln 2\pi - \frac{T}{2}\ln|\Sigma_\varepsilon| - \frac{1}{2}tr\left[(\Delta Y - \alpha\beta' Y_{-1} - \Gamma\Delta X)' \Sigma_\varepsilon^{-1} (\Delta Y - \alpha\beta' Y_{-1} - \Gamma\Delta X)\right] \quad (3.7)$$

To obtain the estimated coefficients, we must maximise the log-likelihood function. We know that maximising the log-likelihood function is equivalent to minimising the determinant of the residuals' covariance (proof of derivation of the determinant and the coefficients: Lütkepohl, 2007, p. 294 ff.). We define the residuals' covariance Σ_ε as:

$$\left|(\Delta YM - \alpha\beta' Y_{-1}M)(\Delta YM - \alpha\beta' Y_{-1}M)' / T\right| \quad (3.8)$$

where

$M := I_T - \Delta X'(\Delta X \Delta X')^{-1} \Delta X$.

[36] After estimating β, we perform a normalisation to interpret the results.

The minimum of the determinant is accomplished for:

$$\tilde{\beta}' = [v_1, \ldots, v_r]' S_{11}^{-1/2} \tag{3.9}$$

$$\tilde{\alpha} = S_{01}\tilde{\beta}\left(\tilde{\beta}' S_{11}\tilde{\beta}\right)^{-1} \tag{3.10}$$

where

$S_{gh} := R_g R_h' / T$ with $g, h = 0, 1$

$R_0 := \Delta Y M$

$R_1 := Y_{-1} M$

$v_1, \ldots, v_K$ are the orthonormal eigenvectors of $S_{11}^{-1/2} S_{10} S_{00}^{-1} S_{01} S_{11}^{-1/2}$

After deriving the coefficients $\tilde{\beta}'$ and $\tilde{\alpha}$, we can estimate the short-run dynamics Γ by employing OLS:

$$\tilde{\Gamma} := \left(\Delta Y - \tilde{\alpha}\tilde{\beta}' Y_{-1}\right)\Delta X'(\Delta X \Delta X')^{-1} \tag{3.11}$$

In practice, we estimate the three coefficients step by step, i.e., we estimate $\tilde{\beta}'$ first, then $\tilde{\alpha}$ and, at last, $\tilde{\Gamma}$.

After introducing a VECM without a deterministic term and the corresponding ML estimator, we show that a VECM with a deterministic trend does not cause major changes to the ML estimator (Lütkepohl, 2007, p. 299 f.). Specifically, deterministic trends can be polynomial trends, seasonal dummies, other dummies or constant means. We define the VECM with a deterministic trend as (Lütkepohl, 2007, p. 299):

$$\Delta y_t = \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + \Psi D_t + \alpha[\beta' : \xi'] \begin{bmatrix} y_{t-1} \\ D_{t-1}^{co} \end{bmatrix} y_{t-1} + \varepsilon_t \tag{3.12}$$

where D_{t-1}^{co} are the deterministic terms that are in the cointegrating equation with the corresponding coefficient ξ', and D_t are all of the remaining deterministic terms with the coefficient Ψ. Each deterministic term can appear either inside or outside of the cointegrating equation but not both. We simplify the VECM model as follows:

$$\Delta Y = \Gamma^+ \Delta X^+ + \Pi^+ Y_{-1}^+ + \mathrm{E} \tag{3.13}$$

where

$$Y_{-1}^+ := \left[y_0^+, y_1^+, \ldots, y_{T-1}^+\right] \qquad \text{with} \quad y_t^+ := \begin{bmatrix} y_t \\ D_t^{co} \end{bmatrix}$$

$$\Delta X^+ := \left[\Delta X_0^+, \Delta X_1^+, \ldots, \Delta X_{T-1}^+\right] \qquad \text{with} \quad \Delta X_{t-1}^+ := \begin{bmatrix} \Delta y_{t-1} \\ \Delta y_{t-2} \\ \vdots \\ \Delta y_{t-p+1} \\ D_t \end{bmatrix}$$

$$\Gamma^+ := \left[\Gamma_1, \Gamma_2, \ldots, \Gamma_{p-1}, \Psi\right]$$

$$\Pi^+ := \alpha\left[\beta' : \xi'\right] = \alpha\beta'$$

Estimating a VECM with deterministic terms with the help of the ML regression, we obtain the following coefficients:

$$\tilde{\beta}^{+'} = \left[v_1^+, \ldots, v_K^+\right]' (S_{11}^*)^{-1/2} \tag{3.14}$$

$$\tilde{\alpha}^+ = S_{01}^+ \tilde{\beta}^+ \left(\tilde{\beta}^{+'} S_{11}^+ \tilde{\beta}^+\right)^{-1} \tag{3.15}$$

$$\tilde{\Gamma}^+ := \left(\Delta Y - \tilde{\alpha}^+ \tilde{\beta}^{+'} Y_{-1}^+\right) \Delta X^{+'} \left(\Delta X^+ \Delta X^{+'}\right)^{-1} \tag{3.16}$$

where

$$S_{gh}^+ := R_g^+ R_h^+ / T \qquad \text{with } g, h = 0, 1$$

$$R_0^+ := \Delta Y M^+$$

$$R_1^+ := Y_{-1}^+ M^+$$

$$M^+ := I_T - \Delta X^{+'} \left(\Delta X^+ \Delta X^{+'}\right)^{-1} \Delta X^+$$

$v_1^+, \ldots, v_K^+$ are the orthogonal eigenvectors of $(S_{11}^+)^{-1/2} S_{10}^+ (S_{00}^+)^{-1} S_{01}^+ (S_{11}^+)^{-1/2}$

To determine the correct price transmission model, we must conduct some tests. As explained previously, a VECM has nonstationary times series in their level that are cointegrated.

As described previously, the process y_t has K variables. In section 4.1.2 and 4.1.3, we use two price series to estimate the price transmission in Germany (i.e, $K = 2$). As a result and for the sake of simplicity, we assume that y_t has two variables: x_t and z_t.

First, we test each variable for stationarity and its integration order by using an augmented Dickey-Fuller (1979) test:

$$\Delta x_t = \kappa + \rho x_{t-1} + \tau t + \zeta_1 \Delta x_{t-1} + \zeta_2 \Delta x_{t-2} + ... + \zeta_{t-s} \Delta x_{t-s} + \varepsilon_t \quad \text{with } \rho = \delta - 1 \qquad (3.17)$$

where x_t is a time series, t a time trend and κ, τ, ρ, ζ_1, ... ζ_{t-s}, are coefficients to be estimated.[37] The null hypothesis is that x_t has a unit root[38], which suggests nonstationarity (H_0: $\rho = 0$). The alternative hypothesis H_1 is that $\rho < 0$. Based on the Akaike information criterion (AIC), we derive the number of lagged differences s. Afterwards, we can perform a t-test for $\tilde{\rho}$ (similarly, we can perform the augmented Dickey-Fuller test for the variable z_t). If the null hypothesis is not rejected, then we difference the time series to render them stationary (Wooldridge, 2003, p. 372 ff. and p. 607 ff.)

Second, we perform Johansen's (1988, 1995; Johansen and Juselius, 1990) test on cointegration to determine whether a long-run relationship exists and to derive the number of cointegrating relations (Granger, 1981; Engle and Granger, 1987). We conduct two likelihood ratio (LR) tests: the trace statistic and the maximum-eigenvalue statistic.

We define the trace statistic as:

$$LR(\psi_0, K) = -T \sum_{i=\psi_0+1}^{K} \ln(1-\lambda_i) \qquad (3.18)$$

where ψ_0 is the assumed number of cointegrating relations (ψ = 0, 1, …, K-1), K is the number of endogenous variables, λ_i is the i-th largest eigenvalue of the Π matrix and T is the number of time periods. At most, K-1 cointegrating vectors exist. The null hypothesis is H_0: $rk(\Pi) = \psi_0$, i.e., the cointegrating rank rk is ψ_0 (H_1: $\psi_0 < rk(\Pi) \le K$).

The maximum-eigenvalue statistic is:

$$LR(\psi_0, \psi_0 + 1) = -T \ln(1-\lambda_{\psi_0+1}) \qquad (3.19)$$

---

[37] Here we include a time trend and a constant in the equation for the augmented Dickey-Fuller test because we can best describe the price series for Germany by including a time trend. We can also apply the augmented Dickey-Fuller test without a constant and a time trend or without a time trend and with a constant. The procedure remains the same regardless of whether a time trend is included.

[38] If a time series process has a unit root, then the process is highly persistent. That is, its current value equals the last period's value plus a weakly dependent disturbance. Hence, a time series with a unit root is nonstationary (Wooldridge, 2003, p. 374 ff.)

The null hypothesis is H_0: $rk(\Pi) = \psi_0$ versus H_1: $rk(\Pi) = \psi_0 + 1$. Therefore, cointegration between variables can only exist if the variables have the same order of integration.
To determine the cointegrating rank of a system of K variables, we must test several null hypotheses:

$$H_0 : rk(\Pi) = 0 \,,\ H_0 : rk(\Pi) = 1 \,,\ \ldots,\ H_0 : rk(\Pi) = K - 1 \tag{3.20}$$

We terminate the tests once the null hypothesis cannot be rejected. Next, we find the correct cointegrating rank. Thus, we use both statistics. For example, we assume that a system of two variables exists ($K = 2$). First, we test $rk(\Pi) = 0$. If the null hypothesis cannot be rejected, then a cointegration rank of $\psi = 0$ exists, and we use a VAR model with first differences. If the null hypothesis is rejected, then we test $rk(\Pi) = 1$. If this null hypothesis cannot be rejected, then we can estimate a VECM with a cointegration rank of $\psi = 1$. If $rk(\Pi) = 1$ still cannot be rejected, then we can account for a stationary VAR model for the levels of the variables (Lütkepohl, 2007, p. 329).
Third, we determine the causality among the variables by using a Granger (1969, 1988) causality test. As previously explained, we assume that y_t has two variables: x_t and z_t. We test if z_t Granger causes x_t and vice versa. To determine whether z_t causes x_t, we estimate a regression with x_t as the dependent variable and both the lagged x_t and the lagged z_t as the independent variables:

$$x_t = \eta_0 + \sum_{i=1}^{n} \eta_i x_{t-i} + \sum_{j=1}^{m} \gamma_j z_{t-j} + \varepsilon_t \tag{3.21}$$

The null hypothesis is $\gamma_1 = \gamma_2 = \ldots = \gamma_m = 0$ (H_1: $\gamma_j \neq 0$ for at least one $j \leq m$). If the null hypothesis is rejected, i.e., z_t provides additional explanatory power for x_t, then z_t Granger causes x_t. We conduct an F-test to determine whether the null hypothesis can be rejected. We utilise the same but reversed regression to test whether x_t causes z_t.
Fourth, we test for linearity towards the adjustment process and the short-run dynamics. If linearity exists, then we will use a VECM. Otherwise, we prefer a non-linear VECM, such as a TVECM (e.g., Ben-Kaabia and Gil, 2007; Serra and Goodwin, 2003). A TVECM is a nonlinear VECM that accounts for multiple regimes, such as the following two regimes:

$$\Delta y_t = \begin{cases} \eta_1 \varpi_{t-1}(\phi) + \sum_{j=1}^{p-1} \Gamma_j^1 \Delta y_{t-j} + \varepsilon_t^1 & if \ \varpi_{t-1}(\phi) \le \upsilon \\ \eta_2 \varpi_{t-1}(\phi) + \sum_{j=1}^{p-1} \Gamma_j^2 \Delta y_{t-j} + \varepsilon_t^2 & if \ \varpi_{t-1}(\phi) > \upsilon \end{cases} \tag{3.22}$$

where ϖ_{t-1} is the threshold variable that represents the once lagged residuals of the equilibrium relationship (i.e., the error correction term); ϕ is a cointegrating vector; and υ is the threshold parameter that causes the switching of regimes (Hansen and Seo, 2002).

The Hansen and Seo test compares a linear VECM with a non-linear TVECM (Hansen and Seo, 2002). Specifically, a supremum Lagrange Multiplier (sup-LM) test of a linear VECM against a TVECM with two regimes is used:

$$SupLM = \sup_{\upsilon_L \le \upsilon \le \upsilon_U} LM(\tilde{\phi}, \upsilon) \tag{3.23}$$

where the search region $[\upsilon_L, \upsilon_U]$ is defined such that υ_L is the π_0 percentile of $\varpi_{t-1}(\tilde{\phi})$ and υ_U is the $(1 - \pi_0)$ percentile. $\tilde{\phi}$ is the estimated coefficient of ϕ. The null hypothesis is linear cointegration, i.e., no threshold effect exists. As the distribution is non-standard, we utilise two bootstrapping methods to calculate the asymptotic critical values and the p-values of the linearity test.

4.1.2 Data

We use the monthly price data for raw milk at the producer level and for dairy products at the wholesale level to estimate the VECM. We collect the data on the German market for the period from January 1997 to December 2006. The producer price for raw milk p_t is listed in cents per kilogram and compiled by Zentrale Markt- und Preisberichtsstelle (ZMP, 1998-2007). We calculate the wholesale price w_t as the weighted average of the wholesale prices of fresh milk, cheese, butter and milk powder in cents per kilogram (based on data from ZMP, 1998-2007) while accounting for the quantity of raw milk in each kilogram of these products.[39]

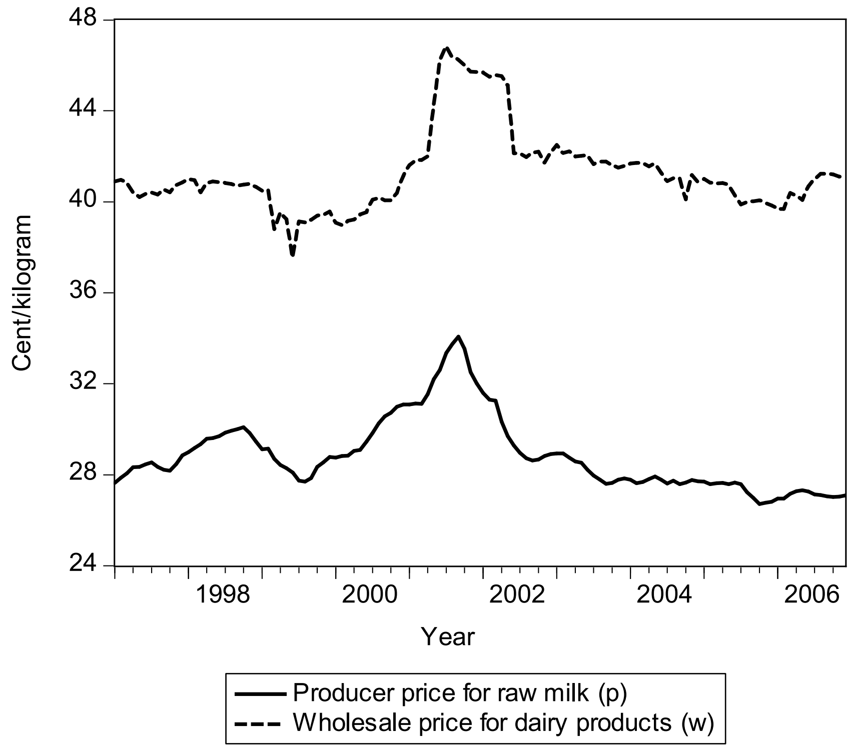
[39] We use the price time series p_t and w_t in place of the variables x_t and z_t of section 4.1.1. We combine the price time series p_t and w_t in vector P_t, which is called y_t in section 4.1.1.

Table 16: Descriptive statistics of producer and wholesale prices (in cents/kg)

	Producer price p_t	Wholesale price w_t
Mean	28.77	41.26
Median	28.44	40.87
Maximum	34.79	46.84
Minimum	26.23	37.54
Std. Dev.	1.83	1.82
Observations	120	120

Table 16 provides the descriptive statistics, and Figure 26 depicts the price series. The mean producer price is 28.77 cents per kilogram and fluctuates between 26.23 and 34.79 cents per kilogram. The mean wholesale price is 41.26 cents per kilogram and ranges from 37.54 to 46.84 cents per kilogram. The standard deviations between the prices are not significantly different. Figure 26 shows that the prices have similar movements and that they both peak in 2001.

Figure 26: Graphs of the producer and wholesale prices



4.1.3 Empirical results and interpretation

Based on our visual inspection and analysis of the data (Hamilton, 1994, p. 501 ff.) we perform an augmented Dickey-Fuller test by including a constant and a time trend. For both price series at the level the null hypothesis of a unit root is not rejected at the 10% significance level but is rejected at the 1% significance level for the first difference (Table 17). Therefore, all of the producer and wholesale prices are integrated of order one, i.e., the variables are nonstationary at their level and stationary at their first differences.[40]

Table 17: Augmented Dickey-Fuller (ADF) test results (with a constant and time trend)

	p_t	w_t
	Test results for variable in levels	
ADF t-statistic	-2.34	-1.63
p-value	0.41	0.77
	Test results for first-differenced variable	
ADF t-statistic	-4.85	-9.91
p-value	0.00	0.00

To determine the number of lags in Johansen's test, Granger causality test and the VECM we use two alternative model selection criteria: the AIC and the final prediction error (FPE). We estimate and analyse several VAR models with different lag lengths (i.e., from zero to twelve lags) with regard to their AIC and FPE values. The model with the lowest AIC value and the smallest FPE value has the optimal lag length for a VAR (Holtemöller, 2004; Yang et al., 2006; Brüggemann, 2006). For a VECM, the optimal lag length is the lag length chosen for a VAR model minus one lag (Lütkepohl, 2007, p. 325 ff.). The AIC and FPE show that the optimal choice for a VAR model is four lags for Germany. Therefore, we use three lags for the tests and the VECM.

Table 18 shows the results of Johansen's cointegration test. The precondition for cointegration that both variables have the same order of integration is fulfilled. Each cointegration equation includes an intercept and the price variables. The null hypothesis of no cointegrating equation is rejected at the 5% significance level based on both, the trace and the maximum-eigenvalue statistics. In both cases, we failed to reject the null hypothesis of one

[40] For the sake of comparison and completeness, we also conducted an ADF test for all of the other options (i.e., no constant and no time trend; constant and no time trend) The results are equal to the case presented here (i.e., a constant and a time trend) except for the case of no constant and no time trend, where the null hypothesis of a unit root for the producer price at the level is not rejected at the 5% significance level.

cointegrating equation. Therefore, the results indicate that one cointegrating relation exists, i.e., a long-run relationship between the producer price and the wholesale price exists.

