Economies of Scale in Production versus Diseconomies in Transportation: On Structural Change in the German Dairy Industry

Ole Boysen and Carsten Schröder

TEP Working Paper No. 0209

November 2009

Trinity Economics Papers

Department of Economics

Trinity College Dublin

Economies of Scale in Production versus Diseconomies in Transportation: On Structural Change in the German Dairy Industry

Ole Boysen* and **Carsten Schröder†**

November 2009

Abstract

This paper analyzes the structural change in the German dairy sector using a sector-wide optimization model. In particular, the model includes a spatially explicit representation of dairy processing farms and dairy farming regions to account for the trade-off between economies of scale in dairy production and diseconomies of scale in transportation. We simulate cost-optimal sectoral structures for different time horizons and various transport cost levels. The results demonstrate that the model is able to explain the trend towards fewer but larger dairies as currently observed in reality and indicate, *ceteris paribus*, a continuation of this trend. However, if the importance of transport costs increases relative to other costs in dairy production this trend might level off. The structural impacts found differ markedly by region.

*Ole Boysen, e-mail: boyseno@tcd.ie, Trinity College Dublin, Ireland.

†Carsten Schröder, e-mail: carsten.schroeder@wiwiss.fu-berlin.de, Free University Berlin, Germany.

We are grateful to colleagues of the German Federal Research Centre for Nutrition and Food, Institute for Economics of the Food Industry for their assistance and two anonymous referees for their valuable comments.

An earlier version of this paper has been published (in German) as "Boysen, O. and Schröder, C. (2006). Economies of Scale in der Produktion versus Diseconomies im Transport: Zum Strukturwandel in der Milchindustrie, *German Journal of Agricultural Economics* **3**: 152–167".

1 Introduction

The dairy industry is the largest division of the German food industry with a turnover of about 21 billion euro and about 36,000 employees (Deutscher Bauernverband, 2004, p. 147). But the number of dairy companies and processing plants has been decreasing since years (Weindlmaier, 2004a, p. 70), a trend which is already advanced in most other EU countries (Drescher and Maurer, 1999, p. 166). This observed structural change is a reaction to stagnating sales quantities, to increasingly competition-oriented agricultural policies, to the EU eastward enlargement, and to the increasing market power of the wholesale sector. Given these factors, a continuation of this trend is expected. The farmers' association expects that of the 112 dairy companies with 243 processing plants existing in 2003 only 30 companies will persist in 2010 (Deutscher Bauernverband, 2004). At the same time, there is a trend towards larger processing plants which is also reflected in a changed cost composition at firm and industry level. While large processing plants benefit from economies of scale in processing they also face higher average transport costs because of their larger milk collection areas relative to smaller plants.

In contrast to many other sectors, transportation is a significant cost component in the agricultural sector. This might be explained by the high transport volumes of agricultural products and by the fact that the products often are quickly perishable, thus requiring *regular* transportation in special transporters with short collection intervals (Butler and Keenan, 2005). Furthermore, it might be expected that the significance of transport costs relative to other costs will increase further in the future due, for instance, to rising crude oil prices, highway tolls, and new environmental regulations (e.g. Kyoto Protocol, emission certificates or taxes, etc.).

How might the structure of the dairy sector develop in the short- and long-run when transport costs rise relative to other costs? To what extent are, for instance, small or large processing plants affected by such a change in the relative importance of transport costs and what are the consequences for their relative competitiveness? To answer these questions we model the German dairy sector as a capacitated facility location problem (CFLP). Methodologically, our model differs from the standard CFLP model in that we consider (i) variable economies of scale in processing, (ii) time restrictions (collection intervals), and (iii) restrictions on the mode of transportation (indivisibility of transporters). We utilize a micro database of 360 dairy processing plants and dairy farm output of 316 German counties. The objective function of the model minimizes the sum of individual plants' overhead, transport, and processing costs *over all plant locations*. We show that the model is capable of replicating the current trend towards fewer but larger processing plants. The simulation results indicate *ceteris paribus* a further continuation of this trend. The analysis of different transport cost level scenarios shows that the trend might subside and terminate much earlier if the importance of transport rises *relative* to other costs, e.g., through rising fuel prices or technological advances in milk processing.

One could criticize the sector-wide cost minimization approach as not necessarily corresponding to the firm's optimal production (production at the minimum long-run average costs) for each individual plant. But we show that the average total costs of all plants actually converge almost perfectly in the long-run sector-wide optimum under variable production capacities.

This paper is structured as follows: Section 2 introduces the database, the model, and the solution method. Section 3 presents the results. The impact of the model's assumptions and data restrictions on the results are discussed in Section 4 and Section 5 summarizes the main results.

2 Data, Model, and Solution Method

2.1 Data

To the best of our knowledge, there is no publicly available database which contains comprehensive and representative micro data on dairy capacities, product mixes, processing, overhead, and distribution costs, regional milk suppliers, and distribution centers of the retailers in Germany. Hence, for the following computations we had to merge several data sources:

- Raw milk supply. We use a dataset of annual dairy farm raw milk output in aggregate form for 316 German counties (henceforth called regions) from 2000/2001.[1]
- Dairy processing plants. We utilize a compilation of dairy plant specific capacities for the year 2000.[2]
- Costs.
  - Raw milk costs. Empirical results from within the EU (see Aarts and Stemne, 1997; Keane, 1998a; Irish Farmers Journal, 1997) show that there is no systematic relationship between the price paid to farmers and dairy

[1] The data has been provided by the Federal Research Center for Nutrition and Food, Location Kiel, Germany.

[2] The data has been provided by the Federal Research Center for Nutrition and Food, Location Kiel, Germany.

size. Consequently, we assume identical raw milk costs for all dairy processing plants.

- Transport costs. According to (Janz, 2002, p. 253) and the literature cited therein, a milk tanker has a capacity of 9 t and average unit costs of 0.00598 euro (originally 0.0117 DM) per 100 distance kilometers, assuming complete utilization of tank capacity. The (utilization independent) total costs per transport kilometer are then $\frac{0{,}00598 euro}{100 km \times kg} \times 9.000 kg = 0{,}5382 \frac{euro}{km}$. But transport costs per ton do not only vary with distance but also with (a) the number of vehicles employed, (b) the tank capacity ($\eta = 9$ t), (c) maximum daily traveling distance ($\omega = 480$ km) and (d) the length of the collection cycles (at least every other day).
- Processing costs. Generally, the literature assumes increasing economies of scale in processing (see, e.g., Caraveli and Traill, 1998; Dalton et al., 2002; Höper et al., 2000; Keane, 1998a). Furthermore, processing costs vary with the respective product mix. Since we have no data about product mixes on individual dairy plant-level, we assume an average product range with a staircase cost function as given in Höper et al. (2000) (see Table 1).[3]
- Overhead costs. Overhead costs are annual costs relating to the operation of a dairy processing plant which occur regardless of the extent of utilization. To the best of our knowledge, no scientific data about the level of overhead costs in the dairy sector is readily available. Thus, we rely on statements of the Federal Research Center for Nutrition and Food (Kiel, Germany). Accordingly, fixed costs can be assumed to amount to 10 euro per ton of dairy capacity.

2.2 Representation of the Dairy Sector

For a spatial representation of the dairy sector we position the 360 dairy plants and the geographical centers of the 316 dairy supply regions in Germany within a Cartesian coordinate system. Using this, we construct a 360 × 316 distance matrix between the dairy plants and the geographical centers of the regions. The transit distance of a milk tanker includes the distance between dairy and region plus some distance within the region itself. Intuitively, this intraregional distance is negatively

[3]The model can handle individual processing cost functions corresponding to a dairy's product mix if such data becomes available.