Table 18: Johansen's cointegration test results

Null hypothesis	Eigenvalue	Trace statistics	Max-Eigenvalue Statistic
$\psi = 0$	0.14	21.89*	16.97*
$\psi \leq 1$	0.04	4.93	4.93

* Significant at the 5% level. Critical values: 20.26 (ψ = 0) and 9.17 ($\psi \leq 1$) at the 5% level for the trace test; 15.89 and 9.17 at the 5% level for the maximum eigenvalue test.

Table 19 describes the results of the Granger causality test. They show that a bidirectional relationship exists between the producer and the wholesale price, i.e., the causality relationship goes both downstream and upstream.

Table 19: Granger causality test results (with three lags)

Null hypothesis	F-statistic
Producer price does not Granger cause the wholesale price	4.59*
Wholesale price does not Granger cause the producer price	4.86*

* Significant at the 1% level.

Table 20 shows the outcome of the Hansen and Seo test with respect to the linearity of the model. The null hypothesis of linearity is not rejected at the 10% level.

Table 20: Test for non-linearity (Hansen and Seo test; with three lags)

Null hypothesis	Test statistics	p-value
linearity	6.06	0.49

Note: We obtain the p-value by using the fixed regressor bootstrapping method with 5000 simulations.
We estimate the test statistic and the p-value by using the software R and the package tsDyn (Stigler, 2010).

Based on all of the test results, we estimate a VECM with three lags:

$$\Delta P_t = \sum_{j=1}^{3} \Gamma_j \Delta P_{t-j} + \Pi P_{t-1} + \tau_1 BSE_1 + \tau_2 BSE_2 + \varepsilon_t \tag{3.24}$$

where P_t is a (2×1) vector of p_t and w_t; BSE_1 and BSE_2 are dummies that account for the abnormal price peak of milk during the BSE crisis. The dummy BSE_1 depicts the strong positive influence of the BSE crisis on milk prices from November 2000, when the first BSE case in Germany was officially verified (MUGV, 2010), to September 2001, whereas BSE_2 depicts the rapid price decline that occurred from October 2001 to Mai 2002.

Table 21 presents the coefficients of the cointegrating equation and their t-statistics. The alpha coefficient for the producer price is significant at the 10% level. The speed of adjustment coefficient for the wholesale price is statistically significant at the 1% level. The beta coefficients are significant at the 1% level. Hence, a long-run relationship exists between the producer price and the wholesale price.

Table 21: Estimated speed of adjustment coefficients (α's) and cointegrating coefficients (β's)

Independent Variable	p_t	w_t
Alpha	0.0036	0.0167
	(1.8157)	(2.9587)
Beta	1.00[†]	-6.8539
	(---)	(-4.6726)

Note: T-statistics are in brackets.

[†] We normalise the cointegrating equationd by setting the cointegrating coefficient β of the producer price equal to one.

Table 22 presents the estimates of the VECM. The results show the long-run relationship and the short-run dynamics. As the long-run relationship was already explained, we now concentrate on the short-run dynamics.

Table 22: Estimates of the VECM (dependent variables are Δp_t and Δw_t, t-statistics are in brackets)

	Δp_t	Δw_t
P_{t-1}	0.0036* (1.1857)	0.0167*** (2.9587)
Δp_{t-1}	0.375*** (4.186)	0.361 (1.429)
Δp_{t-2}	0.013 (0.137)	0.531** (1.991)
Δp_{t-3}	-0.163** (-2.032)	-0.412* (-1.817)
Δw_{t-1}	0.089** (2.700)	-0.051 (-0.551)
Δw_{t-2}	0.088*** (2.658)	-0.117 (-1.259)
Δw_{t-3}	0.054 (1.619)	-0.002 (-0.023)
BSE_1	0.135*** (2.216)	0.687*** (3.997)
BSE_2	-0.279*** (-3.274)	0.527** (2194)

* Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

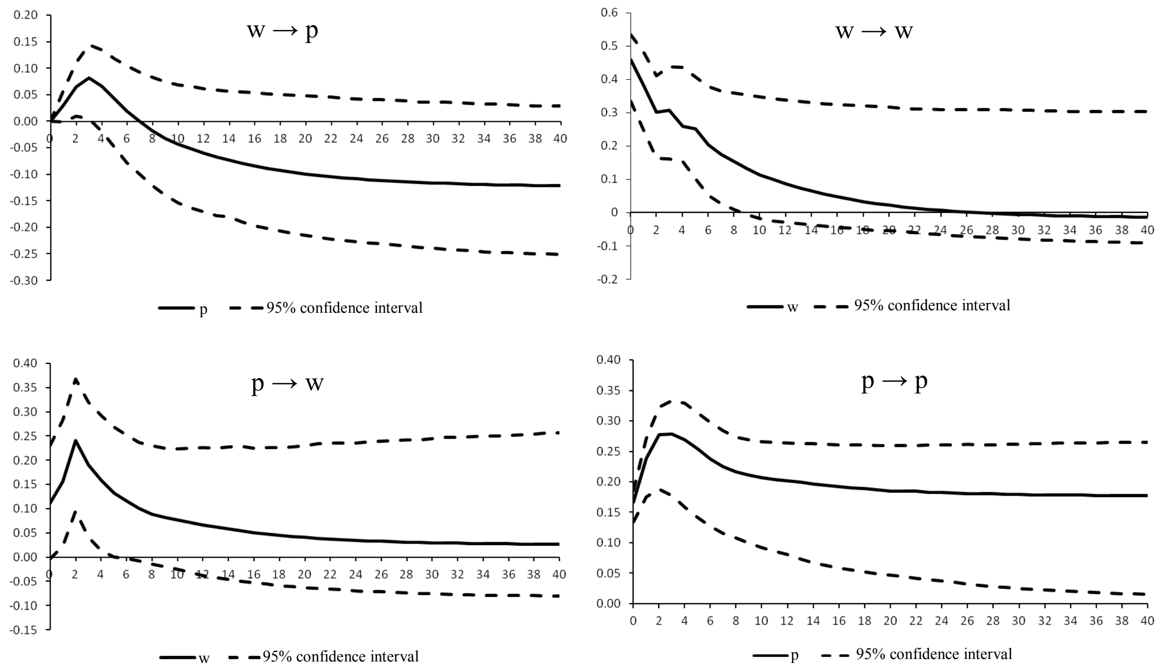
As shown by the table, the VECM clearly shows the upstream and downstream relationships. The second column (Δp_t) represents the transmission from downstream prices (wholesale price) to upstream prices (producer price). The third column (Δw_t) depicts the converse relationship, i.e., the influence of upstream prices on downstream prices. The short-run dynamics for the dependent variables Δp_t and Δw_t include three periods. Therefore, we use three lagged variables of the producer price and the wholesale price as the independent variables. The equation for the dependent variable Δp_t shows that all of the lagged producer and wholesale prices are significant at least at the 5% level, with the exclusion of Δp_{t-2} and Δw_{t-3}. However, only the independent variables Δp_{t-2} and Δp_{t-3} are significant at the 5% or the 10% level for the equation of the dependent variable Δw_t (see column 3). For both equations, the dummies BSE_1 and BSE_2 are significant at least at the 5% level.

To determine empirically whether the price transmission is in line with PM or HS competition we investigate the short-run dynamics by computing impulse-response functions (irf). The irfs show the response of one variable in a system to an impulse of another variable that is the size of one standard deviation (Lütkepohl, 2007, p. 51 ff.). In this instance, we orthogonalise the irf by using a Cholesky decomposition of the covariance matrix. We use the orthogonalised irf if the shocks of the different variables are not likely to be independent (Lütkephol, 2007, p. 57). Additionally, we implement a 95% confidence interval to make a statistically significant statement. Interpreting the results, we consider an effect of a one-time impulse to be transitory if the variable returns to its previous equilibrium of zero after some periods have passed since the impulse occurred. In contrast, we consider an impulse to be permanent if the variable does not return to its previous equilibrium but settles down at a new equilibrium (Lütkephol and Reimers, 1992).

Figure 27 presents the results of the irf for both prices. The top two figures illustrate the impulse of the wholesale price on the producer price ($w \rightarrow p$) and on itself ($w \rightarrow w$). The lower two figures depict the impulse of the producer price on the wholesale price ($p \rightarrow w$) and on itself ($p \rightarrow p$). To analyse the price transmission from the wholesale price to the producer price and thus test our theoretical findings on price transmission under PM and HS competition, we focus on the graph $w \rightarrow p$. An impulse of the wholesale price that is the size of one standard deviation leads to an increasing producer price for six months with a peak of 0.1. Afterwards the producer price declines until it stabilises at a value approximately -0.12 after 36 months. The upper limit of the confidence interval is always positive, and the lower limit of the confidence interval is negative or almost zero in the beginning. By considering the irf together with the 95% confidence interval, we find that an impulse of the wholesale price has a transitory effect on the producer price because the lower limit of the confidence interval is negative and the upper limit is positive (Lütkephol and Reimers, 1992). Therefore, the irf is not different from zero at a statistically significant level. This finding is certainly much more in line with PM competition (i.e., price transmission under 0.5) than with HS competition (i.e., price transmission equal to 1). However, we must interpret this result with some caution. Market power is not always the source of an imperfect price transmission. Adjustment costs, the perishability of products, inflation or inventories can also cause imperfect price transmission (Peltzman, 2000; Bunte, 2006).

The downstream price transmission from the producer price to the wholesale price ($p \rightarrow w$) is also rather transitory and always under 0.5. The stabilisation process spans approximately 36 months.

Figure 27: Impulse-response functions (response to one standard deviation shock)



Note: Orthogonal impulse response functions with a 95% Efron percentile confidence interval (5000 bootstrap replications) over 40 months

In section 2.4.1, we theoretically discussed HS and PM competition with overlapping markets and the existence of marketing cooperatives. We revealed that PM competition is in line with cooperative behaviour among the dairies, whereas HS competition represents non-cooperative behaviour, i.e., fierce price competition. The theoretical results confirmed this finding by showing that a perfect price transmission exists under HS and that an imperfect price transmission exists under PM competition. In this section, we estimate the price transmission between German milk processors and producers with the help of a VECM. The empirical results show that relatively low price transmission occurs. Thus, we can assume that PM competition and cooperative behaviour between processors exist in the German raw milk market.

4.2 Empirical analysis of spatial pricing

In the previous section (4.1), we showed that PM competition is most likely to occur in the German raw milk market. Hence, we empirically analyse Alvarez et al.'s (2000) theoretical model, which we presented in section 2.4.2, for the German raw milk market. Specifically, Alvarez et al. (2000) analyse a market with buyer market power, market overlap, ud pricing and PM competition. In Germany, many dairies exist, and we find that market overlap occurs among dairies in reality. Because of the extensive market overlap, we assume that competition exists in the backyard, i.e., overlapping markets exist among dairies and partially exist in the backyard (see section 2.4.2). The primary finding of the theoretical analysis suggests that if space becomes more important, then the dairies can increase their sellers' prices above the monopsony level to reduce the market overlap and increase the market area in which they can act as spatial monopsonists. Hence, if the absolute importance of space s, which we define as the transport costs per unit input times the distance between the dairies, increases, then the producer price p rises. However, this effect only arises under PM competition, ud pricing and competition in the backyard. In the following section, we empirically analyse the influence of the absolute importance of space on the producer price in the German raw milk market. Additionally, we empirically study the impact of the selling price of processed milk, the number of competitors, the quantity of processed milk and the milk density on the German producer price.

Based on different tests described later, we decided that a panel model with fixed effects best represents the German raw milk market.

4.2.1 A panel model with fixed effects

In contrast to the analysis presented in section 4.1, we use panel data instead of time series data. In panel data, observational units, such as households, firms and countries, are pooled over several time periods. One can also divide the panels into micro and macro panels. Micro panels usually consist of a large number of individuals N, often in the hundreds or thousands of individuals, over a short time period T, which usually ranges from 2 years to 20 years. Examples of micro panels include surveys of large numbers of households, individuals or firms. Macro panels consist of a moderate number of individuals N, which varies from 7 to 200 individuals, over a long time period, which usually ranges from 20 years to 60 years. Examples of macro panels often include surveys of moderate numbers of countries. The asymptotic properties of micro and macro panels exist for different values of N and T. For micro panels, the asymptotic properties exist for a large N and a fixed T. For macro panels, asymptotics exist for a large T, but the N can be large or small. In contrast to an analysis of micro panels, an econometric analysis of macro panels must address nonstationarity and cross-country dependence (Baltagi, 2008, p. 1). Because of the data structure for the German milk market, which consists of a large number of firms and a rather short time period, we present a model for micro panels.

One motivation for using panel data is to correct the problem of omitted variables. In the presence of omitted variables, the estimators are inconsistent, which suggests that the estimator does not asymptotically reach the true value (see Wooldridge, 2003, p. 169 f. for a proof). To correct the problem of omitted variables, we can employ one of the following options: a) do nothing and have inconsistent estimators; b) find a proxy for the omitted variable; c) find an instrument for the variables that correlates with the omitted variable; d) find indicators of the omitted variable that can be used in a multiple-indicator, instrumental variables procedure; or e) use panel data (Wooldridge, 2003, p. 485; Wooldridge, 2010, p. 282).

If the omitted variables vary across entities but not time (unobserved individual effects) or vary across time but not entities (unobserved time effects), then we can use panel data to avoid the problem of inconsistency. To compensate for omitted variables, which vary across entities and time, we can apply an instrumental variables regression (Wooldridge, 2010, p. 89 ff.).

We assume that the omitted variables are unobserved effects that can be treated as random variables and not as estimated parameters (Wooldridge, 2010, p. 281). Therefore, we can discern two panel models with unobserved effects, i.e., unobserved effects models. The one-way error component regression model includes unobserved individual effects or unobserved time effects in its error term. In contrast, a two-way error component regression model includes both unobserved effects, i.e., individual and time effects (Baltagi, 2008, p. 13 and p. 35; Wooldridge, 2010, p. 285). We can define the linear panel model with unobserved effects as follows:

$$y_{it} = \varphi x_{it} + \varepsilon_{it} \qquad i = 1, \ldots, N, \quad t = 1, \ldots, T \qquad (3.25)$$

where i denotes the cross-section dimension (e.g., firms, households, individuals or countries); t denotes the time-series dimension (e.g., years, quarters or months); y_{it} is the dependent variable; φ is a $(K \times 1)$ vector of the estimated parameters; x_{it} is a $(1 \times K)$ vector of

K observed explanatory variables, which includes a constant; and ε_{it} is the error term. Therefore, x_{it} can include observed variables that vary only across individual i, variables that vary only across time t, or variables that vary across both individual i and time t (Baltagi, 2008, p. 13; Wooldridge, 2010, p. 285).

To estimate a one-way error component regression model with unobserved individual effects, we divide the error term ε_{it} into:

$$\varepsilon_{it} = \mu_i + \nu_{it} \tag{3.26}$$

where μ_i denotes the unobserved time-invariant effects, which are also called 'individual effects' or 'individual heterogeneity', and v_{it} are the remainder disturbances, which are also called 'idiosyncratic errors' or 'idiosyncratic disturbances'. A one-way error component regression model with unobserved time effects includes λ_t instead of μ_i, which denotes the unobserved individual-invariant effects, i.e., time effects (Baltagi, 2008, p.13; Wooldridge, 2010, p. 285).

To estimate a two-way error component regression model, i.e., a model with unobserved individual and time effects, we divide the error term ε_{it} into (Baltagi, 2008, p. 35):

$$\varepsilon_{it} = \mu_i + \lambda_t + \nu_{it} \tag{3.27}$$

The key issue in estimating a panel model with unobserved effects is determining, whether the unobserved effects correlate with the explanatory variables x_{it}. If the unobserved effects do not correlate with x_{it}, i.e., for unobserved individual effects $E(\mu_i | x_{i1}, \ldots, x_{iT}) = E(\mu_i)$[41], then so-called random effects exist. The corresponding panel model and estimation are called 'random effects analysis', a 'panel model with random effects' or 'random effects (RE) estimation'. If the unobserved effects arbitrarily correlate with x_{it}, i.e., $E(\mu_i | x_{i1}, \ldots, x_{iT}) \neq E(\mu_i)$, then so-called fixed effects exist. The corresponding panel model and estimation are called 'fixed effects analysis', 'panel model with fixed effects' or 'fixed effects (FE) estimation'.

The three most well-known panel models with fixed effects are the FE estimator[42], the fixed effects dummy variable estimator and the first-difference (FD) estimator. These three

[41] For proof, see: Wooldridge (2010, p. 291 ff.). Similarly, for unobserved time effects $E(\lambda_t | x_{1t}, \ldots, x_{Nt}) = E(\lambda_t)$. If the individual and time effects are present, then both expected values must be satisfied.

[42] Also called the 'within estimator'.

estimators achieve consistent estimates by eliminating the unobserved effects. For example, the FE estimator eliminates individual effects by subtracting the time average of each variable from the original equation. The fixed effects dummy variable estimator uses dummies for each individual effect instead of the unobserved individual fixed effects. Finally, the FD estimator eliminates the individual effects by time differencing all of the model variables (Wooldridge, 2010, p. 300 ff.).[43]

When we compare the three panel models with fixed effects, we find that the fixed effects dummy variable estimator has two weaknesses. If the number of individuals N is large, then the dummy variable estimation may be numerically infeasible as the dimension of the covariance matrix that is needed for the estimation rises linearly with N. Additionally, the estimated $\hat{\rho}$ are consistent, but the unobserved effects are inconsistent for $N \rightarrow \infty$ and fixed T. When we compare the FE estimator and the FD estimator, we find that both estimatiors produce identical estimates for two time periods. If $T > 2$ and the explanatory variables x_{it} are strictly exogenous conditional on the unobserved effects and if the idiosyncratic errors are serially uncorrelated, the FE estimator is more efficient than the FD estimator. However, the FD estimator is more efficient if the idiosyncratic errors follow a random-walk pattern. In reality, the idiosyncratic errors are often serially correlated but do not follow a random-walk pattern. Therefore, the FE and FD estimators are usually preferred over the fixed effect dummy variable estimator, but the FE and FD estimators are similarly efficient in most cases (Wooldridge, 2010, p. 307 ff. and p. 321).