Table 1: Processing costs

Production level	Quantity limit in t	Processing costs in $\frac{euro}{t}$
0	0	—
1	50,000	98.68
2	100,000	85.39
3	200,000	78.74
4	300,000	76.49
5	400,000	75.36
6	500,000	74.70
7	600,000	74.29
8	700,000	73.98
9	800,000	73.73
10	900,000	73.52
11	∞	73.37

Source: Janz, 2002, p. 268.

correlated with the regional *milk density* ($\frac{\text{t}}{\text{km}^2}$).[4] To approximate this distance, each milk tanker circumscribes a circular segment proportional to the share of milk it collects from the region's output where the circle's area corresponds to the area of the region. Traveling distances between dairies and distribution centers are disregarded. The reason for this simplifying assumption is that, on the one hand, including distribution would make the computational effort for solving the problem explode. On the other hand, several empirical studies have shown that the distribution transport costs for an average product mix are clearly dominated by the transport costs for milk collection (see, for instance, Keane, 1998a, p. 1 and Keane, 1998b, p. 6). This can be largely attributed to the condensation of the raw milk during processing. For example, 27,100,000 tons of milk have been supplied to dairies in Germany in 2004 but end products only had a total weight of 11,680,000 t.[5] Hence, initial weight was reduced by 57%. Another reason for the lesser relevance of distribution costs in comparison to collection costs is that the distance between the dairy plant and the distribution centers is generally shorter than the distance for collecting the milk. While the milk tanker typically has to stop at several milk supplier locations, the delivery at the distribution center consists of a single stop only. Moreover, it is expected that the relevance of costs for supplying the distribution centers will further

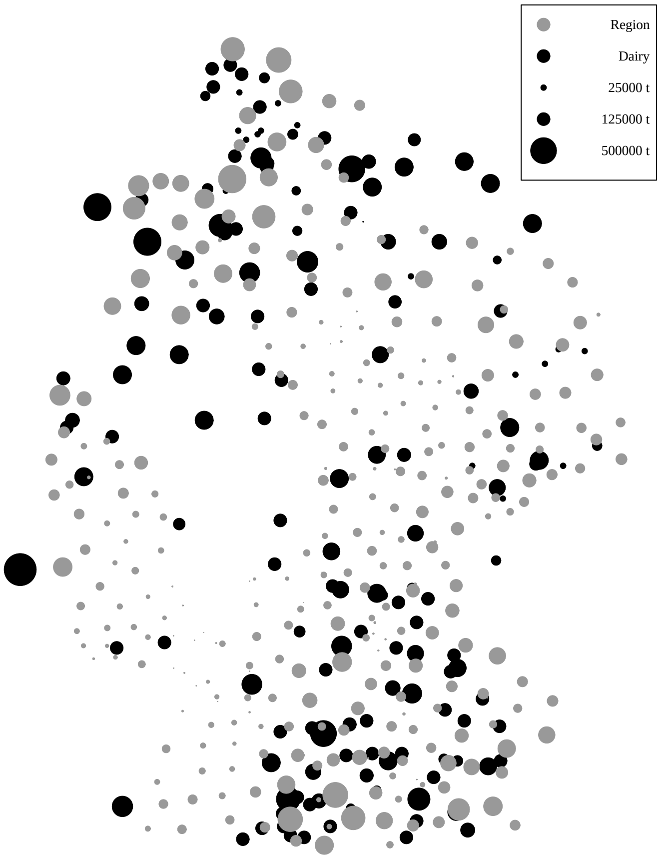
[4] In the model presented we imply that the intraregional milk supply and consequently the regional milk densities are intertemporally constant. This assumption is required to isolate the effect of increased transportation costs from those of other variables.

[5] Of those were milk 6,000,000 t, creme 540,000 t, curdled milk etc. 2,850,000 t, butter 440,000 t, cheese 1,850,000 t (see Milchindustrieverband, 2004, p. 68).

decrease because food retailers increasingly take over logistical functions which in turn decreases distribution costs (see Deutsche Milchindustrie, 2005; Weindlmaier, 2002, 2004a).

The total milk supply from the 316 regions in our dataset – restricted by the milk quotas – amounts to 24,395,801 t with a median raw milk output of 50,986.5 t and a median milk density over all regions of $58.46\frac{t}{km^2}$. The 360 dairy processing plants have a total capacity of 33,196,800 t with a median capacity of 25,000 t. Figure 1 depicts the regional distribution of milk outputs and dairy plants. The areas of the light shaded circles are proportional to the particular milk output of the region, the dark to the dairy capacity.

Figure 1: Spatial distribution of regions and dairy plants



Circular areas are proportional to the respective raw milk output or dairy processing capacity.
Source: Own computation.

2.3 Mathematical Model

The sectoral cost minimization problem has been formulated as a mixed integer linear programming problem (MILP) as stated below:

Minimize

$$F(x,y) = \sum_{d\in D}\left(f_d \cdot \sum_{l\in L_d} y_{dl} + \kappa \cdot \sum_{p\in P} c_{pd}\cdot z_{pd} + \sum_{l\in L_d} s_l \cdot q_{dl}\right) \tag{1}$$

subject to the constraints

$$\sum_{d\in D} x_{pd} = b_p \qquad \forall p \in P \tag{2}$$
$$k_d \cdot \sum_{l\in L_d} y_{dl} \geq \sum_{p\in P} x_{pd} \qquad \forall d \in D \tag{3}$$
$$\sum_{l\in L_d} y_{dl} \leq 1 \qquad \forall d \in D \tag{4}$$
$$\delta\cdot\eta\cdot z_{pd} \geq x_{pd} \qquad \forall p \in P, d \in D \tag{5}$$
$$m_l \cdot y_{dl} \geq q_{dl} \qquad \forall d \in D, l \in L_d \tag{6}$$
$$m_{l-1}\cdot y_{dl} < q_{dl} \qquad \forall d \in D, l \in L_d \tag{7}$$
$$\sum_{l\in L_d} q_{dl} = \sum_{p\in P} x_{pd} \qquad \forall d \in D \tag{8}$$
$$c_{pd} + 2\cdot\pi\cdot r_p \cdot \frac{x_{pd}}{b_p\cdot z_{pd}} \leq \omega \qquad \forall p \in P, d \in D \tag{9}$$
$$x_{pd} \in \mathbb{R}_0^+ \qquad \forall p \in P, d \in D \tag{10}$$
$$y_{dl} \in \{0,1\} \qquad \forall d \in D \tag{11}$$
$$z_{pd} \in \mathbb{N}_0 \qquad \forall p \in P, d \in D \tag{12}$$
$$q_{dl} \in \mathbb{R}_0^+ \qquad \forall d \in D, l \in L_d \tag{13}$$

with

b_p	raw milk output in t p.a. of dairy farming region p,
c_{pd}	distance between region p and dairy d plus the radius r_p and back,
$d = 1, ..., D$	dairies,
f_d	annual overhead costs of operating dairy plant d,
k_d	capacity of dairy d,
m_l	maximum output p.a. on production level l (see Table 1),
$p = 1, ..., P$	dairy farming regions,
q_{dl}	output quantity of dairy d on production level l,
r_p	radius of region p,
s_l	processing costs per t on production level l,
x_{pd}	transport quantity from region p to dairy d,
y_{dl}	$\begin{cases} 1 & \text{dairy } d \text{ operates on production level } l, \\ 0 & \text{otherwise,} \end{cases}$
z_{pd}	number of transports per collection cycle ($z_{pd} = \left\lceil \frac{x_{pd}}{\delta\cdot\eta} \right\rceil$),
L_d	number of feasible production levels for dairy d given its capacity k_d,

δ	minimum number of collection cycles per year ($\delta = 183$ for collection every other day),
κ	transport costs per tanker and km,
η	capacity of a tanker in t,
ω	daily km limit of a tanker.