In this paper, we discuss the FE estimator with unobserved individual effects in more detail.[44] We start by constructing a linear panel model with individual effects:

$$y_{it} = \varphi x_{it} + \mu_i + \nu_{it} \qquad i = 1,\ldots,N\,,\ \ t = 1,\ldots,T \tag{3.28}$$

In vector notation, we stack the T observations for each individual i and rewrite equation (3.28):

$$y_i = \varphi X_i + \mu_i j_T + \nu_i \qquad i = 1,\ldots,N \tag{3.29}$$

where X_i is a $(T \times K)$ matrix and j_t is a $(T \times 1)$ vector of ones. Equation (3.29) shows a single random draw from all cross-sections. To obtain unbiased, consistent, and efficient estimates,

[43] The same is true for time effects. For example, the FE estimator eliminates the unobserved effects by subtracting the cross-section average of each variable from the original equation.

[44] The FE model can be expanded easily with unobserved individual and time effects or only with unobserved time effects (see e.g., Baltagi (2008, p. 35 ff.)).

we need to make some assumptions (Wooldridge, 2010, p. 301 and p. 304).

Assumption 1 (Strict exogeneity)

The explanatory variables x_{it} conditional on μ_i are strictly exogenous. That is $E(\nu_{it}|x_i, \mu_i) = 0$ for t = 1, 2, …, T, where $x_i = (x_{i1}, x_{i2}, \ldots, x_{iT})$ is a ($1 \times KT$) row vector.

Assumption 2 (Full rank)

The matrix of time-demeaned explanatory variables must have full rank. That is, $rank\left(\sum_{t=1}^{T} E(\ddot{x}_{it}^{'}\ddot{x}_{it})\right) = rank(E(\ddot{X}_i^{'}\ddot{X}_i)) = K$, where $\ddot{x}_{it\,i}$ is the explanatory variable minus the time average of the variable ($\ddot{x}_{it} = x_{it} - \bar{x}_i$).[45]

Assumption 3 (Homoskedasticity and serially uncorrelated)

The variance of the idiosyncratic errors must have a constant variance across t and be serially uncorrelated, i.e., $E(\nu_i \nu_i^{'}|x_i, \mu_i) = \sigma_u^2 \mathrm{I}_T$.

Assumption 1 implies that the explanatory variables in each time period are uncorrelated with the idiosyncratic error in each time period, i.e., $E(x_{is}{'}\nu_{it}) = 0$ for s, t = 1, …, T. Additionally, the idiosyncratic errors are uncorrelated with the unobserved individual effects. However, because the unobserved individual effects can be arbitrarily correlated with the explanatory variables x_{it}, we can estimate the parameters in the presence of time-constant omitted variables (individual effects), which are arbitrarily correlated with x_{it}. Hence, FE estimation is more robust than RE estimation. However, the FE estimation has one disadvantage. That is, time-constant observed variables cannot be included in the regression, as we cannot distinguish the unobserved time-constant variables from the observed time-constant variables (Wooldridge, 2010, p. 288 and p. 301).

Under assumptions 1 and 2, the estimated $\hat{\rho}$ are consistent and unbiased conditional on the explanatory variables x_{it}. Under assumption 3, the FE estimator is also efficient (Wooldridge, 2010, p. 303 f.).

The objective of the FE transformation under assumption 1 is to eliminate the unobserved effects μ_i from the model. Therefore, to derive the FE estimator (Wooldridge, 2010, p. 302 ff.), we first average equation (3.28) over t = 1, ..., T:

[45] $rank(E(\ddot{X}_i^{'}\ddot{X}_t))$ is only illustrated in vector notation.

$$\bar{y}_i = \varphi\bar{x}_i + \mu_i + \bar{v}_i \tag{3.30}$$

where $\bar{y}_i = \frac{1}{T}\sum_{t=1}^{T} y_{it}$; $\bar{x}_i = \frac{1}{T}\sum_{t=1}^{T} x_{it}$; $\bar{v}_i = \frac{1}{T}\sum_{t=1}^{T} v_{it}$; and $\mu_i = \bar{\mu}_i = \frac{1}{T}\sum_{t=1}^{T} \mu_i$. Next, we subtract equation (3.30) from equation (3.28) for each *t* and obtain the FE transformed equation:

$$y_{it} - \bar{y}_i = \varphi(x_{it} - \bar{x}_i) + v_{it} - \bar{v}_i \tag{3.31}$$

or

$$\ddot{y}_{it} = \varphi\ddot{x}_{it} + \ddot{v}_{it} \tag{3.32}$$

where $\ddot{y}_{it} = y_{it} - \bar{y}_i$; $\ddot{x}_{it} = x_{it} - \bar{x}_i$; and $\ddot{v}_{it} = v_{it} - \bar{v}_i$. We eliminate the unobserved individual effects μ_i by using the time-demeaning equation (3.31).

By utilising equation (3.32) and the pooled OLS estimation, we can estimate $\hat{\varphi}$. We can express the FE estimator $\hat{\varphi}$ as:

$$\hat{\varphi} = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \ddot{x}_{it}^{'} \ddot{x}_{it} \right)^{-1} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \ddot{x}_{it}^{'} \ddot{y}_{it} \right) \tag{3.33}$$

or in vector notation

$$\hat{\varphi} = \left(\sum_{i=1}^{N} \ddot{X}_i^{'} \ddot{X}_i \right)^{-1} \left(\sum_{i=1}^{N} \ddot{X}_i^{'} y_i \right) \tag{3.34}$$

However, we do not derive interpretation of $\hat{\varphi}$ from equation (3.32) but rather from the conditional expectation $E(y_{it}|x_i, \mu_i) = E(y_{it}|x_{it}, \mu_i) = \varphi x_{it} + \mu_i$. We can calculate the unobserved individual effects $\hat{\mu}$ by estimating $\hat{\mu} = \bar{y}_i - \hat{\varphi}\bar{x}_i$ (Wooldridge, 2010, p. 308).

To determine whether an FE model exists and define the correct FE model, we must conduct several tests.

First, we test a linear panel model for the existence of fixed effects. Specifically, we test the joint significance of the fixed effects by comparing the restricted model, which is the panel model without the fixed effects (i.e., the pooled model), with the unrestricted model, which is the panel model with the fixed effects. To test the joint significance of, for example, the individual fixed effects, we perform an F-test and an LR test (Wooldridge, 2003, p. 559; Baltagi, 2008, p. 15). We define the F-statistic as:

$$F_0 = \frac{(RRSS - URSS)/(N-1)}{URSS/(NT-N-K)} \sim \mathrm{F}_{N-1,N(T-1)-K} \tag{3.35}$$

where *RRSS* are the residual sums of the squares of the restricted model, and *URSS* are the residual sums of the squares of the unrestricted model. We estimate the LR-statistic as:

$$LR = 2(\mathcal{L}_{ur} - \mathcal{L}_r) \sim \chi^2_q \tag{3.36}$$

where $\mathcal{L}_{ur}$ is the log-likelihood value of the unrestricted model; $\mathcal{L}_r$ is the log-likelihood value of the restricted model; q is the number of exclusion restrictions; and χ^2 is the chi-square distribution. The null hypothesis is given by $H_0 : \mu_1 = \mu_2 = \ldots = \mu_N$ ($H_1 : \mu_j \neq 0$ for at least one $j \leq N$). If the null hypothesis is rejected, then the fixed effects of at least one individual is significant.[46]

Second, we conduct Hausman's (1978) test to determine whether the unobserved effects are fixed effects or random effects. The intuition behind the test is if the unobserved effects μ_i correlate with the explanatory variables x_{it}, then the FE estimator is consistent, whereas the RE estimator is inconsistent. Hence, if the FE estimator minus the RE estimator ($\hat{\varphi}_{FE} - \hat{\varphi}_{RE}$) is significantly different from zero, then a correlation between the unobserved effects and explanatory variables exists, and we should use the FE estimator. We define the Hausman statistic as:

$$H = \left(\hat{\lambda}_{FE} - \hat{\lambda}_{RE}\right)' \left[\mathrm{Av\hat{a}r}\left(\hat{\lambda}_{FE}\right) - \mathrm{Av\hat{a}r}\left(\hat{\lambda}_{RE}\right)\right]^{-1} \left(\hat{\lambda}_{FE} \hat{\lambda}_{RE}\right) \sim \chi^2_M \tag{3.37}$$

where $\hat{\lambda}_{FE}$ and $\hat{\lambda}_{RE}$ are $(M \times 1)$ vectors containing the respective FE and RE estimates of the elements of $\hat{\varphi}$, which are time-varying ($M \leq K$); and Avar is the asymptotic variance.[47] The null hypothesis states that no correlation exists between the unobserved effects and the observed explanatory variables. In this case, we should use an RE model.

Third, we test for heteroskedasticity by using a Breusch-Pagan test (Wooldridge, 2010, p. 139 f.). To determine whether heteroskedasticity is present, we estimate a regression with the squared residuals $\ddot{v}_{it}$ of the FE model (3.32) as the dependent variable and all of the explanatory variables x_{it} as the independent variables:

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46 We can also perform the F-test and LR-test for the joint significance of time fixed effects or of individual and time fixed effects, where the unrestricted model is a panel model with time fixed effects or a panel model with individual and time fixed effects.

47 As the FE estimator can only identify the coefficients of time-varying explanatory variables, we cannot compare the FE and RE coefficients of time-constant variables.

$$\ddot{v}_{it} = \psi + \theta x_{it} + u_{it} \tag{3.38}$$

where u_{it} is the error term. The null hypothesis is given by $\theta = 0$, i.e., homoskedasticity exists (H_1: $\theta \neq 0$). We can use two test statistics to proove the null hypothesis: the F-statistic (Breusch and Pagan, 1979) and the LM-statistic (Koenker, 1981). We define the F-statistic as:

$$F = \frac{R_c^2 / K}{(1 - R_c^2)/(N(T-1) - K)} \tag{3.39}$$

where R_c^2 is the centred R-squared of equation (3.38). We estimate the LM-statistic as:

$$LM = NT * R_c^2 \sim \chi_K^2 \tag{3.40}$$

Fourth, we perform two tests on serial correlation. Wooldridge (2010, p. 311) proposes a test on serial correlation for an FE model by regressing the time-demeaned idiosyncratic errors on the one-period-lagged time-demeaned idiosyncratic errors:

$$\hat{\ddot{v}}_{it} = \tau + \varsigma \hat{\ddot{v}}_{i,t-1} + \vartheta_{it} \tag{3.41}$$

where ϑ_{it} is the error term. Therefore, we use a pooled OLS regression with standard errors, which are robust to serial correlation. The null hypothesis is no serial correlation ($H_0 : \varsigma = -1/(T-1)$). The alternative hypothesis H_1 is $\varsigma \neq -1/(T-1)$. The second test on serial correlation is a modified Durbin-Watson test for panel data (Bhargava et al., 1982). We define the Durbin-Watson statistic for panel data as:

$$d_p = \frac{\sum_{i=1}^{N} \sum_{t=1}^{T} \left(\hat{\ddot{v}}_{it} - \hat{\ddot{v}}_{i,t-1} \right)^2}{\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{\ddot{v}}_{it}^2} \tag{3.42}$$

The null hypothesis is no serial correlation and the alternative hypothesis is serial correlation. Similar to the Durbin-Watson (1950) test, both lower (d_{pl}) and upper (d_{pu}) bounds exist. The null hypothesis, i.e., no serial correlation, is rejected if d_p is less than d_{pl}. If d_p is greater than d_{pu}, then the null hypothesis is not rejected. If $d_{pl} < d_p < d_{pu}$, then the test is inclusive. Bhargava et al. (1982) calculate tables of five percent significance points of d_{pu} and d_{pl}. Additionally, Bhargava et al. (1982) determine whether a random walk exists. If a random walk exists, then the FD estimator or a dynamic panel model should be used. Determining whether a random walk exists, we can also use the Durbin-Watson statistic for panel data d_p;

however, the lower (R_{pl}) and upper (R_{pu}) bounds are different ones than the ones for the Durbin-Watson statistic for panel data. The null hypothesis is that the residuals form a random walk. If d_p is less than R_{pl}, then the null hypothesis is rejected. If d_p is greater than R_{pu}, then the null hypothesis is not rejected. If $R_{pl} < d_p < R_{pu}$ the test is inclusive. Bhargava et al. (1982) calculate tables of five percent significance points of R_{pu} and R_{pl}.

If we find groupwise heteroskedasticity[48] and serial correlation, then we can compute a fully robust variance-covariance matrix and the corresponding t-statistics for the FE estimator (Baltagi, 2008, p. 16; Wooldridge, 2010, p. 311):

$$\text{Av}\hat{\text{a}}\text{r}(\hat{\varphi}_{FE}) = \left(\ddot{X}'\ddot{X}\right)^{-1}\left(\sum_{i=1}^{N}\ddot{X}_i'\hat{v}_i\hat{v}_i'\ddot{X}_i\right)\left(\ddot{X}'\ddot{X}\right)^{-1} \quad (3.43)$$

where $\ddot{X}$ is the ($NT \times K$) matrix of the time-demeaned explanatory variables. The robust variance-covariance matrix (equation (3.43)) is valid in the presence of heteroskedasticity and serial correlation in $\{v_{it} : t = 1,\ldots,T\}$ if $N \rightarrow \infty$.

4.2.2 Data

To estimate the model, we utilise panel data. Specifically, we use quarterly data collected from 203 German dairies during the period from 1999 to 2003. Because of the mergers and market entries of the dairies, the panel is unbalanced and contains 3756 observations.

The dependent variable is the producer price for raw milk P_{it} (data are compiled by ZMP). Because of missing data with regard to the explanatory variables, e.g., processing costs of dairies, we can only estimate a reduced form model. Therefore, we consider the following explanatory variables. As we lacked data on the wholesale prices received by the processors, WS_{it} is the national average selling price per litre of bottled pasteurised milk with 3.5% fat content (ZMP, 2001-2005). We expect WS_{it} to have a positive sign, as an increase in the selling price of processed milk should be partially transmitted in an oligopsony. We use the quantity of milk MM_{it} that is processed by the dairy as another explanatory variable. These data are also compiled by ZMP. Because the quantity of milk can represent the economics of scale (see section 2.4.3), we expect MM_{it} to have a positive sign. We calculate the number of competitors N_{it} for dairy i such that the combined quantity of milk processed by the

[48] Groupwise heteroskedasticity indicates that the variance of the idiosyncratic errors is homoskedastic within the cross-sectional units. That is, the variance within the cross-sectional units is constant, but the variance may differ across the cross-sectional units.

competitors equals at least the volume of dairy *i*. Because of competition in the backyard, we expect N_{it} to have a negative sign, as an increasing number of competitors leads to rather fierce competition. In this case, dairies reduce their producer prices to obtain a larger market area without market overlap. As explained in section 2.4.2, we define the absolute importance of space S_{it} as the distance between the dairies multiplied by the transport costs.[49] We define the transport costs as the price per litre of diesel fuel multiplied by the average consumption of diesel fuel by the dairy trucks. We obtain our data on the price per litre of diesel from Mineralölwirtschaftsverband e.V.[50] We assume that the average amount of diesel consumed by the dairy trucks is 30 litres per 100 kilometres. The consumer price index has deflated all prices (2000 = 100; Statistisches Bundesamt, 2004). We calculate the distance between the dairies as the sum of the distances from firm *i* to its nearest competitors such that the combined volume of the competitors at least equals the volume of firm *i*. Additionally, we use $(S_{it})^2$ as an explanatory variable to account for the nonlinear pricing behaviour. Because the producer price changes with the absolute importance of space, as described in Figure 11, we expect S_{it} to have a positive sign but expect $(S_{it})^2$ to have a negative sign. We calculate the milk density DI_{it} as the milk density of the district (i.e., 'Landkreis') in which the dairy is located. We calculate the milk density of each district as the total milk production divided by the area (based on data from the Statistischen Bundesamt and different Statistischen Landesämtern). We expect DI_{it} to have a positive sign because a higher milk density can cause the expenses incurred from collecting milk to decrease and, as a result, induce higher producer prices (see section 2.4.3).

Table 23 provides the descriptive statistics. The mean producer price P_{it} is 30.96 cents per kilogram and fluctuates between 23.26 and 39.42 cents per kilogram. The mean selling price of bottled milk WS_{it} is 46.50 cents per litre and ranges from 43.87 to 51.71 cents per litre. The standard deviations between the prices are not significantly different. The mean number of competitors N_{it} is 2.21. The minimum and maximum numbers of competitors are 2 and 22, respectively. The mean milk density DI_{it} is 127.63 tonnes per squared kilometre (km^2) and fluctuates between 1.13 and 722.47 tonnes per km^2. The mean milk quantity MM_{it} is 1,482,314,500 tonnes and ranges from 14,005,900 to 14,662,446,100 tonnes. The standard deviations for DI_{it} and MM_{it} are notably large.

[49] For simplification's sake, i.e., to avoid large numbers, we divide S_{it} by 100.

[50] Data are published online at www.mwv.de.

Table 23: Descriptive statistics of the observed explanatory variables

	P_{it}	WS_{it}	N_{it}	S_{it}	DI_{it}	MM_{it}
Mean	30.96	46.50	2.21	18.19	127.63	148,231.45
Median	30.68	45.72	2.00	8.21	100.20	79,191.00
Maximum	39.42	51.71	22.00	368.82	722.47	1,466,244.61
Minimum	23.26	43.87	1.00	0.24	1.13	1,400.59
Std. Dev.	2.46	2.47	2.27	35.54	93.77	205,632.90
Observations	3756	4060	3756	3756	4060	3756

4.2.3 Empirical results and interpretation

First, we perform three tests on the joint significance of fixed effects: a test for the individual fixed effects, a test for the time fixed effects and a test for the individual and time fixed effects. The null hypothesis stating that the fixed effects have no joint significance is rejected at the 1% significance level in all three cases (see Table 24). Therefore, we must include unobserved individual and time effects in the panel model.

Table 24: Test on the joint significance of fixed effects

Fixed effects	H_0	F-statistic	LR-statistic	p-value (F-test)	p-value (LR-test)
Individual	$\mu_i = 0$	3.08	606.46	0.00	0.00
Time	$\lambda_t = 0$	407.95	4,222.84	0.00	0.00
Individual and time	$\mu_i = \lambda_t = 0$	62.82	5,995.20	0.00	0.00

Note: We cannot include the variable WS_{it} in the regression if we test for the joint significance of time fixed effects as WS_{it} only varies over time and not over individuals. For the test on the joint significance of time fixed effects, we include a dummy for the type of organisation (1 if the dairy is a cooperative, 0 if the dairy is an iof). As the dummy does not vary over time, we cannot include it in a model with individual fixed effects. We cannot include either the variables WS_{it} or the dummy for the type of organisation in the test on the joint significance of individual and time fixed effects.

Table 25 shows the results of the Hausman test. The null hypothesis of robust effects is rejected at the 1% significance level for both the unobserved individual effects and the unobserved time effects. That is the unobserved individual and time effects are fixed and correlate with the observed explanatory variables.

Table 25: Hausman test

Robust effects	H_0	χ^2-statistic	p-value
Individual	$\hat{\rho}_{FE} - \hat{\rho}_{RE} = 0$	22.45	0.001
Time	$\hat{\rho}_{FE} - \hat{\rho}_{RE} = 0$	50.90	0.000

Based on these test results we estimate a panel model with individual and time fixed effects. As WS_{it} is only available at the national level and unavailable at the level of the dairies, this variable does not vary across the individuals. Therefore, if we use a panel model with time fixed effects and an FE transformation by employing a cross-section demeaning procedure, then we will eliminate WS_{it}. To prevent this occurrence, we replace the time fixed effects with time dummies. Hence, we estimate a panel model with individual fixed effects and time dummies:

$$P_{it} = \varphi_1 C + \varphi_2 N_{it} + \varphi_3 WS_{it} + \varphi_4 S_{it} + \varphi_5 S_{it}^2 + \varphi_6 DI_{it} + \varphi_7 MM_{it} + \omega_1 Q2_t + \omega_2 Q3_t + \omega_3 Q4_t + \psi_1 Y00_t + \psi_2 Y01_t + \psi_3 Y02_t + \psi_4 Y03_t + \mu_i + \nu_{it} \qquad (3.44)$$

where C is a constant; $Q2$, $Q3$ and $Q4$ are dummies for the first, second and third quarters, respectively; and $Y00$, $Y01$, $Y02$ and $Y03$ are dummies for the years 2000, 2001, 2002 and 2003, respectively. We exclude the dummies for the fourth quarter and for the year 1999 to avoid perfect multicollinearity.

Lastly, we must test for heteroskedasticity and serial correlation. Table 26 shows that the null hypothesis of homoskedasticity is rejected at the 1% significance level. Hence, the residuals are heteroskedastic.

Table 26: Breusch-Pagan test for heteroskedasticity

Null hypothesis	F-statistic	p-value
Homoskedasticity	26.47	0.00

To determine whether a serial correlation exists we use two different tests: Wooldridge's test and the modified Durbin-Watson test. The null hypothesis stating that the Wooldridge's test exhibits no serial correlation is rejected at the 1% significance level (see Table 27). The Durbin-Watson statistic is 1.42 (see Table 28). Bhargava et al. (1982) provide tables of five percent significance of d_{pu} and d_{pl}. For T =10, N = 150, K = 13, d_{pl} is 1.8971 and d_{pu} is 1.9341. In this paper, T = 20, N = 203 and K = 13. However, the table shows that the values of d_{pl} and d_{pu} become larger if T or N increases. Therefore, we know, that d_{pl} is not less than 1.8971. As the Durbin-Watson statistic is 1.42 and, therefore, less than d_{pl}, the null hypothesis of no serial correlation is rejected at the 5% significance level. Both tests imply that a serial correlation exists.

Table 27: Wooldridge's test on serial correlation

Null hypothesis	F-statistic	χ^2-statistic
No serial correlation	388.83*	315.79*

* Significant at the 1% level

Additionally we test for the existence of a random walk (see Table 28). As shown previously, we can use the Durbin-Watson statistic of 1.42 and compare this value with the lower R_{pl} and upper R_{pu} bounds, which are calculated by Bhargava et al. (1982). For T =10, N = 150, K = 13 R_{pl} is 0.6023, and R_{pu} is 0.6540. In this paper, T = 20, N = 203 and K = 13. However, the table shows that the values of R_{pl} and R_{pu} become smaller if T or N increases. Therefore, we know that R_{pu} is smaller than 0.6540. As the Durbin-Watson statistic is 1.42 and, therefore, larger than R_{pu}, the null hypothesis of a random walk is rejected at the 5% significance level. Therefore, we estimate model (3.44) by employing a fully robust variance-covariance matrix, which is valid in the presence of heteroskedasticity and a serial correlation.

Table 28: Modified Durbin-Watson test and test for random walk

Null hypothesis	Durbin-Watson statistic
No first-order serial correlation	1.42
No random walk	1.42

Table 29 presents the estimates of an FE model with fixed individual effects. All of the variables are significant at least at the 10% level, with the exception of the milk quantity *MM*. The variable *N* is significant at the 1% level and has a negative sign. If the number of competitors increases, then the producer price *P* decreases. The negative sign of the variable *N* contradicts Alvarez et al.'s (2000) findings, but it is evidently in line with PM competition, as the increasing number of competitors under PM competition can lead to rather fierce competition. Hence, the dairies reduce their producer prices to obtain a larger market area that has no market overlap. That is, the dairies decrease their producer prices to reduce the degree of market overlap and increase the market area in which they can act as spatial monopsonists. The coefficient of the selling price *WS* is positive, relatively low and significant at the 1% level. The value of the selling price is 0.42, which shows that a low price transmission from the selling price *WS* to the producer price *P* exists. This result confirms the low price transmission estimated in section 4.1 and therefore, validates the assumption of PM competition.

Table 29: Estimates of the FE model with fixed individual effects (with a fully robust variance-covariance matrix)

Variable	Coefficient	t-statistic	p-value
C	9.253	8.764	0.000
N	-0.326	-4.800	0.000
WS	0.420	39.204	0.000
S	0.024	3.073	0.002
S^2	-0.00003	-1.713	0.087
DI	0.020	2.792	0.005
MM	-0.0000009	-0.654	0.513
Q2	-0.916	-24.276	0.000
Q3	0.032	0.342	0.732
Q4	1.291	10.307	0.000
Y00	1.755	27.378	0.000
Y01	1.493	23.477	0.000
Y02	-1.541	-19.954	0.000
Y03	-2.083	-26.668	0.000

The variable *S* has a positive sign and is significant at the 1% level. In contrast, the variable S^2 has a negative sign and is significant at the 10% level. Because *S* has a positive sign and because S^2 has a negative sign, we find that the absolute importance of space *S* has a reverse U-shaped influence on the producer price *P*, as predicted by the theoretical model outlined in section 2.4.2. Figure 28 illustrates the U-shaped figure of the absolute importance of space. The optimal producer price *P* occurs at *S* = 375.77. However, only one dairy had an *S* value higher than 375.77, i.e., *S* = 378.23, and this value was observed for only one quarter. Hence, almost all of our processors lie on the increasing portion of the reverse U-shaped curve, where distance is relatively less important, competition extends beyond the dairies' locations (competition in the backyard) and the increasing absolute importance of space induces increasing producer prices. As expected, the coefficient of the variable milk density *DI* is positive and significant at the 1% level. This finding confirms the assumption described in section 2.4.3. Specifically, we assume that a higher milk density decreases the expenses that the dairy incurs while collecting milk from the producers and that smaller expenses imply higher profits for the dairies as well as higher producer prices. Contrary to our expectations, the variable milk quantity *MM* is negative; however, the variable is not significant. Normally *MM* should be positive, as the quantity of milk processed by a dairy can represent the economics of scale and the enterprise size. According to Weindlmaier (2000 and 2005), a rising quantity of processed milk implies decreasing processing costs and, therefore, higher producer prices.

Figure 28: Optimal producer prices under uniform pricing and PM competition

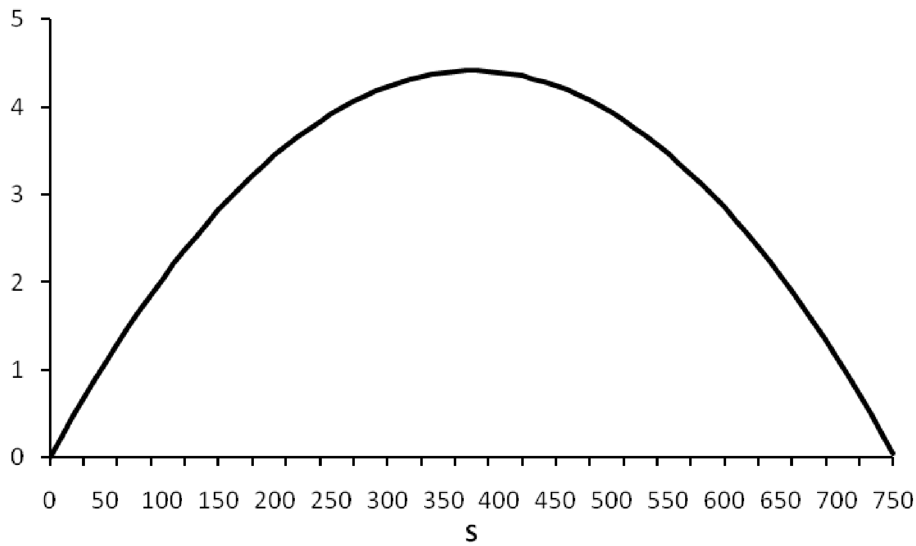


Table 30 reports the results of our tests on the set of dummies accounting for quarterly and yearly differences. According to a Wald test, the null hypothesis of no joint explanatory power is rejected at the 1% level.

Table 30: Wald test on the joint significance of time dummies

Null hypothesis	F-statistic	p-value
$\psi_1 = \psi_2 = \psi_3 = 0$	264.45	0.00
$\omega_1 = \omega_2 = \omega_3 = \omega_4 = 0$	552.18	0.00

4.3 Empirical analysis of spatial competition

After demonstrating that PM competition is most likely to exist in the German raw milk market and that the price transmission from the dairies to the producers is low, we showed in section 4.2 that the correlation between the absolute importance of space and the producer price has a reserve U-shape. Under the assumption of fierce competition, i.e., competition exists in the backyard, the producer price increases if the absolute importance of space increases. Additionally, we revealed that the selling price of processed milk and milk density positively influence the producer price, whereas the number of competitors negatively influence the producer price. This section addresses the spatial competition in the German raw milk market and the spatial impact on the producer price. That is, we empirically analyse the theoretical hypotheses outlined in section 2.4.3. The primary hypothesis is that spatial competition exists for a variety of reasons, for example, dairies may include the milk prices of spatially neighbouring dairies in their pricing decisions, or there may be regional competitive environments and location to sales markets that impact the producer price. Furthermore, we hypothesise that the quantity of processed milk has a positive impact on the producer price because of the economies of scale; that the milk density has a positive impact because it decreases the expenses incurred while collecting milk; and that the positive impact of a dairy, which is an iof, is due to larger investments in brands.

To empirically determine whether spatial competition exists in the German raw milk market, we can utilise a spatial lag model or a spatial error model. Thus, we can implement additional factors that influence the producer price in the empirical spatial model.

4.3.1 A spatial lag and spatial error model

The following estimation focuses mainly on the influence of space on competition in the German raw milk market. Therefore, we must define spatial influence, which we can present as spatial heterogeneity or spatial autocorrelation.[51] Spatial heterogeneity implies that the parameters or functional forms are not constant across space (Anselin, 1988, p. 9). However, spatial autocorrelation is more relevant to our studies. Anselin (1988, p. 11) defines spatial autocorrelation as a functional relationship between events occurring at different points in space. Spatial autocorrelation can be due to the measurement errors associated with spatial observations or the "importance of space as an element in structuring explanations of human behaviour" (Anselin, 1988, p. 12). A second, more fundamental cause of spatial autocorrelation implies that the events occurring at one point in space are partly determined by the same events occurring at other points in space (Anselin, 1988, p. 13).

Before specifying spatial autocorrelation, we must note that two different approaches to modelling spatial autocorrelation exist. One approach starts from theory and defines the structure of spatial autocorrelation a priori by employing theoretical models or hypotheses. Next, this approach incorporates the spatial autocorrelation of the theoretical model into the empirical model. The other approach starts from the data and defies the structure of spatial autocorrelation by utilising different statistical indicators, such as autocorrelation and cross-section tests (Anselin, 1988, p. 13).

Regardless of the approach, we can divide spatial autocorrelation into local spatial autocorrelation and global spatial autocorrelation. Local spatial autocorrelation implies that a change made to a spatial unit only impacts the directly adjacent spatial units (neighbours of the first order). In contrast, global spatial autocorrelation suggests that a change made to a spatial unit affects not only the directly adjacent spatial units but also the neighbouring spatial units of the directly adjacent spatial units (neighbours of higher order) and so on. The impact of the change decreases for the higher-order neighbours, but the spatial influence is global. If we also consider an exogenous variable in a spatial form, then we must address local spatial autocorrelation as well (Pennerstorfer, 2008, p. 26). This paper only addresses global spatial autocorrelation because this type of spatial autocorrelation is more relevant to our research objective.

Assuming that global spatial autocorrelation exists, we focus on the three most well-known spatial autoregressive models for cross-sectional data (Anselin, 1988, p. 34 ff.; Lesage and

[51] Spatial autocorrelation is also called spatial dependence (Anselin, 1988, p. 8).

Pace, 2009, p. 32 f.). The general structural form of the model is:

$$y = \rho W_1 y + \gamma X + \varepsilon \qquad \text{with } \varepsilon = \lambda W_2 \varepsilon + \nu \tag{3.45}$$

where y is a $(N \times 1)$ vector of the dependent variable, with N being the number of observations; W_1 and W_2 are $(N \times N)$ spatial weight matrices[52]; ρ is the coefficient of the spatially-lagged dependent variable; X is the $(N \times K)$ matrix of the independent and exogenous variables, with K being the number of explanatory variables; γ is the $(K \times 1)$ coefficients' matrix of the explanatory and exogenous variables; ε is an $(N \times 1)$ vector of the error term; λ is the spatial error coefficient; and ν is the part of the error term that is independent and normally distributed with a mean of 0 and variance σ^2I.

If λ = 0, then we obtain the mixed-regressive spatial autoregressive model:

$$y = \rho W_1 y + \gamma X + \varepsilon^{53} \qquad \text{with } \varepsilon \sim N(0, \sigma^2 I) \tag{3.46}$$

If $\rho = 0$, then we obtain the linear regression model with a spatial autoregressive error term:

$$y = \gamma X + (I - \lambda W_2)^{-1} \nu \tag{3.47}$$

If $\rho \neq 0$ and $\lambda \neq 0$, then we obtain the mixed-regressive spatial autoregressive model with a spatial autoregressive error term:

$$y = \rho W_1 y + \gamma X + (I - \lambda W_2)^{-1} \nu \tag{3.48}$$

The mixed-regressive spatial autoregressive model is generally termed the 'spatial lag model' and the linear regression model with a spatial autoregressive error term is generally termed the 'spatial error model' (e.g., Anselin, 2002; Dubin, 2004). In the following, we will use these two terms. This paper addresses the spatial lag and spatial error models in more detail.

From an economic perspecive, a spatial lag model shows the influence of the neighbours' dependent variable on the own dependent variable. In contrast, a spatial error model can verify the existence of a spatial influence but cannot explain the type of spatial influence.

The main component of spatial models is the form of the spatial weight matrix *W*. *W* describes how the spatial observations interact among themselves. The matrix *W* contains all of the observations and has the dimensions $(N \times N)$. We exogenously determine the structure

[52] We explain spatial weights matrices and their possible structures in the following section. W_1 and W_2 can be, but are not necessarily, different from each other.

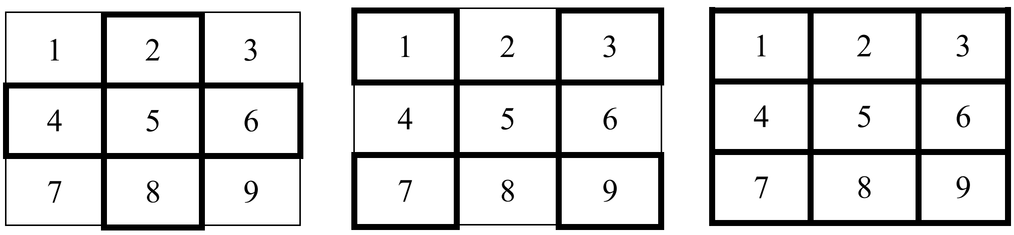
[53] As a special case, the explanatory variables *X* can also be spatially-lagged, i.e., *WX*.

of the spatial weight matrix. An element w_{ij} of the spatial weight matrix defines the grade of the influence that observation j has over observation i. Normally, the spatial weights are defined such that observation j is a 'neighbour' if i and j are close and that observation j is not a 'neighbour' if i and j are far away from each other. [54] By convention, an observation cannot be a neighbour to itself ($w_{ii} = 0$) (Anselin, 1988, p. 16 ff. and Anselin, 2002).

We can classify the spatial observations into areas or points within space. Spatial areas include countries, communities and districts. Spatial observations, which we illustrate as points within space, include cities, firms and universities. It is possible to convert areas into points and points into areas (Pennerstorfer, 2008, p. 31 ff.).