The objective function (1) minimizes the sectoral total costs, i.e. the sum of overhead, transport, and processing costs over all dairy plants in operation. We assume identical raw milk prices for all dairies and therefore may disregard these in the model. Constraint (2) ensures transportation of the total milk output of every dairy farming region (b_p) to dairy plants. Constraint (3) requires compliance with dairy capacity limits (k_d) and also that closed dairies are not supplied. Constraint (4) makes sure that each dairy operates on at most one production level l. Constraint (5) determines the minimal number of milk tankers required to pick up the milk supply for dairy d from region p given the minimum number of pickups per year (δ) and tanker capacities (η). Constraints (6) and (7) link the production quantity with the corresponding production level l for each dairy via the binary variable y_{dl} (compare Table 1), thereby implicitly determining the production costs per ton for each dairy. Moreover, they ensure each dairy produces on exactly one production level. (8) requires that the quantity of milk supplied from all regions to a particular dairy also corresponds to the quantity q_{dl} processed therein. Constraint (9) limits the daily travel distance of each tanker to $\omega = 480$ km. (10), (11), (12), and (13) determine the domains for the variables: y_{dl} takes on binary values for opening a dairy plant location and for selecting its level of production. z_{pd} ensures a discrete number of transports from region p to dairy d per collection cycle. z_{pd} and q_{dl} are dependent variables and entirely determined by the values of the decision variables x_{pd} and y_{dl}.

2.4 Solution Method

Capacitated Facility Location Problems (CFLPs) are combinatorial optimization problems which are commonly employed in production and distribution planning.[6] The goal is the planning of locations and the determination of supply and / or delivery areas and quantities. Locations are selected from a given set of potential locations subject to several constraints so that costs are minimized. Typically, differentiated cost types are processing, transport, and overhead costs. The constraints, in particular, consist of required periodic supply quantities and individual

[6] For an introduction to location planning see, e.g., Günther and Tempelmeier (2005) or Domschke and Drexl (2005).

plant processing capacities. Usually, processing and transport costs are assumed to be proportional to the quantities transported (see Görtz and Klose, 2004, pp. 1).

We represent the dairy sector as such a capacitated location problem: A set of dairy plant locations has to be selected from a given set of existing locations and the individual plants' capacity utilization be determined such that the total sectoral costs are minimized subject to regular and complete raw milk output collection, maximum daily travel distances of milk tankers, and maximum dairy processing and tanker capacities.

Applying the CFLP to the dairy sector requires two modifications to the regular CFLP model. First, regular CFLPs assume constant processing costs per unit of output which would bias the results in the presence of economies of scale as here with dairy plants. Second, regular CFLP models imply a linear relationship between transport costs *per ton* and travel distance. But in the dairy sector, we also have to take other influencing variables (number, capacity, and maximum daily travel distance of the milk tankers as well as collection cycles) into account.

CFLPs belong to the class of NP-hard decision problems[7] (see, e.g., Grünert, 2001), meaning that computational effort increases with the number of decision variables of the problem not only proportionally or polynomially, but even exponentially. Consequently, the application of exact solution procedures to such problems of real-life magnitude is impossible. This led to the development of several approximative heuristic procedures in the literature which generate "good", but not necessarily optimal solutions, with acceptable computation time. For a recent overview of models and solution procedures for location problems see Klose and Drexl (2005) or Görtz and Klose (2004).

Here, we employ a *genetic algorithm* to solve the model. Genetic algorithms are general search procedures for combinatorial optimization problems which attempt, based on an analogy to evolution, to find good solutions by searching the solution space "cleverly" instead of exhaustively. Genetic algorithms evolve over a sequence of generations – analogous to the genetic evolution – by means of the mechanisms selection, inheritance (respectively recombination), and mutation of the chromosomes, with respect to the objective function better fitted populations of solutions. Genetic algorithms have been applied successfully to solve a multitude of complex combinatorial optimization problems.[8] To solve the transportation problems (TPPs) which

[7]The term *non-deterministic polynomial-time hard* (NP-hard) originates from computational complexity theory and refers to the class of computational problems for which no algorithm exists that can solve the problem with a run time no longer than a polynomial function of the problem size n. For an in-depth introduction to NP-completeness see, e.g., Cormen et al. (2001, ch. 34)

[8]For a thorough introduction to genetic algorithms see, for instance, Beasley and Martin (1993), Michalewicz and Fogel (2000), or Reeves (2003).

arise as subproblems, we hybridize the algorithm. First, we generate an initial solution of the relaxed TPP with the Simplex algorithm and then improve it with a Tabu Search procedure (TS_{TPP}).

In our particular implementation of the genetic algorithm, a chromosome is a binary string. For each potential plant location it has a binary variable (genes) which marks it as closed (value is zero) or open (value is one). We denote the subset of open dairies D^o from all potential dairy locations D, $D^o \subseteq D$. One population consists of a multitude of such chromosomes or location constellations. To evaluate a population with respect to its "fitness", we compute the sectoral total costs associated with each chromosome. Since a chromosome determines the selection of locations designated to be open, it implicitly also determines the sectoral overhead costs.

In order to evaluate a chromosome D^o we first solve a transportation problem: The regional raw milk supplies are allocated over D^o such that the sum of transport and processing costs is minimized subject to the constraints. For an initial solution to the transportation problem, first only the constraints (2), (3), and (9), i.e. complete collection of raw milk outputs, dairy capacities and maximum daily travel distance of the milk tankers, are considered. This reduced problem can be solved optimally and efficiently using the Simplex algorithm (see, for example, Cormen et al., 2001, pp. 790).

This is the initial solution for the TS_{TPP}–improvement procedure[9]: Considering the remaining constraints, the TS_{TPP} reallocates the regional milk supplies to the dairies such that the sum of transportation and processing costs for D^o is minimized.[10]

After evaluating all chromosomes the genetic algorithm selects a subset of the chromosomes which pass their genes on to their offspring. Each gene of an offspring's chromosome may originate from either parent with equal probability. Additionally, there is a small probability that "mutation" modifies single chromosomes arbitrarily. The past generation is entirely replaced by the new generation. While doing so, the worst chromosome of the new generation is replaced by the best of the past generation.

This two stage procedure of evaluation and reproduction is repeated for a given number of iterations. Over the course of the iterations of the algorithm, initial plant location constellations are replaced by continuously improving location constellations.

[9]For an introduction into the general approach of Tabu Search see, e.g., Glover (1989) and Glover (1990).

[10]TS_{TPP} can resolve the solution associated with a chromosome in case there exists no feasible solution for D^o.

3 Results

Since no data on individual dairy plant utilization is available to us, our *benchmark* scenario for the initial year 2001 minimizes the sectoral costs subject to the constraint that the entire milk production is distributed equally across all dairy plants resulting in an identical capacity utilization for all plants of $\frac{24{,}395{,}801t}{33{,}196{,}800t} = 73.5\%$.

The benchmark scenario serves as a reference for two alternative scenarios. The simplifying assumption of identical capacity utilization across all plants in the benchmark scenario does not affect the optimal solution of the alternative scenarios.

In contrast to the benchmark scenario, the first alternative scenario allows plants to operate with differing capacity utilization or to even shut down. But the maximum capacity of each plant remains fixed. Considering the existence of a fixed production factor we denote this as the *short-run* scenario. By contrast, the second alternative also allows plant capacities to vary and is therefore called the *long-run* scenario.

We determine sector-wide optima for both the short- and long-run scenarios as well as for different transport cost levels. Similarly, one could determine the optima for different levels of processing costs. We refrain from the latter in the following since a quantitative change in processing costs is equivalent to the effect of a change in transport costs. Both cause a shift in the importance of the cost types relative to each other. For instance, a multiplication of the transport costs which particularly affect large plants with large collection areas is similar to a relative decrease in the economies of scale in milk processing.[11]

Since our heuristic is not guaranteed to find the optimal solution in every run, we generate 100 solutions for each of the alternative scenarios and every transport cost level.[12,13] We use the medians of the corresponding solution vectors as bases for the comparison of different transport cost levels *within* a particular scenario, as well as for comparisons *between* scenarios with identical transportation cost levels.

[11]To validate this claim, we have conducted a sensitivity analysis varying the processing costs proportionally between -25% and +25%. Direction and scale of the resulting effects are comparable to those of a transportation cost multiplication.

[12]This approach is not necessary for the benchmark scenario since there all plants are operated *per definitionem* with identical capacity utilization and – after allocating the regional milk outputs to dairy plants using the Simplex algorithm – the only optimizable cost factor left is the allocation of underutilized tankers.

[13]Lower bounds for the individual cost types can give an indication for the quality of the solutions found (see Table 5). The lower bound for a cost type is computed by ignoring all other constraints. The bounds for the transport costs are calculated using the Simplex algorithm, which allocates the raw milk outputs to all dairies respecting their individual maximum capacities.

3.1 Benchmark Scenario

For the sector-wide costs in the benchmark scenario we find an optimal value of 2637.133m euro p.a.. These are composed of 331.968m euro overhead costs, 2039.697m euro processing costs, and 265.169m euro transport costs. The associated annual mileage is 493.252m km ($20.22\frac{km}{t}$) with an average tanker utilization of 97.1%.

We classify dairy plants into three size ranges (SR) according to their capacities: SR_I: 0t $\leq k \leq 25,000$t, SR_{II}: 25,000t $< k \leq 125,000$t, SR_{III}: $k > 125,000$t. Of the 360 plants in the database 182 fall into SR_I, 108 into SR_{II}, and 70 into SR_{III}. The median plant capacity is 25,000t. How is the total milk production distributed across the range of dairy sizes? Only 5% of the milk production is processed in plants with capacities of 25,000t or less. Dairies with capacities of up to 125,000t account for 25% of the milk production. The interquantile range of dairy capacities lies between 125,000t and 250,000t (accommodating 50% of total milk production) and dairies above 250,000t account for another 25%.

Table 4 describes the benchmark cost situation. The table details the average overhead (K_O), processing (K_P), and transport (K_T) costs as well as the total cost per ton (ΣK) for each size range individually and in aggregate (ΣSR). Additionally, it shows the shares of cost types $i \in \{O, P, T\}$ in total costs ($\frac{K_i}{\Sigma K}$). One ton costs 108.10 euro on average. The overhead costs per ton are identical for all sizes. This follows from the assumptions of identical capacity utilization and proportionally capacity-dependent overhead costs. Since processing is characterized by large economies of scale (cost savings of 25.65% from the lowest to the highest processing level, compare Table 1) and thus processing costs dominate the transport cost differences between the size ranges (<11.1%), the total cost per ton shrinks with increasing dairy size. Large dairies have a cost advantage of 17.35% per ton relative to small dairies. The coefficient of variation of average costs per ton over all dairies can be interpreted as a measure for the convergence or variability of total cost per ton and amounts to 8.8% in the benchmark scenario. Thus, there are quite substantial differences in average costs between dairies, thus indicating inefficiencies in the sector. Consequently, we expect that average costs between dairies converge more strongly when plants may shut down and adapt capacities in the short- and long-runs.[14]

[14] Weindlmaier (2004a, pp. 72-74) provides a verbal discussion of the counteracting effects of the economies of scale in processing versus the diseconomies in transport. Keane (1998a, p. 8) compares empirical results for Ireland and Germany.

Table 4: Benchmark scenario

	SR_I		SR_{II}		SR_{III}		ΣSR	
	$\frac{K}{q}\|_{0.50}$	$\frac{K_i}{\Sigma K}\times 100$	$\frac{K}{q}\|_{0.50}$	$\frac{K_i}{\Sigma K}\times 100$	$\frac{K}{q}\|_{0.50}$	$\frac{K_i}{\Sigma K}\times 100$	$\frac{K}{q}\|_{0.50}$	$\frac{K_i}{\Sigma K}\times 100$
K_O	13.61	11.00	13.61	12.49	13.61	13.31	13.61	12.59
K_P	98.68	79.76	85.07	78.06	77.33	75.63	83.61	77.35
K_T	11.44	9.25	10.30	9.45	11.31	11.06	10.88	10.06
ΣK	123.72		108.98		102.25		108.10	

Costs per ton for the different size ranges SR_I-SR_{III} and total ($\sum SR$) as well as their cost type compositions. Source: Own computation.

3.2 Short-Run Scenarios

In contrast to the benchmark scenario, the short-run scenario allows capacity utilization to vary freely and plants to shut down. We assume that no new plants are opened, similar to the actual development of recent years. The heuristic generates optimal solutions for different transport cost levels subject to given production technology. The levels result from a multiplication of the transport cost per kilometer by different factors $\tau = 1, 2, 4, 6, 10$ where $\tau = 1$ is the current cost level.[15] But recent empirical trends point to a relative increase in transports costs in comparison to other costs. In particular, fuel prices increased dramatically over recent months but additionally the introduction of highway tolls for trucks and ecological taxes have increased the cost of transportation. Apart from that, we might underestimate real transport costs by the computation of distances between dairies and milk farming regions as beelines as well as by the method of approximation of intraregional driving distances in the model. Moreover, the model does not consider any reserve capacity of the tankers to allow for possible variation in the daily raw milk output and seasonal variations. In any case, the transport cost multiplier might also be interpreted as an internalization of external effects of transportation as intended, for instance, by tradeable environmental certificates.

First, we analyze the case of unmodified transport costs. The sum of sector-wide costs decreases by about 11% from 2637.133m euro to 2343.145m euro in comparison to the benchmark scenario. The costs' compositions and their deviations from their lower bounds are presented in Table 5.

As shown in the first line of Table 6, the number of operated plants drops from

[15] During the last three decades, the cost of milk collection remained rather constant despite increasing factor costs due to technical progress. But the choice of the multipliers is not motivated by the representation of current trends but rather by the question what size of change would be necessary to cause structural change. The multipliers might be interpreted as a decrease of processing costs relative to transport costs.

Table 5: Deviation of the cost medians from the lower bounds in the short-run

τ	K_O	$\Delta\%$	K_P	$\Delta\%$	K_T	km	$\Delta\%$	ΣK	$\Delta\%$
$\underline{K}$	243.958		1879.566		170.385	316.58		2293.908	
1	244.133	0.07	1903.152	1.25	195.656	363.54	14.83	2343.145	2.14
2	246.606	1.09	1914.148	1.84	372.367	345.94	9.27	2533.236	2.31
4	249.837	2.41	1928.926	2.63	720.607	334.73	5.73	2899.292	2.83
6	252.678	3.57	1939.305	3.18	1065.754	330.04	4.25	3257.603	3.30
10	256.884	5.30	1954.602	3.99	1748.949	324.96	2.65	3960.429	4.03

$\underline{K}$ denotes lower bounds. $\Delta\%$ is the percentage deviation from the lower bound, where we calculate the percentage deviation for ΣK as $\frac{K_0+K_P+0.5382\cdot km}{2293.908}$. All costs are in million euro p.a. Source: Own computation.

360 in benchmark scenario to 155-158 in the short-run scenario where the number of smaller dairies decreases substantially (from 108 to 18-21). In fact, a similarly radical change happened in reality where, over the period from 1994 to 2004 alone, the number of dairies in Germany decreased by 30% (Thiele, 2004). According to a 2004 survey on the economic sustainability of the structure of the dairy sector, another decrease of 50 to 60% is expected within the next 10 years (ibidem).

Table 7 presents the total costs per ton for each of the three size ranges individually and for the aggregate. Given are statistics for the 25% and 75% quartiles and medians over all 100 iterations. The total costs per ton (ΣK) point to an increased competitiveness of the plants, reflected in a cost reduction from 108.10 euro to 96.05 euro per ton. The difference in total costs between dairies is generally lower: The coefficient of variation of total costs per ton is now 4.9% in contrast to the 8.8% in the benchmark scenario. In the optimal solution of the short-run the average total costs of the remaining dairies have further converged. Thus, we can reject the hypothesis stated at the outset that a sector-wide cost minimum might not be associated with a convergence of the individual dairies' average cost minima.