There are many different definitions of the structure of the spatial weight matrix. This paper shows the five most well-known spatial weight matrices. For instance, there are the contiguity weights of spatial observations that we classify as areas. We assume that the spatial units refer to a regular grid and define a neighbour in the case of both spatial units having a common boundary. However, different definitions of a common boundary exist. Figure 29 illustrates the three possible definitions of a common boundary. If we define a common edge as a common boundary, then the neighbours of cell 5 are cells 2, 4, 6 and 8 (see Figure 29 a). This spatial weight matrix is called a 'rook contiguity'. If we define a common vertex as a common boundary, then the neighbours of cell 5 are cells 1, 3, 7 and 9 (see Figure 29 b). This spatial weight matrix is called a 'bishop contiguity'. If we define both a common edge and a common vertex as a common boundary, then the neighbours of cell 5 are all of its surrounding cells (see Figure 29 c). This spatial weight matrix is called a 'queen contiguity'. Figure 29 only shows contiguities of the first order, but higher-order spatial contiguities can exist. For example, a rook contiguity of the second order accounts for not only the direct neighbours of cell 5 but also the neighbours of cell 5's neighbours that share a common edge with one another (Anselin, 1988, p. 17).

Figure 29: Spatial contiguity weight matrix



a) Rook contiguity b) Bishop contiguity c) Queen contiguity

[54] Therefore, neighbours can consist of competing firms, adjacent countries and cities.

Additionally, there are the 'k-nearest' neighbours weight matrix and the distance weight matrices for the observations that we classify as spatial points. For the *k*-nearest neighbours weight matrix, we must exogenously determine the value of *k*. If *k* is equal to two, then each spatial unit has two neighbours, which are the two neighbours closest to the spatial unit. For a distance weight matrix, we exogenously determine a distance. Scholars usually use the Euclidian distance, i.e., they draw a circle around the spatial unit, all of the spatial units within the circle are neighbours (Anselin, 1988, p. 17 f.; Anselin and Bera, 1998, p. 243 ff.; Anselin, 2002). Anselin and Bera (1998, p. 234 ff.) and Anselin (2006, p. 909 f.) describe additional spatial weight matrices.

After determining the neighbours of each spatial observation, we must measure the elements of the spatial weight matrix. We can use many different approaches to measure the elements (see Anselin, 1988, p. 17 ff.; Anselin and Bera, 1998, p. 243 f.). The most well-known measure is the binary structure of the spatial weight matrix, which, for example, Case et al. (1993) and McMillen et al. (2007) empirically applied to their studies. The binary weight matrix implies that the structure of the neighbours is defined by the values of 0 and 1. If observation j is a neighbour of observation i, then the element w_{ij} has the value of 1. If observation j and observation i are not neighbours, then w_{ij} has the value of 0. Therefore, we define the binary weight matrix as:

$$w_{ij} = \begin{cases} 1 \quad \text{if} \quad i \text{ and } j \text{ are neighbours and } \; i \neq j \\ 0 \quad \text{otherwise} \end{cases} \tag{3.49}$$

Another well-known approach utilises a distance function. Instead of the value 1, if observation i and observation j are neighbours, then distance functions such as $w_{ij} = 1/d_{ij}^{\omega}$ or $w_{ij} = e^{-\delta d_{ij}}$ (where d is the distance between observation i and observation j; and ω and δ are the parameters) can be used. Another well-known weight matrix based on distance is the Cliff-Ord weight matrix:

$$w_{ij} = \frac{c_{ij}^{\delta}}{d_{ij}^{\omega}} \tag{3.50}$$

where c is the proportion of observation i's boundary that is in contact with observation j. The Cliff-Ord weight matrix uses a combination of the distance between the neighbours and the shared common boundary. Other distance functions and the socioeconomic or economic functions define the spatial weight matrix.

Scholars normally utilise the spatial weight matrix because the term $(I - \lambda W)$ can be singular if the weight matrix is not normalised. Hence, the term $(I - \lambda W)$ is not invertible, and the spatial model cannot be calculated (Kelejian and Prucha, 2010). Therefore, scholars normalise and typically row-standardise the spatial weight matrix.[55] By doing so, the row elements of the spatial weight matrix add up to one (Anselin, 2006, p. 909):

$$w_{ij}^{*} = \frac{w_{ij}}{\sum_{j=1}^{N} w_{ij}} \tag{3.51}$$

Because of row-standardisation, our interpretation of the estimated spatial coefficient changes. Specifically, we can interpret a spatial lagged variable as the spatially-weighted average of the variable. If we assume that a spatial lag model that employs y as a price variable exists, then $W^{*}y$[56] is the vector of the neighbours' weighted average price. The advantage of row-standardisation is that $W^{*}y$ depends on the neighbours' prices but not on the number of neighbours[57] (Pennerstorfer, 2008, p. 37).

After determining the spatial weight matrix, we can regress the spatial model. The structural form of the spatial lag model and the spatial error model are:

$$y = \rho W y + \gamma X + \varepsilon \qquad \text{with } \varepsilon \sim N(0, \sigma^2 I) \tag{3.52}$$

$$y = \gamma X + \varepsilon \qquad \text{with } \varepsilon = \lambda W \varepsilon + \nu \text{ and } \nu \sim N(0, \sigma^2 I) \tag{3.53}$$

We rewrite equations (3.52) and (3.53) in their reduced forms:

$$y = (\mathrm{I} - \rho W)^{-1} \gamma X + (\mathrm{I} - \rho W)^{-1} \varepsilon \tag{3.54}$$

$$y = \gamma X + (\mathrm{I} - \lambda W)^{-1} \nu \tag{3.55}$$

As an OLS regression causes biased and inconsistent estimators for a spatial lag model and unbiased but inefficient estimators for a spatial error model (Anselin, 1988, p. 57 ff.), we use ML regression. The corresponding log-likelihood functions are (Anselin, 1988, p. 63):

[55] The literature uses the terms 'normalised' and 'standardised' interchangeably.
[56] *W** is the row-standardised weight matrix.
[57] In contrast, *Wy* increases with the number of neighbours.

$$\ln L = (-N/2)\ln(2\pi) - (N/2)\ln\sigma^2 + \ln|\mathrm{I} - \rho W|$$
$$-\left[(y - \rho Wy - X\gamma)'(y - \rho Wy - X\gamma)\right]/(2\sigma^2) \tag{3.56}$$

$$\ln L = (-N/2)\ln(2\pi) - (N/2)\ln\sigma^2 + \ln|\mathrm{I} - \lambda W|$$
$$-\left[(\mathrm{I} - \lambda W)(y - X\gamma)\right]'\left[(\mathrm{I} - \lambda W)(y - X\gamma)\right]/(2\sigma^2) \tag{3.57}$$

We maximise the log-likelihood function with respect to the parameters γ, ρ and σ^2 for a spatial lag model and with respect to γ, λ and σ^2 for a spatial error model. The partial derivatives consist of first-order conditions, which have an analytical solution, and of one parameter, which is nonlinear. Hence, no analytical solution exists, and we can only solve the system by utilising numerical methods. Because only one nonlinear parameter exists, the solution to the system of partial derivatives is not overly complex (Anselin, 1988, p. 64).
As an alternative to the ML regression, we can utilise the two-stage least squares (TSLS) estimation method (Anselin, 2006, p. 927). To employ this instrumental variable estimator, we must formulate equation (3.52) as:

$$y = \tau Z + \varepsilon \tag{3.58}$$

where $Z = [Wy, X]$ and $\tau = [\rho, \gamma]$. In the first stage, we regress the instrumental variables on the variable *Z* by using OLS to obtain the predicted values of *Z*. Here, the instrumental variables are the spatially-lagged *X* variables. The predicted values of *Z* are:

$$\hat{Z} = Q(Q'Q)^{-1}Q'Z \tag{3.59}$$

where *Q* is the ($N \times q$) matrix of the instruments, including the exogenous variables *X*, with $q \geq K + 1$. In the second stage, we regress equation (3.58) with OLS, but we replace the variable *Z* with the predicted variable $\hat{Z}$. The spatial TSLS estimators ρ and γ are:

$$\hat{\tau} = (\hat{Z}'\hat{Z})^{-1}\hat{Z}'y \tag{3.60}$$

To determine whether spatial autocorrelation is present and which type of spatial model (i.e., spatial error or spatial lag model) exists, we must perform some tests.
To test for spatial autocorrelation, we calculate the Moran's *I* statistic (Moran, 1948) for the regression residuals (Moran, 1950a and 1950b):

$$I = \hat{\varepsilon}' W \hat{\varepsilon} / \hat{\varepsilon}' \hat{\varepsilon} \tag{3.61}$$

where $\hat{\varepsilon}$ is a $(1 \times N)$ vector of the OLS residuals $y - \hat{\gamma} X$, and W is the spatial weights matrix.[58] The inference on the Moran's *I* test is based on our calculations of an asymptotically normal standardised *z*-value:

$$z = \frac{I - E(I)}{SD(I)} \tag{3.62}$$

where E(*I*) is the expected value of the Moran's *I* statistic, and SD is the standard deviation of the Moran's *I* statistic (Cliff and Ord, 1972). The null hypothesis is that no spatial autocorrelation exists.

If the null hypothesis of no spatial autocorrelation is rejected, then we can perform two LM tests to determine whether a spatial lag model or a spatial error model is the correct choice (Anselin et al., 1996 and Anselin, 2006, p. 935 ff.). In both cases, the OLS model without a spatial lag term and without a spatial error term is the restricted model.

We define the LM (lag) statistic as:

$$LM_{lag} = \frac{\left[\hat{\varepsilon}' W y / (\hat{\varepsilon}' \hat{\varepsilon} / N)\right]^2}{D} \tag{3.63}$$

where *D* is the denominator term:

$$D = \left[(WX\hat{\gamma})' \left[I - X(X'X)^{-1} X'\right](WX\hat{\gamma}) / \hat{\sigma}^2\right] + tr(W'W + WW) \qquad (3.64)^{59}$$

The null hypothesis is that no spatial lag exists while assuming that no spatial error autocorrelation exists (H_0: $\rho = 0$). The alternative hypothesis is H_1: $\rho \neq 0$.

The LM (error) statistic is:

$$LM_{error} = \frac{\left[\hat{\varepsilon}' W \hat{\varepsilon} / (\hat{\varepsilon}' \hat{\varepsilon} / N)\right]^2}{tr\left[W'W + WW\right]} \tag{3.65}$$

The null hypothesis is that no spatial error autocorrelation exists while assuming that no spatial lag dependence exists (H_0: $\lambda = 0$). The alternative hypothesis is H_1: $\lambda \neq 0$. Both LM statistics are asymptotically $\chi^2(1)$ distributed.

If only one of the two LM statistics reject the null hypothesis, the optimal choice of spatial

[58] Equation (3.61) shows Moran's *I* for the row-standardised weights.

[59] tr = matrix traces.

model is obvious. However, if both LM statistics reject the null hypothesis, then we must conduct a robust version of the LM (lag) test and the LM (error) test (Anselin et al., 1996 and Anselin, 2006, p. 939 ff.). The robust LM tests assume that a spatial lag and a spatial error exist in the model, i.e., we test for the existence of a spatial lag while assuming that a spatial error exists (and vice versa). Hence, we estimate a model with a spatial lag and a spatial error:

$$y = \rho Wy + \gamma X + \varepsilon \qquad \text{with } \varepsilon = \lambda W\varepsilon + \nu \tag{3.66}$$[60]

The robust LM statistics are also asymptotically $\chi^2(1)$ distributed and are defined as:

$$LM^{r}_{lag} = \frac{\left([\hat{\varepsilon}'Wy/(\hat{\varepsilon}'\hat{\varepsilon}/N)] - [\hat{\varepsilon}'W\varepsilon/(\hat{\varepsilon}'\hat{\varepsilon}/N)]\right)^2}{D - tr[W'W + WW]} \tag{3.67}$$

$$LM^{r}_{error} = \frac{\left([\hat{\varepsilon}'W\hat{\varepsilon}/(\hat{\varepsilon}'\hat{\varepsilon}/N)] - tr[W'W + WW]D^{-1}[\hat{\varepsilon}'Wy/(\hat{\varepsilon}'\hat{\varepsilon}/N)]\right)^2}{[(tr(W'W + WW))(1 - tr[W'W + WW]D)]} \tag{3.68}$$

For the robust LM (lag) test, the null hypothesis is H_0: $\rho = 0$, i.e., no spatial lag dependence exists. The alternative hypothesis is H_1: $\rho \neq 0$. For the robust LM (error) test, the null hypothesis is H_0: $\lambda = 0$, i.e., no spatial error autocorrelation exists (H_1: $\lambda \neq 0$).

If only one robust LM test is significant, then we adopt the corresponding spatial effect and model (e.g., if only the robust LM lag is significant, then we use the spatial lag model). If both robust LM tests are significant, then we apply the model with the higher significance value. However, two significant robust LM tests can suggest that other sources of misspecification exist, e.g., incorrect spatial weights. The problem of misspecification also applies if two significant LM tests and two corresponding insignificant robust LM tests exist (Anselin, 2005, p. 200 ff.).

We test for heteroskedasticity by using a modified Breusch-Pagan test for the spatial models, which accounts for the coefficient of the spatial lag or the spatial error (Bivand, 2010, p. 20 f.). If the null hypothesis of no homoskedasticity is rejected, then we can use a generalised spatial TSLS estimator, e.g., for a spatial lag model (Bivand, 2010, p. 180 ff.).

4.3.2 Data

To estimate the spatial model, we utilise cross-sectional data from Germany in 2001. We use cross-sectional data from the year 2002 to verify the stability of the results. In 2001, the data

[60] The assumption is that the spatial weights for the lag are the same as those for the error ($W_1 = W_2 = W$).

included 189 processors. In 2002, 182 processors remained in Germany.

The dependent variable is the producer price of raw milk P_i in cents per kilogram (data are compiled by ZMP). Because we lack data on the explanatory variables, e.g., the processing costs of the dairies, we can only estimate a reduced model. Therefore, we consider the following explanatory variables. We calculate the milk density DI_{it} as the milk density of the district (i.e., 'Landkreis') in which the dairy is located. We calculate the milk density of each district as the total milk production divided by the area (based on data from the Statistischen Bundesamt and different Statistischen Landesämtern). We expect DI_{it} to have a positive sign, as a higher milk density can decrease the expenses incurred while collecting milk and, as a result, induce higher producer prices (see section 2.4.3). We use the milk quantity MM_i (in 10,000 tonnes) that is processed by the dairy as another explanatory variable. These data are also compiled by ZMP. Additionally, we use the squared milk quantity MM_i^2 as the explanatory variable. Because the quantity of milk can represent the economics of scale (see section 2.4.3), we expect MM_{it} to have a positive sign. Finally, we use a dummy for the organisational form of each dairy G_i as compiled by ZMP. G_i has a value of 0 if the dairy is an iof and a value of 1 if the dairy is a cooperative. We expect G_i to have a negative sign because a dairy organised as a cooperative invests in brands less than a dairy that is an iof. A cooperative induces a deficit in value and, consequently, a lower producer price.

Table 31 and Table 32 provide descriptive statistics for the variables. With respect to the milk density and the collected quantities of milk, the values do not differ considerably between 2001 and 2002. However, the producer price is higher and its standard derivation is lower in 2001 than in 2002.

Table 31: Descriptive statistics of the explanatory variables for 2001

	Producer price	Milk quantity	Milk density
Mean	34.359	14.423	0.129
Median	34.326	8.000	0.104
Maximum	38.862	111.910	0.674
Minimum	31.577	0.168	0.001
Std. Dev.	0.988	19.401	0.095

Table 32: Descriptive statistics of the explanatory variables for 2002

	Producer price	Milk quantity	Milk density
Mean	31.149	14.730	0.131
Median	31.470	7.944	0.106
Maximum	35.380	120.318	0.698
Minimum	27.021	0.170	0.001
Std. Dev.	1.505	20.207	0.095

4.3.3 Empirical results and interpretation

We must determine the spatial weight matrix to perform the ML estimation and the TSLS estimation:

$$w_{ij} = \begin{cases} 1 \text{ if } d_{ij} < 79.99 \text{ and } i \neq j \\ 0 \text{ otherwise} \end{cases} \tag{3.69}$$

where d_{ij} is the distance in kilometres between dairies i and j. We define all of the dairies within a radius of 79.99 km as neighbours.[61] According to expert opinions, the average dairy in Germany collects milk in an area with a radius of 40 km from its own location. However, we used a distance of 79.99 km instead of 40 km, as two dairies that are, for example, 60 km away from each other will operate in partially overlapping markets. Therefore, these two dairies are still competitors and concerning the spatial weight matrix they are neighbours. Hence, we assume that no overlapping markets exist if two dairies are separated by a distance of 80 km. As a consequence, we remove one dairy from the original sample in 2001 and two dairies from the original sample in 2002, as the neighbours nearest to these dairies are farther away than 79.99 km.[62] Furthermore, the spatial weight matrix is symmetric and row-standardised.

After defining the spatial weight matrix, we perform the Moran's *I* test and the LM tests. Table 33 describes the results of the tests for global spatial autocorrelation. For both years, the null hypothesis of no spatial autocorrelation is rejected at the 1% significance level (see Moran's *I* test). The LM tests also show that both the null hypothesis of no spatial lag (see

[61] However, each dairy is not a neighbour of itself. Therefore, the diagonal elements of the weight matrix are zero.

[62] In empirical papers, each spatial unit normally has at least one neighbour. That is, there are no islands, i.e., having no neighbours. We adjusted the data described in section 4.3.2 to compensate for the missing dairies.

LM (lag) test) and the null hypothesis of no spatial error (see LM (error) test) are rejected at the 1% significance level. As both LM tests are rejected, we need to conduct the robust LM tests to determine which type of spatial autocorrelation exists. Table 33 shows that the robust LM (lag) test is rejected at the 1% significance level. However, we failed to reject the null hypothesis of the robust LM (error) test. Hence, a spatial lag model is the correct spatial model for 2001 and 2002.

Table 33: Tests for global spatial autocorrelation

	2001		2002	
	Statistic	p-value	Statistic	p-value
Moran's I (error)	0.47	0.00	0.64	0.00
LM (lag)	201.60	0.00	340.47	0.00
Robust LM (lag)	27.57	0.00	43.45	0.00
LM (error)	174.66	0.00	297.11	0.00
Robust LM (error)	0.63	0.43	0.09	0.77

Based on all of the test results, we estimate the following model:

$$P_i = \gamma_1 C + \rho W P_i + \gamma_2 DI_i + \gamma_3 MM_i + \gamma_4 MM_i^2 + \gamma_5 G_i + \varepsilon \qquad (3.70)$$

where C is a constant.

Finally, we test for heteroskedasticity. Table 34 presents the results of the Breusch-Pagan test for a ML estimation of a spatial lag model. As shown by the table, the null hypothesis of homoskedasticity is not rejected at the 1% significance level for the year 2001. However, the null hypothesis is rejected at the 10% significance level for the year 2002. Therefore, we need robust standard errors for the year 2002.

Table 34: Test for heteroskedasticity

		2001		2002	
	H_0	F-value	p-value	F-value	p-value
Breusch-Pagan Test	Homoskedasticity	6.50	0.17	29.14	0.00

Table 35 displays the output of the ML estimation and the TSLS estimation for 2001. Table 36 presents the estimates for 2002. For 2002, the TSLS estimation has robust standard errors but the ML estimation only has the "normal" standard errors.[63]

Table 35: Results of the spatial lag model for 2001

	ML estimation			TSLS estimation		
Variable	Coefficient	z-value		Coefficient	t-value	
C	8.5607	4.456	***	4.9817	1.328	
DI	1.1524	2.246	**	0.8997	1.583	
MM	0.0120	1.779	*	0.0094	1.285	
MM^2	-0.00015	-2.039	**	-0.00012	-1.588	
G	-0.1814	-1.897	*	-0.1630	-1.671	*
$\rho^{\#}$	0.7464	13.245	***	0.8519	7.705	***

* Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.
# ρ is the coefficient of the spatial lag

Table 36: Results of the spatial lag model for 2002

	ML estimation			TSLS estimation		
Variable	Coefficient	z-value		Coefficient	t-value	
C	4.9223	4.215	***	2.3815	0.649	
DI	0.1571	0.265		-0.0065	-0.011	
MM	0.0134	1.787	*	0.0098	1.257	
MM^2	-0.00011	-1.500		-0.00008	-1.173	
G	-0.5049	-4.383	***	-0.4717	-3.818	***
ρ	0.8453	22.645	***	0.9281	7.758	***

* Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

As shown by the table, the estimated coefficients are stable, as the values do not differ considerably between the two estimation methods.[64] Additionally, the coefficients are similar between the two years. However, the significance of the coefficients varies between the estimations and the years. For 2001 and the ML estimation, all of the coefficients are significant. However, for 2001 and 2002 and the TSLS estimation, only the coefficients of the spatial lag and of the organisational form are significant.[65]

For the analysis of spatial competition, the coefficient of the spatial lag is crucial. In both years, the coefficient is positive and varies between 0.75 and 0.93. Additionally, the

63 Only the TSLS estimation has robust standard errors as the software programs used in this study have no code for the spatial ML estimation with robust standard errors.

64 Exception is the milk density for the year 2002 for which the coefficient is 0.16 by ML estimation and -0.0065 by TSLS estimation.

65 As the ML estimation for 2002 has no robust standard errors, we cannot consider the significance of this estimation.

coefficient is highly significant at the 1% level. However, the coefficient is larger in 2002 than in 2001. Ceteris paribus, in 2001, an increase of one cent in the average producer price of all neighbouring competitors leads to an own price increase of 0.75 cents.[66] In 2002, ceteris paribus, an increase of one cent in the average producer price of all neighbouring competitors leads to an own price increase of 0.85 cents.[67] Thus, global spatial autocorrelation is positive, and an increase in the producer price of all spatially neighbouring competitors leads to a smaller own price increase. Thus, this finding confirms our theoretical hypothesis, which states that the pricing and competition in the German raw milk market are influenced by the pricing of spatially neighbouring dairies. Furthermore, the results suggest that PM competition exists. A dairy might expect its neighbouring competitors to largely match any price variations. However, we must interpret this result with some caution, as PM competition refers to the expectations of a dairy regarding price changes, and the spatial lag coefficient refers to the reactions of a dairy to price changes.

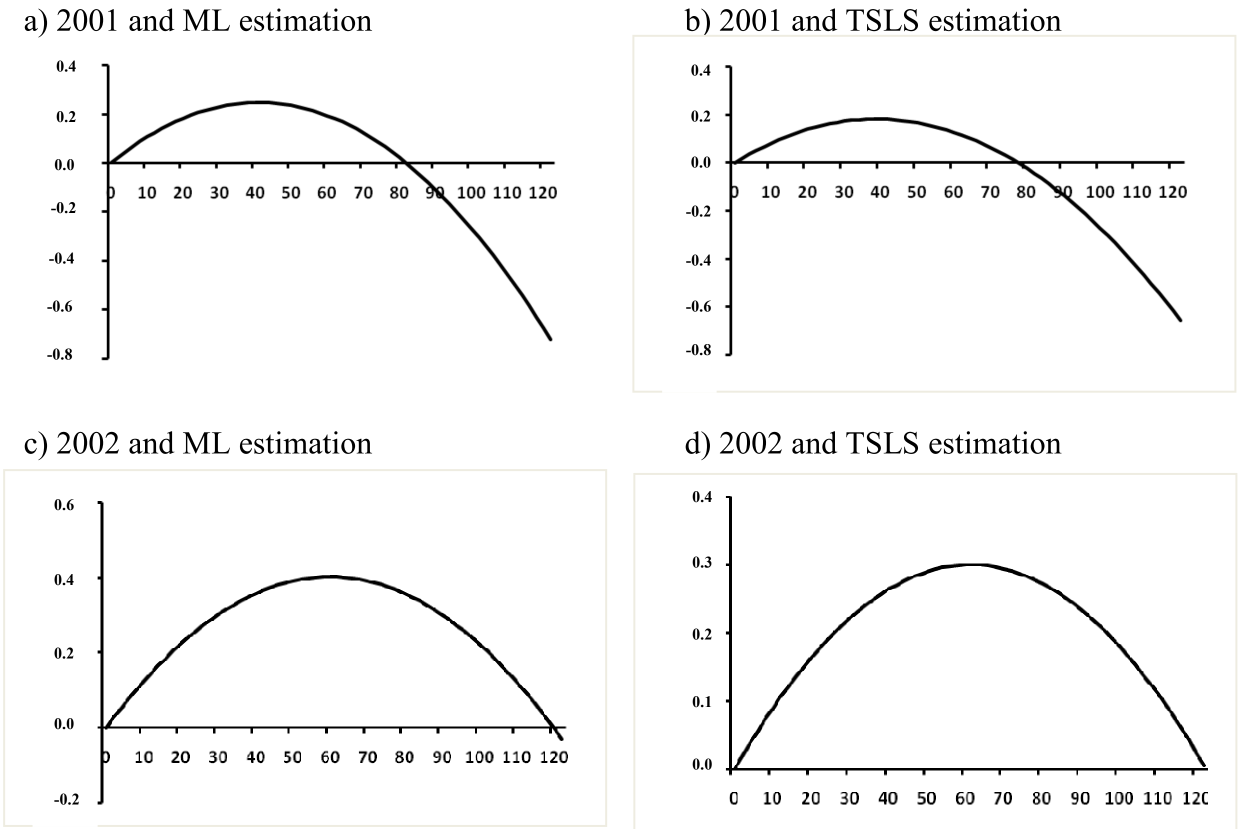
With regard to the other variables, only the organisational form *G* is significant in all of the models. The variable shows that, ceteris paribus, a dairy that is organised as a cooperative pays less to the producers than an investor-owned dairy. In 2001, the producer price was 0.16 cents (respectively 0.18 cents using ML estimation) lower if the dairy was a cooperative than if the dairy was an iof. However, in 2002, the influence of the organisational form increased and a cooperative paid a producer price that was approximately 0.47 cents lower (respectively 0.51 cents using ML estimation) than the price paid by an investor-owned dairy. Hence, we empirically confirm the theoretically hypothesis, that the producer price obtained by a member of a cooperative is lower than the producer price obtained by a seller to an iof because a cooperative invests less in brands. The variable milk quantity *MM* confirms the theoretical hypothesis, which states that the positive effects of milk quantity are due to the economies of scale. For both years, the milk quantity has a positive sign, and the squared quantity of milk has a negative sign. Therefore, we find that the milk quantity has a reverse U-shaped influence on the producer price *P*. According to Figure 30, the optimal producer price was paid by the firms at a size of 409,116 tonnes (ML estimation) or 387,562 tonnes (TSLS estimation) in 2001. In 2002, the optimal price was paid by the firms at a size of 599,107 tonnes (ML estimation) or 612,688 tonnes (TSLS estimation). Ceteris paribus, a higher milk quantity implies lower processing costs and, therefore, higher producer prices, at

[66] This result applies to the ML estimation. Ceteris paribus, for the TSLS estimation, an increase of one cent in the average producer price of all neighbouring competitors leads to an own price increase of 0.85 cents.

[67] This result applies to the ML estimation. Ceteris paribus, for the TSLS estimation, an increase of one cent in the average producer price of all neighbouring competitors leads to an own price increase of 0.93 cents.

least until the optimal milk quantity is achieved. A dairy that processed a quantity of milk larger than 387,562 tonnes in 2001 lost the cost advantage (see Figure 30). Only 15 dairies produced more than the optimal milk quantity in 2001, and only eight dairies produced more than the optimal milk quantity in 2002. The variables milk quantity and squared quantity of milk are significant only in 2001 under the ML estimation.

Figure 30: Optimal producer price P concerning the milk quantity (x-axis: milk quantity in 10,000 tonnes; y-axis: producer price in cents per kilogram)



The results regarding the variable milk density *DI* are unclear. In 2001, the milk density was positive. However, in 2002, the variable had a positive sign under the ML estimation and a low value with a negative sign under the TSLS estimation. The variable is significant at the 5% level only in 2001 and under the ML estimation. We can assume that a higher milk density implies that fewer expenses are incurred while collecting milk. If the milk density increases, then the dairies have lower personnel costs and/or lower total expenditures on transportation, as the market area in which each dairy can collect milk decreases. Ceteris paribus, a reduced expenses imply higher profits for the dairies, and therefore, an increasing milk density implies a higher producer price. However, we must handle this interpretation with caution, as the results in 2002 are contradictory and as only one of the four coefficients is significant.

5. Summary and discussion

This doctoral thesis addresses spatial pricing and competition in input markets. It provides general insights to spatial monopsony and oligopsony, a market situation, which has not been analysed to a great extent in the prevailing literature.

Hence, this thesis contributes to the literature by deriving analytical solutions for the most well-known types of spatial pricing schemes (fob, ud and od) in combination with possible spatial competition situations (Löschian, HS and GO) within one consistent model. In addition, we analyse in more detail a concrete market in which spatial market power of buyer exists, namely the German milk sector. We present two theoretical models of spatial pricing and competition taking into account some special characteristics of the raw milk market like marketing cooperatives and overlapping market areas. Lastly, we derive several spatial and non-spatial hypotheses concerning the German raw milk market. Following, these two models and our hypotheses are tested. In particular, we determine which type of spatial competition exists between German dairies utilising a VECM and time series data. Secondly, we investigate the impact of spatial and non-spatial factors, e.g., the absolute importance of space, on the milk producer price utilising a panel model with fixed effects. Thirdly, we analyse how and to which extent spatial competition among dairies affects the milk producer price utilising a spatial lag model and cross-section data. Additionally, further spatial and non-spatial factors that influence the milk producer price are determined.

Summarising, the three most important empirical results are: i.) the existence of spatial competition, ii.) the impact of spatial factors on the milk producer price and iii.) the impact of non-spatial factors on the milk producer price.

In regard to the first result, we demonstrated that PM competition exists in the German raw milk market. Thus, a dairy assumes that its competitor reacts to an own price change with the same price change in terms of direction and magnitude. Additionally, we showed that competition and pricing of a dairy is influenced by the pricing of spatial neighbouring dairies. Thereby, a dairy reacts to an increase in the milk producer prices of all spatial neighbouring dairies with a price change in the same direction but to a lower extent.

In regard to the second result, the thesis shows that spatial factors have a significant impact on the milk producer price. Depending on the spatial location of the dairy, the producer prices can be higher than those in other regions. If a dairy in one region increases its own producer price, then spatially neighbouring dairies will do the same to a lower extent. Hence, the producers that have contractual relationships with these nearby dairies benefit from another dairy's primary price increase. Another spatial factor influencing the pricing is the absolute importance of space. As competition exists in the dairy's backyard, an increase in the absolute importance of space induces an increasing producer price. Furthermore, the producer price is positive depending on the milk density, i.e., the producer price increases if the milk density increases. We can partially consider the variable milk density as a spatial factor because of its dependence on soil properties.

In regard to the third result, we analysed the non-spatial factors that influence the milk producer price, such as the selling price of processed milk, the quantity of milk processed, the organisational form of a dairy and the number of competitors. We found that the producer price is positive depending on the selling price. However, the results show that the price transmission from the selling price to the producer price is low. The quantity of milk processed by a dairy shows that in Germany, the producer price increases if the milk quantity increases. Furthermore, a German dairy pays a lower producer price if the dairy is a cooperative instead of an iof because cooperatives invest less on average. Finally, the number of competitors has a negative impact on the producer price. If the number of competitors increases, the milk producer price decreases.

Additional results include: As previously shown, price transmission from the selling price to the producer price is low. Furthermore, we derived that the price transmission under PM competition increases with increasing supply elasticity. This finding is of particular interest with regard to the process of abolishing the quota system in the EU. Because we can expect that the abolition will increase supply elasticity at the farm level, this change may increase the price transmission and may have a positive impact on producer prices (see section 2.4.1 and 4.3). Another interesting result is the political option for increasing the producer price. One already known solution is the support of farm marketing cooperatives' foundation. Producers may cooperate and concentrate their supply of raw milk and thereby increase their market power. Due to their increased market power, the milk producer price may increase (see section 2.4.1).

In regard to future prospects, there are two possible fields of research. One issue that remains to be solved is the cooperatives' low investment level. In the future, scholars in both economic and juristic research could address the Cooperative Societies Act in Germany. Thereby, the scholars could propose possible changes of the Cooperative Societies Act, which cause a higher investment level of cooperatives. Another future research subject may be a spatial panel model (e.g., a dynamic panel model that includes a serially lagged dependent variable and a spatially lagged dependent variable) that analyses competition and pricing not only from a spatial perspective but also from a temporal perspective. This research could determine whether the current milk producer price depends on space and/or on the producer prices of previous time periods.

References

Alvarez, A. M., Fidalgo, E. G., Sexton, R. J. & Zhang, M. (2000). Oligopsony power with uniform spatial pricing: Theory and application to milk processing in Spain. *European Review of Agricultural Economics, 27*, 347-364.

Anderson, S. P., de Palma, A. & Thisse, J.-F. (1989). Spatial price policies reconsidered. *The Journal of Industrial Economics, 38*, 1-18.

Anderson, S. P., de Palma, A. & Thisse, J.-F. (1992). *Discrete choice of theory of product differentiation*. Cambridge (Massachusetts): The MIT Press.

Anselin, L. (1988). *Spatial econometrics: Methods and models*. Doordrecht: Kluwer Academic Publishers.

Anselin, L. (2002). Under the hood. Issues in the specification and interpretation of spatial regression models. *Agricultural Economics, 27*, 247-267.

Anselin, L. (2005). Exploring spatial data with Geoda: A workbook. Retrieved from Center for Spatially Integrated Social Science website: http://www.csiss.org/clearinghouse/GeoDa/ geodaworkbook.pdf

Anselin, L. (2006). Spatial econometrics. In K. Patterson & T. C. Mills (Eds.), *Palgrave handbook of econometrics. Volume 1: Econometric theory* (pp. 901-969). Houndmills: Palgrave McMillan.

Anselin, L., Bera, A. K., Florax, R. & Yoon, M. J. (1996). Simple diagnostic tests for spatial dependence. *Regional Science and Urban Economics, 26*, 77-104.

Anselin, L. & Bera, A. K. (1998). Spatial dependence in linear regression models with an introduction to spatial econometrics. In A. Ullah & D. Giles (Eds.), *Handbook of applied economic statistics* (pp. 237-289). New York: Marcel Dekker.

Bakucs, Z. B. & Fertő, I. (2008). Milk market integration in Hungary horizontal integration on the Hungarian milk market. In C. Csáki & C. Forgács (Eds.), *Agricultural* *economics and transition: „What was expected, what we observed, the lessons learned”* (pp. 342-352). Halle: Leibniz-Insitut für Agrarentwicklung in Mittel- und Osteuropa.

Baltagi, B. H. (2008). *Econometric analysis of panel data* (4th ed.). Chichester: John Wiley & Sons Ltd.

Baye, M. R. & Morgan, J. (2002). Winner-take-all price competition. *Economic Theory, 19*, 271-282.

Beckmann, M. J. (1976). Spatial price policies revisited. *The Bell Journal of Economics, 7*, 619-630.

Ben-Kaabia, M. & Gil, J. M. (2007). Asymmetric price transmission in the Spanish lamb sector. *European Review of Agricultural Economics, 34*, 53-80.

Bhargava, A., Franzini, L. & Narendranathan, W. (1982). Serial correlation and the fixed effects model. *Review of Economic Studies, 49*, 533-549.

Bivand, R. (2010). Spdep*: Spatial dependence: Weighting schemes, statistics and models*. Retrieved from The Comprehensive R Archive Network website: http://cran.r-project.org/web/packages/spdep/spdep.pdf

Bossaerts, P. (1988). Common nonstationary components of asset prices. *Journal of Economic Dynamics and Control, 12*, 347-364.

Bouamra-Mechemache, Z., Jongeneel, R. & Réquillart, V. (2008). *Removing EU milk quotas, soft landing versus hard landing* (Conference paper at 12th Congress of the European Association of Agricultural Economists- EEAE 2008, Ghent, Belgium). Retrieved from http://ageconsearch.umn.edu/bitstream/43656/2/002.pdf

Bouamra-Mechemache, Z., Chavas, J.-P., Cox, T. & Réquillart, V. (2002). EU dairy policy reform and future WTO negotiations: a spatial equilibrium model. *Journal of Agricultural Economics, 53*, 233-257.

Breusch, T. S. & Pagan, A. R. (1979). A simple test for heteroskedasticity and random coefficient variation. *Econometrica, 50*, 987-1007.

Brüggemann, R. (2006). Sources of German unemployment: A structural vector error correction analysis. *Empirical Economics, 31*, 409-431.