As in the benchmark scenario, a relative cost advantage of large dairies compared to medium and medium compared to small dairies remains. While the total costs per ton for large dairies are 95.07 euro these increase to 96.80 euro for medium-sized dairies and to 115.45 euro per ton for small-sized dairies. This competitive advantage (17.6% lower costs per ton for SR_{III} compared to SR_I) is due to economies of scale in processing and persists in the short-run since we assume that capacities can only adapt in the long-run.

What pattern of different cost types emerges? In comparison to the benchmark scenario, we see decreases in transport costs per ton (from 10.88 to 8.02 euro, compare Table 8, column K_T) and mileage per ton (by about 26% from 20.22km to

14.90km). In contrast to the benchmark scenario where transport costs do not vary systematically with dairy size now a clear relationship emerges. Transport costs increase with dairy size from 6.74 euro per ton for small dairies, by 0.22 euro for medium dairies, and by 1.87 euro for large dairies. Independent of dairy size, overhead costs also decrease on average from 13.61 to 10.01 euro per ton as a result of better capacity utilization. In fact, this implies almost full utilization (see Table 8, column K_O). The closure of small dairies, as well as increased utilization, leads to a reduction in processing costs by 5.60 euro to 78.01 euro per ton (compare Table 8, column K_P).

How does the multiplication of the transports cost per kilometer affect the sector-wide economic structure of the dairy sector and the relative competitiveness of different sizes in the short-run? The transport cost increase is reflected in a rise in average total costs per ton (compare Table 7, column ΣSR). The relative increase in total costs per ton is positively correlated with the dairy size (see Table 7, $\Delta\%$ columns). While the competitiveness, measured as average costs per ton, increases unambigously with dairy size for $\tau = 1$ and $\tau = 2$, medium- and large-sized dairies display similar total costs per ton for $\tau = 4$ (compare Table 7, row 3). For $\tau > 4$ size range SR_{II} has a clear cost advantage over SR_{III}. Although small dairies display the highest total costs in all cases, the competitive disadvantage diminishes with increasing transport costs in absolute, as well as relative, terms.

The coefficient of variation of average total costs increases over this course from 4.9% for $\tau = 1$ to maximal 19.9% for $\tau = 10$. Hence, the dispersion of total costs per ton between dairies is higher, the higher the assumed transport cost multiplier. This can be attributed to the fact that dairies with large collection areas and/or disadvantaged location are no longer able to fully offset the transport costs through exploitation of economies of scale when transport cost multipliers get sufficiently high. The particular spatial location of a dairy becomes increasingly relevant as the determinant for plant survival instead of the capacity-restricted economies of scale. Now, it might also be advantageous to operate a dairy with higher average cost since the alternative – closing the dairy and transport to a more remote dairy – would again lead to increased sector-wide costs.

The number of small and medium dairies increases in the optimal solution due to improved competitiveness. For $\tau = 10$ the number of operated small dairies increases by 76 compared to $\tau = 1$, implying almost a quadruplication (+387.18%). Also, the number of medium dairies increases by 9. By contrast, the number of large dairies drops slighty from 63 to 57. Thus, the total number of dairies operated increases continuously from 156 for $\tau = 1$ to 237 for $\tau = 10$ (compare Table 6, column ΣSR).

How is milk production distributed across dairy size? For transport costs of $\tau = 1$, dairies with a maximum capacity of 80,000 and 125,000 tons process only 5% and 25% of the total raw milk output, respectively. Another 50% (the interquantile range) of the total production is processed in dairies with 125,000 to 281,000 tons capacity. This range shifts towards smaller plants with rising transport costs. The median dairy size falls from 125,000t for $\tau = 1$ to 90,000t for $\tau = 10$.

Table 8 shows how the composition of total costs per ton changes with τ. The increase of overhead costs per ton by 5.22% for $\tau = 10$ indicates that the capacity utilization of the dairies decreases slightly with increasing transport costs. The rising transport costs cause more small dairies to remain in operation and thus a decrease in average dairy size which, together with lower capacity utilization, leads to an increase in processing costs by 2.7%. The increased number of smaller dairies counteracts an increase in total costs because sector-wide transport costs rise less than proportionally with increasing τ. The higher number of operated plants also causes transport kilometers per ton to decrease by 10.6% from 14.9 km to 13.32 km.

What is the spatial distribution of the dairies remaining in operation? To answer this question we choose a centrally located point in Germany – in the center of county Northeim (Lower Saxony) – from which we divide the country into four regions, in clockwise order, northwest (NW), northeast (NE), southeast (SE), and southwest (SW). We then count the number of operated dairies in each of the four regions and classify them according to the three size ranges. Figure 2 summarizes the results for the four regions dependent on τ. An increase in transport costs relative to processing costs results in a higher number of smaller dairies. But the strength of the effects vary by region. For instance, while the number of small dairies in the northwest increases fourfold for $\tau = 4$ compared to $\tau = 1$, it only doubles in the southeast.

3.3 Long-Run Scenarios

While the dairy *capacities* were exogenously given in the short-run these are variable production factors and are thus endogenous decision variables in the long-run. Consequently, the individual capacity of each dairy is now an outcome of the cost-minimization approach. What are the adjustment effects in comparison to the other two scenarios?

First, we consider the case of unchanged transport costs. Compared to the bench-

Table 6: Number of operated dairy plants in the short-run scenario

	SR_I				SR_{II}				SR_{III}				ΣSR			
τ	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\Delta\%$	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\Delta\%$	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\Delta\%$	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\Delta\%$
1	18.00	19.50	21.00		73.00	74.00	75.00		62.00	62.50	63.00		155.00	156.00	158.00	
2	33.00	34.00	36.00	74.36	77.00	78.00	79.00	5.41	60.00	60.00	61.00	-4.00	171.00	173.00	174.00	10.90
4	55.00	56.50	59.00	189.74	80.00	80.00	81.00	8.11	58.00	58.00	58.00	-7.20	194.00	195.00	197.00	25.00
6	72.00	74.00	76.00	279.49	81.75	82.00	83.00	10.81	56.00	57.00	57.00	-8.80	211.00	213.00	215.00	36.54
10	92.00	95.00	97.00	387.18	85.00	85.00	86.00	14.86	56.00	57.00	57.00	-8.80	234.00	237.00	239.00	51.92

Number of operated dairy plants for the size ranges $SR_I - SR_{III}$ and in total (ΣSR). $\Delta\%$ denotes the change of the median $n_{0.50}$ compared to $\tau = 1$. Source: Own computation.

Table 7: Total costs per ton in the short-run scenario

	SR_I				SR_{II}				SR_{III}				ΣSR			
τ	$\frac{K}{q}\vert_{0.25}$	$\frac{K}{q}\vert_{0.50}$	$\frac{K}{q}\vert_{0.75}$	$\Delta\%$	$\frac{K}{q}\vert_{0.25}$	$\frac{K}{q}\vert_{0.50}$	$\frac{K}{q}\vert_{0.75}$	$\Delta\%$	$\frac{K}{q}\vert_{0.25}$	$\frac{K}{q}\vert_{0.50}$	$\frac{K}{q}\vert_{0.75}$	$\Delta\%$	$\frac{K}{q}\vert_{0.25}$	$\frac{K}{q}\vert_{0.50}$	$\frac{K}{q}\vert_{0.75}$	$\Delta\%$
1	115.16	115.45	115.68		96.69	96.81	96.86		95.00	95.07	95.16		96.04	96.05	96.06	
2	121.66	121.90	122.17	5.58	103.30	103.36	103.47	6.77	103.04	103.10	103.17	8.44	103.82	103.85	103.85	8.11
4	134.10	134.41	134.89	16.42	116.44	116.53	116.71	20.38	118.66	118.75	118.85	24.91	118.82	118.84	118.87	23.74
6	145.61	146.02	146.34	26.47	129.55	129.71	129.90	33.99	134.30	134.41	134.52	41.38	133.52	133.53	133.55	39.03
10	168.87	169.32	170.11	46.66	155.98	156.15	156.40	61.30	165.17	165.40	165.61	73.97	162.29	162.34	162.38	69.02