Bundeskartellamt. (2009). *Sektoruntersuchung Milch* (Zwischenbericht Dezember 2009). Bonn: Author. Retrieved from http://www.bundeskartellamt.de/wDeutsch/download/pdf/Stellungnahmen/1001_Sektoruntersuchung_Milch_Zwischenbericht_2009.pdf

Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz BMELV (Ed.) (2008). *Statistischen Jahrbuch über Ernährung, Landwirtschaft und Forsten*. Bremerhaven: NW-Verlag.

Bunte, F. (2006). Pricing and performance in agri-food supply chains. In C. J. M. Ondersteijn, J. H. M. Wijnands, R. B. M. Huirne & O. van Kooten (Eds.), *Quantifying the agri-food supply chain* (pp. 37-45). Dordrecht: Springer.

Capozza, D. R. & van Order, R. (1978). A generalized model of spatial competition. *The American Economic Review, 68*, 896-908.

Case, A. C., Rosen, H. S. & Hines Jr., J. R. (1993). Budget spillovers and fiscal policy interdependence. Evidence from the states. *Journal of Public Economics, 52*, 285-307.

Cliff, A. & Ord, K. (1972). Testing for spatial autocorrelation among regression residuals. *Geographical Analysis, 4*, 267-284.

Cook, M. L. (1995). The future of U.S. agricultural cooperatives: A neo-institutional approach. *American Journal of Agricultural Economics, 77*, 1153-1159.

Coterill, R. W. (2006). Pricing and policy problems in the northeast fluid milk industry. *Agricultural and Resource Economics Review, 35*, 239-250.

Cramon-Taubadel, S. von & Gloy, D. (1991). Auszahlungspreise für Rohmilch in Schleswig-Holstein. Bestimmungsgründe und der Einfluß der Agrarpolitik. *Agrarwirtschaft, 40*, 231-239.

Council Regulation (ECC) No 856/84 of 31 March 1984, Official Journal L 090, 01/04/1984, p. 0010-0012.

Council Regulation (EC) No 1255/1999 of 17 May 1999, Official Journal L 160, 26/06/1999, p. 0048-0072.

Council Regulation (EC) No 1787/2003 of 29 September 2003, Official Journal L 270, 21/10/2003, p. 0121-0122.

Council Regulation (EC) No 1234/2007 of 22 October 2007, Official Journal L 299, 16/11/2007, p. 0001-0149.

Dasgupta, P. & Maskin, E. (1986). The existence of equilibrium in discontinuous economic games, I: Theory. *Review of Economic Studies, 53*, 1-26.

Dickey, D. & Fuller, W. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, *74*, 427-431.

Dijk, D. van, Teräsvirta, T. & Franses, P. H. (2002). Smooth transition autoregressive models – A survey of recent developments. *Econometric Reviews, 21*, 1-47.

Dixon H. (1990). Bertrand-Edgeworth equilibria when firms avoid turning customers away. *Journal of Industrial Economics, 39*, 131–146.

Dubin, R. (2004). Spatial lags and spatial errors revisited: Some Monte Carlo evidence. In J. P. Lesage & K. R. Pace (Eds.): *Spatial and spatiotemporal econometrics* (pp. 75-98). Amsterdam: Elsevier.

Durbin, J. & Watson, G. S. (1950). Testing for serial correlation in least squares regression I. *Biometrika, 37*, 409-428.

Eaton, B. C. & Lipsey, G. C. (1977). The introduction of space into the neoclassical value theory. In M. J. Artis & A. R. Nobay (Eds.), *Studies in modern economics* (pp. 59-96). Oxford: Basil Blackwell.

Engle, R. F. & Granger, C. W. J. (1987). Co-integration and error corrections: Representations, estimation and testing. *Econometrica, 55*, 251-276.

European Commission. (2010). *Single Payment Scheme – the concept*. Retrieved November, 26, 2010, from http://ec.europa.eu/agriculture/capreform/infosheets/pay_en.pdf

European Commission. (2010). *The milk sector*. Retrieved November, 26, 2010 from http://ec.europa.eu/agriculture/capreform/infosheets/milk_en.pdf

Fousekis, P. (2011). Free-on-board and uniform delivery pricing strategies in a mixed duopsony. *European Review of Agricultural Economics, 38*, 119-139.

Frey, G. & Manera, M. (2007). Econometric models of asymmetric price transmission. *Journal of Economic Surveys, 21*, 349-415.

Gerlach, S., Spiller, A. & Wocken, C. (2006). Der Markt für Milch und Milcherzeugnisse. *Agrarwirtschaft, 55*, 29-50.

Gillmeister, W., Yonkers, R. & Dunn, J. (1996). Hedonic pricing of milk components at the farm level. *Review of Agricultural Economics*, *18*, 181-192.

Gonzalo, J. (1994). Five alternative methods of estimating long-run equilibrium relationships. *Journal of Econometrics, 60*, 203-233.

Granger, C. W. J. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica*, *37*, 424-438.

Granger, C. W. J. (1981). Some properties of time series data and their use in econometric model specification. *Journal of Econometrics*, *16*, 121-130.

Granger, C. W. J. (1988). Some recent developments in a concept of causality. *Journal of Econometrics*, *39*, 199-211.

Grant, W. (1997). *The common agricultural policy*. Basingstoke: Macmillan Press Ltd.

Graubner, M. (2010). *The spatial dimension of pricing and competition in agricultural markets*. Doctoral dissertation, Martin-Luther Universität Halle-Wittenberg, Halle (Saale).

Graubner, M., Koller, I., Salhofer, K. & Balman, A. (2009). Cooperative vs. non-cooperative spatial competition for milk in the presence of farm marketing cooperatives (Working paper). Technische Universität München, Environmental Economics and Agricultural Policy Group.

Graubner, M., Koller, I., Salhofer, K. & Balman, A. (2011). Cooperative vs. non-cooperative spatial competition for milk. *European Review of Agricultural Economics, 38*, 99-118.

Greenhut, M. L., Norman, G. & Hung C.-S. (1987). *The Economics of imperfect competition*. Cambridge: Cambridge University Press.

Greenhut, M. L. & Ohta, H. (1975). *Theory of spatial pricing and market areas*. Durham: Duke University Press.

Gronberg, T. & Meyer, J. (1981). Competitive equilibria in uniform delivered pricing models. *The American Economic Review, 71*, 758-763.

Hamilton, J. D. (1994). *Time Series Analysis*. Princeton: Princeton University Press.

Hansen, B. & Phillips, P. C. B. (1990). Estimation and interference in models of cointegration: A simulation study. *Advances in Econometrics, 8*, 225-248.

Hansen, B. E. & Seo, B. (2002). Testing for two-regime threshold cointegration in vector error-correction models. *Journal of Econometrics*, *110*, 293-318.

Hausman, J., A. (1978). Specification tests in econometrics. *Econometrica, 46*, 1251-1271.

Hill, B. (1984). *Common agricultural policy: past, present and future*. London: Methuen & Co. Ltd.

Hobbs, B. F. (1986). Mill pricing versus spatial price discrimination under Bertrand and Cournot spatial competition. *The Journal of Industrial Economics, 35*, 173-191.

Holtemöller, O. (2004). A monetary vector error correction model of the Euro area and implications for monetary policy. *Empirical Economics, 29*, 553-574.

Hotelling, H. (1929). Stability in competition. *Economic Journal, 39*, 41-57.

Huck, P., Salhofer, K. & Tribl, C. (2005). *Spatial competition among cooperatives. The case of milk processing in northern Germany*. Retrieved from Technische Universität München, Publications of Environmental Economics and Agricultural Policy Group website: http://www.wzw.tum.de/ap/

Iozzi, A. (2004). Spatial duopoly with uniform delivered pricing when firms avoid turning customers away. *Annals of Regional Science, 38*, 515-529.

Isermeyer, F. (2007). *Zukunft der Milchquotenregelung – wie sind die verschiedenen Politikoptionen zu beurteilen* (Arbeitsberichte des Bereichs Agrarökonomie 2007/01). Braunschweig: FAL. Retrieved from http://literatur.vti.bund.de/digbib_extern/bitv/zi041934.pdf

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control, 12*, 231-254.

Johansen, S. (1995). *Likelihood-based inference in cointegrated vector autoregressive models*. Oxford: Oxford University Press.

Johansen, S. & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration – With applications to the demand for money. *Oxford Bulletin of Economics and Statistics*, *52*, 169-210.

Kats, A. & Thisse, J.-F. (1993). Spatial oligopolies with uniform delivered pricing. In H. Ohta & J.-F. Thisse (Eds.), *Does economic space matter?* (pp. 274-296). New York: St Martin's Press.

Kay, A. (1988). *The reform of the common agricultural policy: The case of the MacSharry reforms*. Oxon: CABI Publishing.

Kelejian, H. H. & Prucha, I. R. (2010). Specification and estimation of spatial autoregressive models with autoregressive and heteroskedastic disturbances. *Journal of Econometrics, 157*, 53-67.

Köhler, M. (1997). Marktorganisation für Milch und Milcherzeugnisse. In ZMP/aid (Eds.), *Agrarmarktordnungen in der Europäischen Union und Agrarmärkte in Deutschland* (pp. 121-140). Bonn: Zentrale Markt- und Preisberichtsstelle.

Koenker, R. (1981). A note on studentizing a test for heteroskedasticity. *Journal of Econometrics, 17*, 107-112.

Kommission der Europäischen Gemeinschaft. (2002). *Bericht über die Milchquoten* (Arbeitsdokument der Kommission SEK (2002) 789). Brüssel: Author. Retrieved from http://ec.europa.eu/agriculture/capreform/milkrep/text_de.pdf

LeSage, J. & Pace, R. K. (2009). *Introduction to spatial econometrics*. Boca Raton: Chapman & Hall/CRC.

Löfgren, K. G. (1985). The pricing of pulpwood and spatial price discrimination: Theory and practice. *European Review of Agricultural Economics, 12*, 283-293.

Löfgren, K. G. (1986). The spatial monopsony: A theoretical analysis. *Journal of Regional Science, 26*, 707-730.

Lösch, A. (1962). *Die räumliche Ordnung der Wirtschaft* (3rd ed.). Stuttgart: G. Fischer.

Lütkepohl, H. (2007). *New introduction to multiple time series analysis* (2nd ed.). Berlin: Springer.

Lütkephol, H. & Reimers, H.-E. (1992). Impulse response analysis of cointegrated systems. *Journal of Economic Dynamics and Control, 16*, 53-78.

McMillen, D. P., Singell Jr., L. D. & Waddell, G. R. (2007). Spatial competition and the price of college. *Economic Inquiry, 45*, 817-833.

Meyberg, K. & Vachenauer, P. (2003). *Höhere Mathematik 2* (4th ed.). Berlin: Springer.

Milchindustrie-Verband e.V. (2010). *Milchquote*. Retrieved Dezember 8, 2010, from http://www.meine-milch.de/milkipedia/milchquote

Moran, P. A. P. (1948). The interpretation of statistical maps. *Journal of the Royal Statistical Society. Series B (Methodological), 10*, 243-251.

Moran, P. A. P. (1950a). Notes on continuous stochastic phenomena. *Biometrika, 37*, 17-23.

Moran, P. A. P. (1950b). A test for the serial dependence of residuals. *Biometrika, 37*, 178-181.

MUGV (Ministerium für Umwelt, Gesundheit und Verbraucherschutz Brandenburg) (2010). *BSE – Bekämpfung und Überwachung*. Retrieved Dezember 20, 2010, from http://www.mugv.brandenburg.de/cms/ detail.php/lbm1.c.285684.de

Norman, G (1981). Spatial competition and spatial price discrimination. *Review of Economic Studies, 48*, 97-111.

Nubern, C. A. & Kilmer, R. L. (1997). Impact of spatial price discrimination within Florida dairy cooperatives. *Agricultural and Resource Economics Review, 26*, 94-105.

Peltzman, S. (2000). Prices rise faster than they fall. *Journal of Political Economy, 108*, 466-502.

Pennerstorfer, D. (2008). *Strategische Interaktion und räumlicher Preiswettbewerb im Treibstoffhandel. Eine räumlich-ökonometrische Analyse.* Doctoral dissertation, Wirtschaftsuniversität Wien, Wien. Retrieved October, 9, 2009 from http://epub.wu.ac.at/1905/.

Perekhozhuk, O. & Grings, M. (2007). *Econometric analysis of market power on the Ukrainian market for raw milk* (Conference paper at 47th Annual Conference of the German Association of Agricultural Economists (GEWISOLA), Freising/ Weihenstephan, Germany). Retrieved from http://ageconsearch.umn.edu/bitstream/ 7575/1/cp07pe02.pdf

Peters, J. (1992). *Der Einfluß der Rechtsform auf die Wettbewerbsstellung von Unternehmen des Ernährungssektors – dargestellt am Beispiel der Milchverarbeitung*. Doctoral dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn.

Phillips, P. C. B. (1991). Optimal interference in cointegrated systems. *Econometrica, 59*, 283-306.

Phlips, L. (1983). *The economics of price discrimination*. Cambridge: Cambridge University Press.

Pindyck, R. S. & Rubinfeld, D. L. (2005). *Mikroökonomie* (6th ed.). München: Pearson Studium.

Ritson, C. (1997). Introduction to the CAP. In C. Ritson & D. R. Harvey (Eds.), *The common agricultural policy and the world economy* (2nd ed., pp. 1-9). Wallingford: CAB International.

Roger, R. T. & Sexton, R. J. (1994). Assessing the importance of oligopsony power in agricultural markets. *American Journal of Agricultural Economics, 76*, 1143-1150.

Rotan, B. (2001). *Analysis of financial statements: Local farm supply, marketing cooperatives* (RBS Research Report 182). Washington, DC: U.S. Department of Agriculture. Retrieved from http://www.rurdev.usda.gov/rbs/pub/rr182.pdf

Sanner, H. & Schöler, K. (1998). Spatial price discrimination in two-dimensional competitive markets. *Journal of Regional Science, 38*, 89-107.

Schöler, K. (1988). *Räumliche Preistheorie. Eine Partialanalytische Untersuchung kontinuierlicher Wirtschaftsräume* (Volkswirtschaftliche Schriften, Heft 378). Berlin: Duncker & Humblot.

Schöler, K. (2005). *Raumwirtschaftstheorie*. München: Verlag Franz Vahlen.

Schramm, M., Spiller, A. & Staack, T. (2005). Zur Brand Orientation genossenschaftlicher Unternehmen der Ernährungsindustrie. In I. Darnhofer, S. Pöchtrager & E. Schmid (Eds.), *Jahrbuch der ÖGA – Band* 14 (pp. 141 – 152). Wien: Facultas Verlag.

Schuler, R. E. & Hobbs, B. F. (1982). Spatial price duopoly under uniform delivered pricing. *The Journal of Industrial Economics, 31*, 175-187.

Serra, T. & Goodwin, B. K. (2003). Price transmission and asymmetric adjustment in the Spanish dairy sector. *Applied economics, 35*, 1889-1899.

Sexton, R. J. (1990). Imperfect competition in agricultural markets and the role of cooperatives: A spatial analysis. *American Journal of Agricultural Economics, 72*, 709-720.

Smithies, A. (1941). Optimum location in spatial competition. *Journal of Political Economy, 49*, 423-439.

Soßna, R. (2007). *Deutsche Milchwirtschaft Spezial: Die umsatzstärksten Mopro-Anbieter 2007*. Gelsenkirchen: Th-Mann Verlag.

Statistisches Bundesamt. (2004). *Preise. Verbraucherpreisindizes für Deutschland* (*Fachserie 17/ Reihe 7*). Wiesbaden: Author.

Statistisches Bundesamt. (2006). *Arbeitskosten 2004 in den neuen Bundesländern um 28% unter dem Westniveau* (Pressemitteilung Nr. 286). Retrieved September 3, 2010, from http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Presse/pm/2006/07/PD06__282__621,templateId=renderPrint.psml

Steffen, N., Schlecht, S. & Spiller, A. (2009). *Das Preisfindungssystem von Genossenschaftsmolkereien* (Discussion Paper Nr. 0910). Retrieved from Georg-August Universität Göttingen, Department of Agricultural Economics and Rural Development website http://www.uni-goettingen.de/en/72592.html

Stigler, M. (2010). Threshold cointegration: overview and implementation in R. *Working paper*.

Stock, J. H. (1987). Asymptotic properties of least squares estimators of cointegrating vectors. *Econometrica, 55*, 1035-1056.

Stock, J. H. & Watson, M. W. (1998). Testing for common trends. *Journal of the American Statistical Association, 83*, 1097-1107.

Sydsæter, K., Hammond, P., Seierstad, A. & Strøm, A. (2008). *Further mathematics for economic analysis* (2nd ed.). FT Prentice Hall: Harlow.

Thisse, J.-F. & Vives, X. (1988). On the strategy choice of spatial price policy. *The American Economic Review, 78*, 122-137.

Treaty establishing the European Community (Amsterdam consolidated version), Official Journal C340, 10/11/1997, p. 0173-0306.

Treaty on the Functioning of the European Union, Official Journal C115, 09/05/2008, p. 0001-0388.

Tribl, C. (2009). *Spatial competition of food processing cooperatives in a mixed market – the case of uniform delivered pricing*. Retrieved from Bundesanstalt für Agrarwirtschaft website: http://www.agraroekonomik.at/fileadmin/download/Tribl_Working_paper 2009.pdf

Weindlmaier, H. & Betz, J. (2005). Zur aktuellen Situation der Milcherfassung in Deutschland und Österreich im Jahr 2003. *Deutsche Milchwirtschaft, 56*, 405-409.

Weindlmaier, H. & Betz, J. (2009). Zur aktuellen Situation der Milcherfassung in Deutschland und Österreich im Jahr 2007. *Deutsche Milchwirtschaft, 60*, 12-17.

Weindlmaier, H. & Huber, A. (2001). Vor- und Nachteile des bayerischen Erzeugerorientierungspreises (EOP). *Deutsche Milchwirtschaft, 52*, 1087-1092.

Weindlmaier, H. (2000). *Absatz- und Beschaffungsmarketing als Rahmenbedingungen für die Wettbewerbsfähigkeit des Molkereisektors in Deutschland. Anhang 2 zum Gutachten des wissenschaftlichen Beirats „Zur Wettbewerbsfähigkeit der deutschen Milchwirtschaft"* (Schriftenreihe des Bundesministeriums für Ernährung, Landwirtschaft und Forsten, Reihe A: Angewandte Wissenschaft, Heft 486). Münster: Verlagsgesellschaft W.E. Weinmann mbH.

Weindlmaier, H. (2005). Entwicklung der Erzeugermilchpreise: Welche Chancen bietet eine aktive Marktbeeinflussung? *dmz Deutsche Molkereizeitung, 126*, 26-31.

Wissenschaftlicher Beirat beim Bundesministerium für Ernährung, Landwirtschaft und Forsten. (2000). *Zur Wettbewerbsfähigkeit der deutschen Milchwirtschaft* (Schriftenreihe des Bundesministeriums für Ernährung, Landwirtschaft und Forsten, Reihe A: Angewandte Wissenschaft, Heft 486). Münster: Verlagsgesellschaft W.E. Weinmann mbH.

Wooldridge, J., M. (2003). *Introductory econometrics: a modern approach* (2nd ed.). Ohio: Thomson South-Western.

Wooldridge, J., M. (2010). *Econometric analysis of cross section and panel data* (2nd ed.). Cambridge: The MIT Press.

Xia, T. & Sexton, R. J. (2009). Retail prices for milk by fat content: A new theory and empirical test of retailer pricing behaviour. *Journal of Agricultural and Resource Economics, 34*, 256-275.

Yang, J., Hsiao, C., Li, Q. and Wang, Z. (2006). The emerging market crisis and stock market linkages: further evidence. *Journal of Applied Economics, 21*, 727-744.

Zhang, M. & Sexton, R. J. (2001). FOB or uniform delivered prices: Strategic choice and welfare effects. *The Journal of Industrial Economics, 49*, 197-221.

ZMP (1998-2009). *ZMP Marktbilanz Milch*. Bonn: Zentrale Markt- und Preisberichtsstelle (ZMP).

Appendix

Appendix A: Derivation and proof of the optimal mill price for HS competition

We define the market area R as:

$$R = (m_i - m_j + \tau d)/2\tau \tag{A1}$$

Utilising equation (A1), we obtain the following profit function:

$$\pi = 2 \int_0^{(m_i - m_j + \tau d)/2\tau} (w - m_i) b (m_i - \tau r) dr \tag{A2}$$

or

$$\pi = \frac{b}{4\tau}(m_i - m_j + \tau d)(w - m_i)(3m_i + m_j - \tau d) \tag{A3}$$

For a maximum at m^*_{HS} the first derivation of the profit function must be zero at m^*_{HS}, and the second derivation of the profit function must be negative at m^*_{HS}.

HS competition requires that $\partial m_j/\partial m_i = 0$. Hence, maximising profit with respect to m_i yields the following first-order condition:

$$\pi': \ \frac{b}{4\tau}\left[(3m_i + m_j - \tau d)(w - 2m_i + m_j - \tau d) + 3(m_i - m_j + \tau d)(w - m_i)\right] \tag{A4}$$

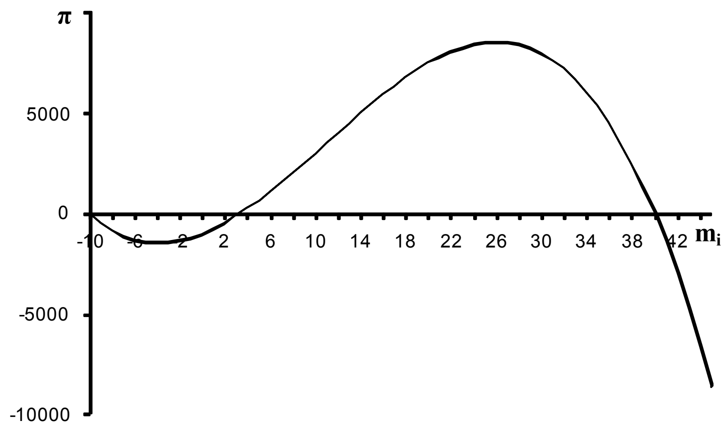
The second derivation is:

$$\pi': \ \frac{b}{4\tau}(6w - 18m_i + 4m_j - 4\tau d) \tag{A5}$$

We cannot state with certainty whether the optimal mill price is reflected in equation (2.65) or equation (2.66). The first term of the equation $(-2R + (1-\theta)w/2\tau + R(1-\theta)/2)\frac{\tau}{(1-\theta)}$), which is equal for both equations, can be positive or negative for HS competition. The second term of the equation, $\sqrt{(4R^2 + w^2(1-\theta)^2/4\tau^2 + R^2(1-\theta)^2/4 - R^2(1-\theta) - wR(1-\theta)^2/2\tau)/((1-\theta)^2/\tau^2)}$, is also positive. Therefore, equation (2.65) is a possible solution for m_i, and equation (2.66) can be a possible solution for m_i if the first term of the equation is positive. Inserting each optimal mill price into the second derivation does not yield a precise solution, as we cannot determine whether the second derivation is positive or negative. Hence, we solve this problem graphically.

To illustrate graphically the profit function and its derivations, we need to assign numbers to the competitor's mill price m_j, the distance between the firms d, the transport costs τ, the net sales price w and the constant b. For the following graphs, we assume that $m_j = 20$, $d = 30$, $\tau = 1$, $w = 40$ and $b = 1$.[68] We will demonstrate the profit function, the first derivation and the second derivation.

Figure A1: Profit function under HS competition



As Figure A1 shows, the profit is negative if the mill price is greater than 40 or less than 3.33 but greater than -10. However, a negative profit does not make economic sense. By analysing the graph, we see that a negative profit is caused by a negative supply ($m_i < 3.33$) or a negative margin ($m_i > 40$). The profit is once again positive if $m_i < -10$. However, a negative supply, margin or mill price is economically impossible. Therefore, only the positive part of the profit function, where m_i ε]3.33; 40[matters from an economic perspective. This conclusion holds true for the first and second derivations.

[68] For the other values of m_j, d, τ, w, and b, the final results, i.e., the optimal mill price, are the same.

Figure A2: First derivation of the profit function with respect to m_i under HS competition

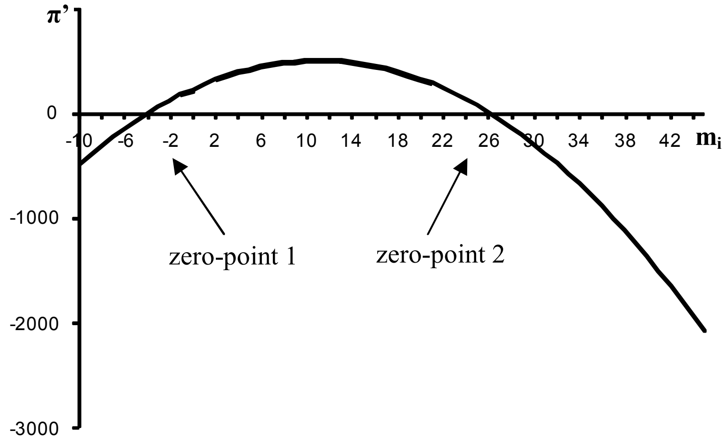
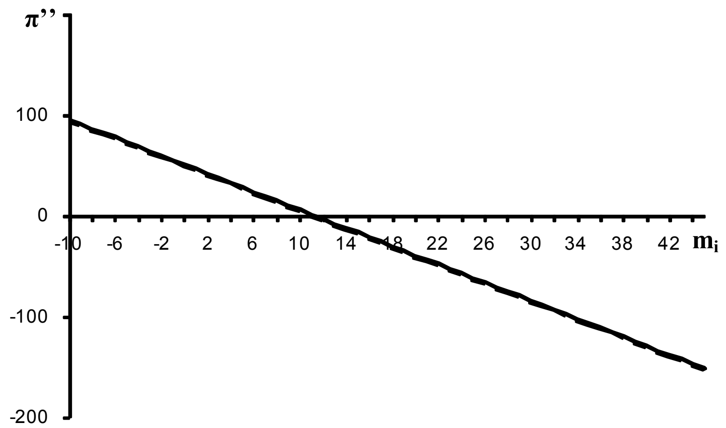


Figure A2 proves that two zero-points exist but that one zero-point, $m_i \approx -3.84$, is negative, which is economically impossible. Hence, only zero-point 2 is a possible extremum. An extremum can only be a maximum if the second derivation is negative at the value of the extremum.

Figure A3 provides evidence that $m_i \approx 26.06$ is a maximum, as the second derivation is negative at $m_i \approx 26.06$.

Figure A3: Second derivation of the profit function with respect to m_i under HS competition



Thus, only zero-point 2 is both a maximum and a possible solution. Based on previous information, we know that the first term of the optimal mill price can be positive or negative and that the second term can be added to or subtracted from the first term. Equation (2.65) exhibits the higher optimal mill price, as the second term is added to the first term in this equation. In contrast, equation (2.66) is lower, as the second term is subtracted from this equation. Equation (2.65) presents zero-point 2, and equation (2.66) shows zero-point 1.

Hence, equation (2.65) is the solution for the optimal mill price, and, therefore, we have shown the proof for equation (2.67).

Appendix B: Derivation and proof of the optimal mill price for GO competition

The market area and the profit function are the same under GO competition and HS competition (see equations (A1) and (A3)). As shown previously, we search for a maximum and analyse the first and second derivations of the profit function.

In contrast to HS competition, GO competition requires that $\partial m_j/\partial m_i$ = -1. Again, we maximise the profit with respect to m_i. The first-order condition and the second-order condition are:

$$\pi': \ \frac{b}{2\tau}\left[\left(\frac{3}{2}m_i+\frac{1}{2}m_j-\frac{1}{2}\tau d\right)\left(2w-3m_i+m_j-\tau d\right)+\left(m_i-m_j+\tau d\right)\left(w-m_i\right)\right] \quad \text{(B1)}$$

$$\pi'': \ \frac{b}{\tau}\left(2w-6m_i\right) \quad \text{(B2)}$$

As shown previously for HS competition, the first terms of equations (2.65) and (2.66) can be positive or negative, and the second term is positive for GO competition. We cannot mathematically solve this problem whether equations (2.65) or (2.66) display the optimal mill price. Therefore, we will graphically solve the problem in the same manner as we did for HS competition (see Appendix A).

Figure B1: Profit function under GO competition

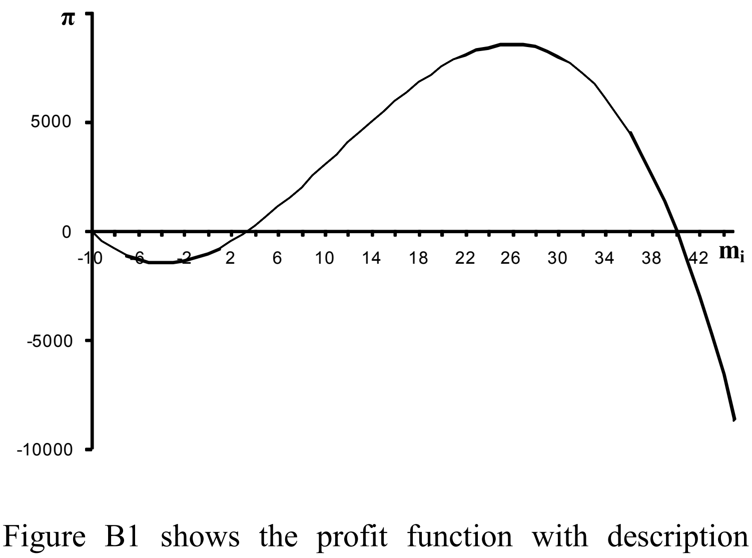


Figure B1 shows the profit function with description that is the same as that of HS competition, which we wrote in Appendix A.

Figure B2: First derivation of the profit function with respect to m_i under GO competition

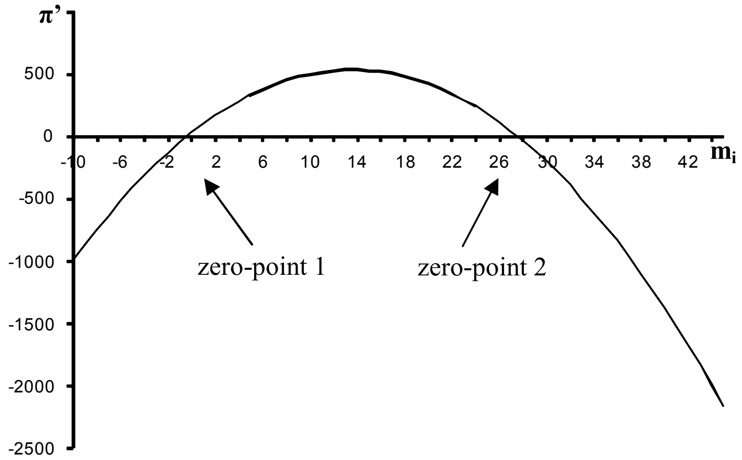
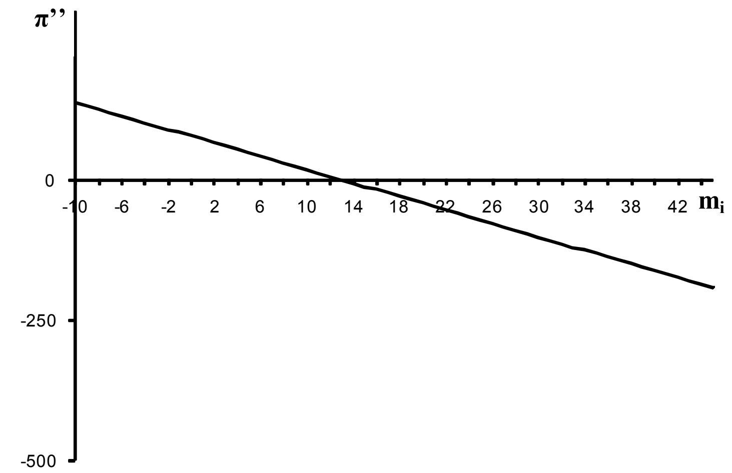


Figure B2 shows that two zero-points exist. Zero-point 2 is a possible extremum, as the value of m_i lies inside the area of a positive profit. In contrast, zero-point 1 is not a feasible solution, as $m_i \approx -0.33$ is negative. Figure B3 shows that the zero-point 2 is a maximum, as the second derivation is negative at $m_i \approx 27.60$.

Figure B3: Second derivation of the profit function with respect to m_i under GO competition



Hence, the same argument used previously is valid. Equation (2.65) presents zero-point 2, and equation (2.66) describes zero-point 1. Thus, we confirm the proof for equation (2.68) and for selecting equation (2.65).

Appendix C: Derivation and proof of the optimal mill price for Löschian competition

In contrast to HS and GO competition, the proof procedure is easier for Löschian competition. As the condition for Löschian competition is that the market area is fixed, we can derive the profit function (see equation (2.60)) with respect to m_i without inserting equation (2.59) for the market area R. Equation (2.69) presents the optimal mill price. To prove that the optimal mill price displays a maximum, we must show that the second derivation is negative at m_L^*. The second derivation of the profit function is:

$$\pi'': \; -4bR \quad < 0 \tag{C1}$$

Hence, the second derivation is negative for every m_i, and m_L^* is a maximum.

Appendix D: Profit maximisation under ud pricing and monopsonistic competition

Under monopsonistic competition and ud pricing, the profit function is:

$$\pi = \int_0^R (w - p - \tau r) p^e dr = p^e R(w - p - \frac{1}{2}\tau R) \tag{D1}$$

Maximising the profit with respect to p and R yields the following first-order conditions:

$$p = \frac{e\left(w - \frac{1}{2}\tau R\right)}{(e+1)} \tag{D2}$$

$$R = \frac{w - p}{\tau} \tag{D3}$$

Substituting equation (D3) into the seller's net price (and equation (D2) into the market area), we can find that the optimal price and market radius are:

$$p^* = \frac{ew}{(2+e)} \tag{D4}$$

$$R^* = \frac{2p}{(2+e)\tau} \tag{D5}$$

If the price elasticity of supply e is equal to one and, therefore, there is a linear supply function, then we obtain the results from section 2.2.2 regarding a monopsony under ud pricing.

Appendix E: Market overlap illustrated with dependence on s/w

As in section 2.2.2, we defined the optimal market area as $R^* = (w - p)/\tau$ (see equation 2.26). There are three possible causes concerning the market overlap:

a) There is no market overlap. Both firms act as spatial monopsonists, i.e., the market area is equal to or smaller than half of the distance between the firms ($R \leq d/2$)

   The optimal market area in a monopsony is $2w/3\tau$ (see equation 2.35). Therefore, we can rewrite $R \leq d/2$ as:

$$\frac{2w}{3\tau} \leq \frac{d}{2} \tag{E1}$$

   From this, it follows that

$$\frac{4}{3} \leq \frac{\tau d}{w} \qquad \text{and} \qquad \frac{s}{w} \geq \frac{4}{3} \tag{E2}$$

   Thus no market overlap is present if $s/w \geq 4/3$.

b) Market overlap only exists between the firms (i.e., competition en route). That is, $d/2 < R < d$.

   The seller's optimal net price is shown in equation (2.105):

$$p = \frac{w}{2} - \frac{s}{8} \tag{E3}$$

   Setting equation (E3) in R^*, we obtain the optimal market area:

$$R = \frac{\left(w + \frac{s}{4}\right)}{2\tau} \tag{E4}$$

   Now, we can rewrite $d/2 < R < d$ as:

$$d/2 < \frac{\left(w + \frac{s}{4}\right)}{2\tau} < d \tag{E5}$$

Hence, we can present *d/2 < R* in terms of *s/w* as:

$$s/w < \frac{4}{3} \tag{E6}$$

Additionally, we can write *R < d* as:

$$\frac{4}{7} < s/w \tag{E7}$$

Consequently competition en route occurs if 4/7 < *s/w* < 4/3.

c) Market overlap reaches the backyard of the competitor (i.e., competition in the backyard). That is, $R \geq d$.

Given the results of case a) and b), competition in the backyard exists if *s/w* ≤ 4/7 (i.e., 0 < *s/w* ≤ 4/7).