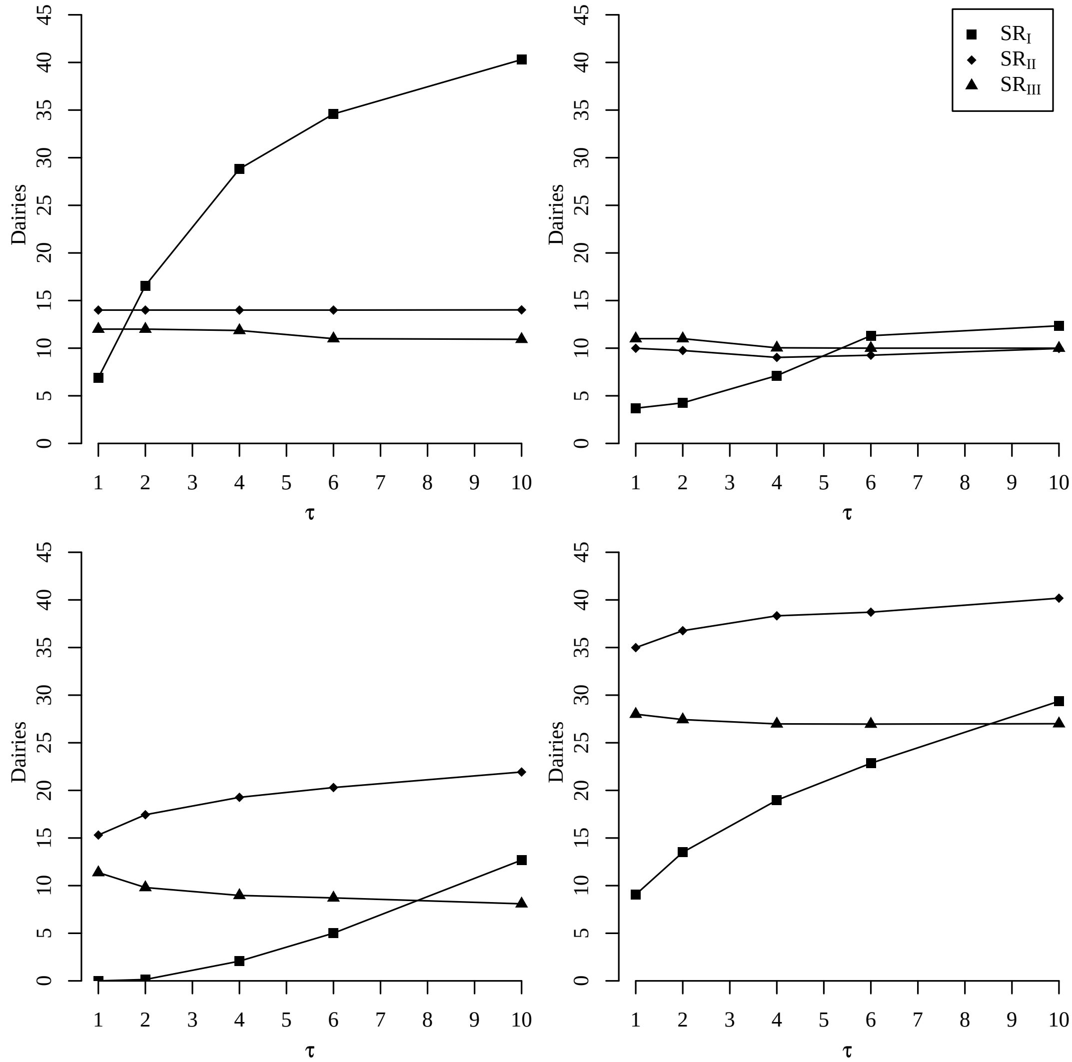
Total costs per ton for the size ranges $SR_I - SR_{III}$ and over all size ranges (ΣSR). $\Delta\%$ denotes the change of the median $\frac{K}{q}|_{0.50}$ comparted to $\tau = 1$. Source: Own computation.

Table 8: Cost type composition in the short-run scenario

	K_O				K_P				K_T				ΣK			
τ	$\frac{K_O}{q}\vert_{0.25}$	$\frac{K_O}{q}\vert_{0.50}$	$\frac{K_O}{q}\vert_{0.75}$	$\Delta\%$	$\frac{K_P}{q}\vert_{0.25}$	$\frac{K_P}{q}\vert_{0.50}$	$\frac{K_P}{q}\vert_{0.75}$	$\Delta\%$	$\frac{K_T}{q}\vert_{0.25}$	$\frac{K_T}{q}\vert_{0.50}$	$\frac{K_T}{q}\vert_{0.75}$	$\Delta\%$	$\frac{K}{q}\vert_{0.25}$	$\frac{K}{q}\vert_{0.50}$	$\frac{K}{q}\vert_{0.75}$	$\Delta\%$
1	10.00	10.01	10.01		77.97	78.01	78.08		7.95	8.02	8.07		96.04	96.05	96.06	
2	10.08	10.11	10.13	1.01	78.43	78.46	78.50	0.58	15.24	15.26	15.30	90.32	103.82	103.84	103.85	8.11
4	10.23	10.24	10.26	2.34	79.03	79.07	79.10	1.35	29.50	29.54	29.57	268.30	118.82	118.84	118.87	23.74
6	10.34	10.36	10.39	3.50	79.46	79.49	79.55	1.90	43.62	43.69	43.72	444.71	133.52	133.53	133.55	39.03
10	10.48	10.53	10.57	5.22	80.05	80.12	80.17	2.70	71.62	71.69	71.74	793.89	162.29	162.34	162.38	69.02

The composition of cost types over all size ranges. $\Delta\%$ denotes the change of the median $\frac{\cdot}{q}|_{0.50}$ compared to $\tau = 1$. Source: Own computation.

Figure 2: Spatial distribution in the short-run



Source: Own computation.

mark and short-run scenarios, total sectoral costs decrease by an additional 16.4% and 5.9% from 2637.133 and 2343.145 respectively to 2204.534m euro. The total number of dairies decreases again from 150-162 in the short-run to 63-66 (compare Table 9, column ΣSR). The high capacities of the remaining dairies show that in the long-run, and at the given spatial structure, cost-efficient dairy sizes under our assumptions are almost *exclusively* medium and large sizes (see Table 9).

Total costs per ton decrease by 5.76 euro from 96.05 euro in the short-run to 90.37 euro (compare Table 10, column ΣK). The variation of total costs per ton over all dairies is now notably lower than in the short-run. The coefficient of variation amounts to only 2.0% which indicates an increased convergence of average total costs relative to the short-run. This also means that it becomes increasingly less advantageous to operate dairies with higher average costs. The decrease in total costs can be attributed to both decreases in processing and transport costs (see Table 10, columns K_P and K_T). The capacity adjustment of dairies in spatially favorable locations reduces the mileage per ton from 14.90 km in the short-run to 10.34 km.

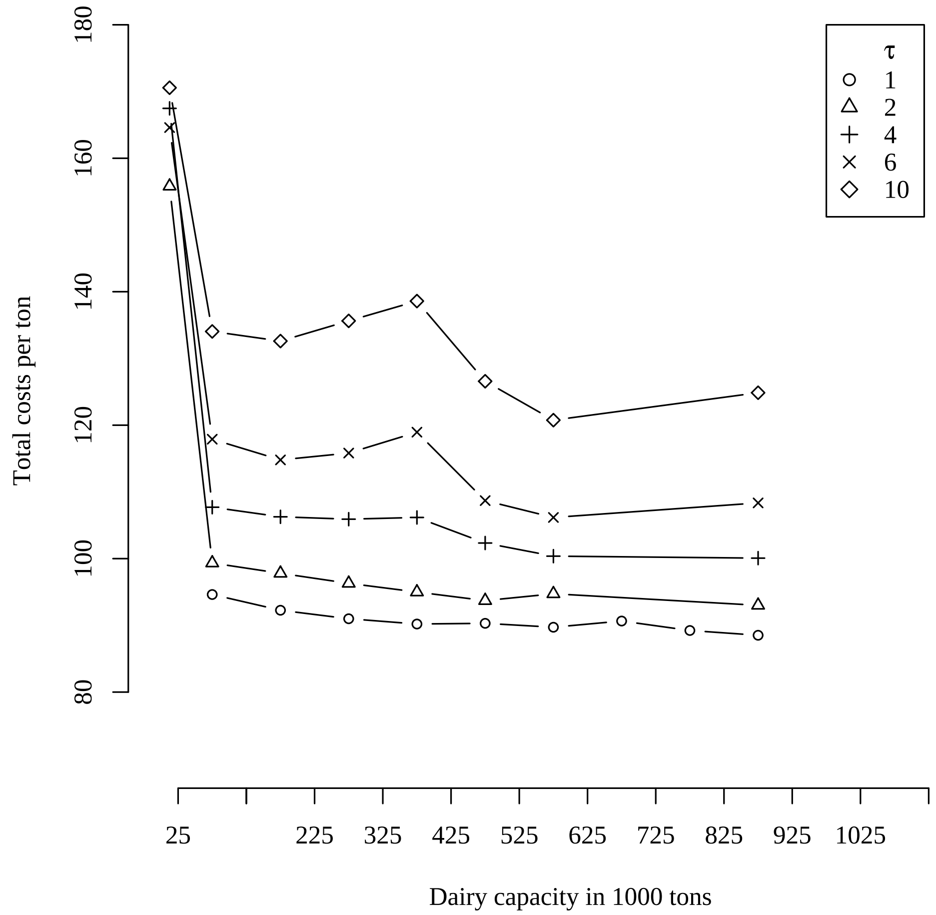
What are the effects of a rise in transport costs in the long-run? Table 10 shows the total costs per ton over all dairies as well as the distribution of total costs across the different cost types. As in the short-run, the coefficient of variation of total costs increases with the transport cost level. However, the increase is now considerably smaller. While the coefficient of variation in the short-run increased from 4.9% for $\tau = 1$ to a maximum of 19.9% for $\tau = 10$ the corresponding values for the long-run are only 2.0% and 9.5%, respectively. Hence, capacity adjustment is sufficient to equalize the differences in average cost per ton caused by the spatial layout to a large extent. The increasing coefficient of variation suggests that the current spatial layout is inappropriate and thus, at given regional dairy farm outputs, generates strong incentives for green-field investments in new locations.

When comparing the effect of varying multipliers τ on total costs between the short- and long-runs, it becomes apparent that the increase in total costs is smaller in the long-run. For example, while relative costs in the short-run rise by 23.74% for $\tau = 4$ the corresponding figure for the long-run is only 17.26% with a generally lower cost level. The smaller increase follows from the fact that, in the long-run, plants centrally located in the proximity of large raw milk supplies can react with increased capacity, while in the short-run capacities are exogenous.

Figure 3 shows total costs per ton according to dairy capacity and transport cost level.[16] While total costs decrease monotonically with increasing dairy sizes between 25,000 t and 225,000 t p.a. further increases of average capacity result only in a weakly decreasing trend for $\tau = 1, 2, 4$. For $\tau = 6, 10$, the trend is ambiguous: In the interval between 225,000 t and 425,000 t average costs are actually systematically increasing. A plausible interpretation of this result is that – under the given spatial

[16] The dairies are classified into capacity intervals. The actual data points are located in the middle of the corresponding interval.

Figure 3: Long-run costs per ton in euro



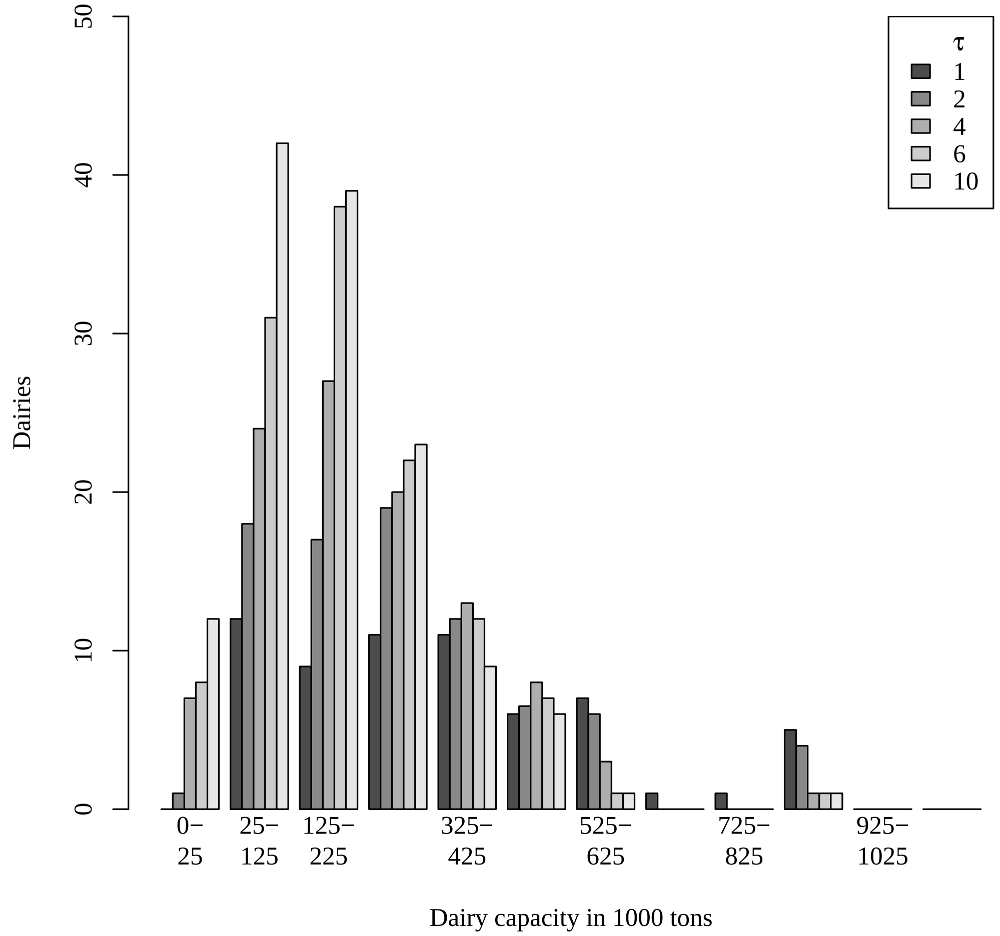
Source: Own computation.

distribution of dairies and dairy farm outputs – with increasing τ, transport costs gain so much importance relative to other cost types that further convergence of the average costs through capacity enlargement is impossible. This interpretation is supported by the fact that, in the long-run, the total mileage for $\tau = 10$ (218.918m km) deviates by only 2.46% from the lower bound (213.670m km).

Table 10 also details the changes in different types of costs. In contrast to the short-run, overhead costs per ton now remain constant which follows from the assumption that capacities are allowed to adapt perfectly to the quantities processed. Similar to the short-run, processing and transport costs per ton increase where the latter increase less than proportionally with τ. The mileage per ton shrinks by 13.2% from 10.32 km for $\tau = 1$ to 8.97 km for $\tau = 10$.

Table 9 and Figure 4 give an overview of the number of dairies in operation.

Figure 4: Distribution of dairies over capacity intervals in the long-run



Source: Own computation.

Analogous to the short-run, a trend towards smaller dairies emerges with increasing transport costs. Here, smaller dairies are typically located in the periphery, particularly in the southwest. But in contrast to the short-run, the number of larger dairies also increases. These typically emerge in the proximity to dairy farming regions with high outputs so that these dairies can benefit from both economies of scale in processing and relatively low transport costs. This also affects the cost situation in relation to dairy size. While in the short-run for $\tau > 4$, a relative advantage emerges for dairies of medium size, the relative competitive advantage of larger dairies continues to a large extent in the long-run. Weindlmaier (2004a, p. 79) assumes a similar pattern in his qualitative outlook for future structural change. But dairy size is still limited by the given spatial distribution of dairy farm outputs, which causes dairy sizes to progressively concentrate within a range between 25,000 t and

325,000 t when transport costs rise. The median dairy size shrinks by 55.37% from 327,501 t for $\tau = 1$ to 146,110 t for $\tau = 10$. For $\tau = 1$, only 25% of the milk is processed in dairies with a maximum capacity of 318,802 t. 50% of the milk, the interquantile range, is processed in dairies between 318,802 t and 681,541 t. The corresponding capacities for $\tau = 10$ are 151,410 t and 390,792 t.

Figure 5 shows the spatial distribution of operated dairies for the four regions (NW, NE, SE, and SW). While an increasing transport cost multiplier τ led to a notable increase in the number of small dairies in the short-run, their number remains virtually constant and at a low level in the long-run regardless of τ. Only the southwest features a regional concentration of small dairies. In contrast, the increase of τ causes an increase of the number of medium and large dairies, in particular in the northwest and southeast. According to the assumptions, this is not due to a decrease in average dairy utilization but rather to a decrease in average dairy size within those two size ranges.

4 Discussion of the Results

The results presented in the previous chapter were derived under simplifying assumptions. These assumptions were necessary because of a lack of micro data rather than the intrinsic restrictions of the model. The structure of our model would allow the incorporation of individual firm data for cost functions and product mixes as well as, for instance, the regional relocation of dairy farms. The model could also be extended to include additional cost types. Dalton et al. (2002, p. 990) attribute the lack of data to the high competitive pressure in the dairy sector, confidentiality, as well as to an effort by dairy managements to preserve a potential information advantage over competitors.

However, the following plausibility considerations allow for the inference of additional results in the absence of additional quantitative data. The computations assumed that all dairies produce an identical representative average product mix. This facilitated the use of identical cost curves for dairies of identical capacity. But in reality product mixes diverge as do the cost compositions of different dairy plants.

Table 9: Number of operated dairy plants in the long-run

	GK_I				GK_{II}				GK_{III}				ΣGK			
τ	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\triangle\%$	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\triangle\%$	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\triangle\%$	$n_{0.25}$	$n_{0.50}$	$n_{0.75}$	$\triangle\%$
1	0	0	0		10.75	12	13.25		52	53	54		63	65	66	
2	0.00	1.00	1.00	—	17.00	18.00	20.00	50.00	62.00	63.00	64.00	18.87	81.00	82.00	83.00	26.15
4	10.00	11.00	11.00	—	23.00	24.00	25.00	100.00	72.00	73.00	75.00	37.74	106.00	107.00	109.00	64.62
6	10.00	11.00	12.00	—	30.00	31.00	32.00	158.33	80.00	80.00	80.00	50.94	122.00	122.00	123.00	87.69
10	13.00	13.00	14.00	—	42.00	42.00	43.00	250.00	79.00	79.00	80.00	49.06	134.00	135.00	136.00	107.69

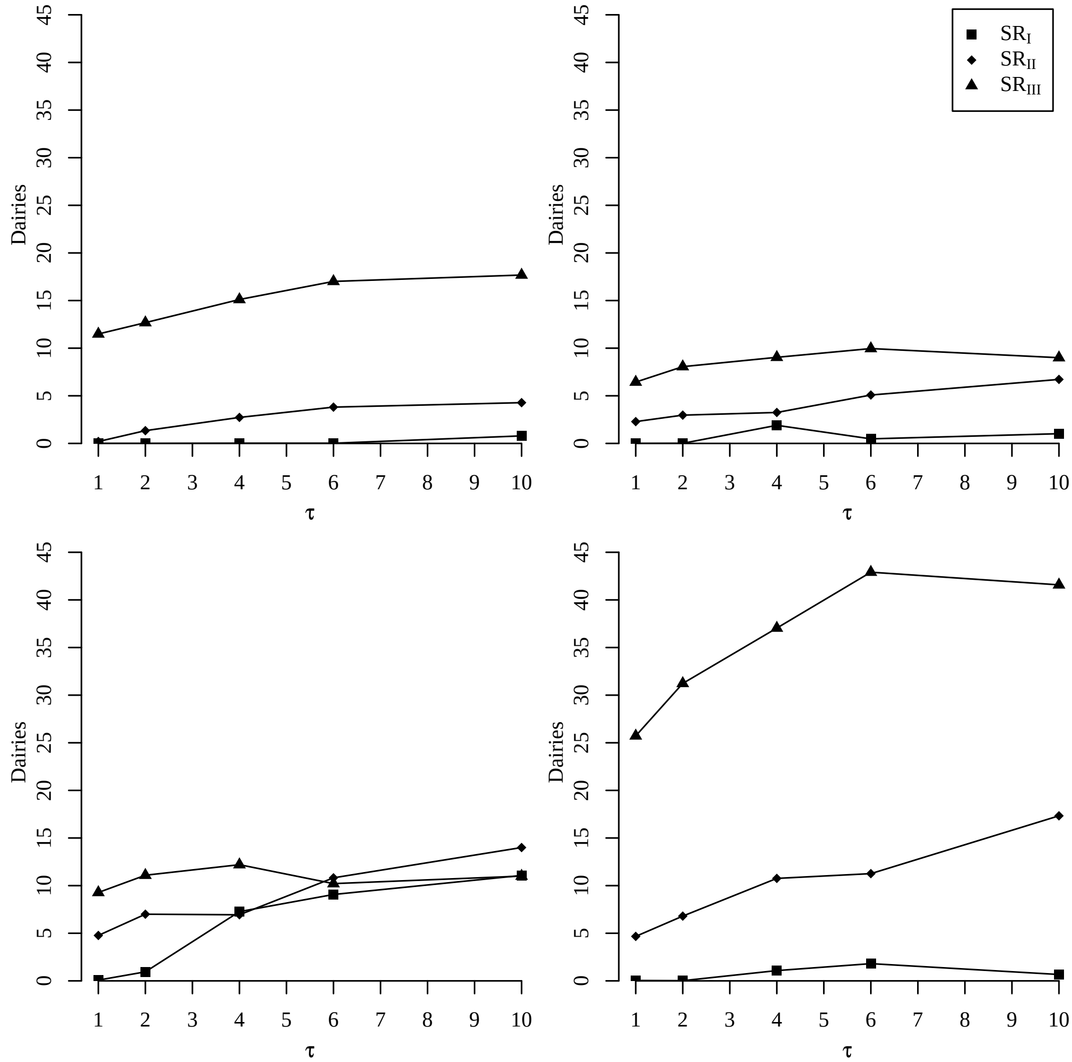
Number of operated dairy plants for the size ranges $SR_I - SR_{III}$ and over all size ranges (ΣSR). $\triangle\%$ denotes the change of the median value $n_{0.50}$ compared to $\tau = 1$. Source: Own computation.

Table 10: Total cost per ton and its composition in the long-run

	K_O				K_P				K_T				ΣK			
τ	$\frac{K_O}{q}\|_{0.25}$	$\frac{K_O}{q}\|_{0.50}$	$\frac{K_O}{q}\|_{0.75}$	$\triangle\%$	$\frac{K_P}{q}\|_{0.25}$	$\frac{K_P}{q}\|_{0.50}$	$\frac{K_P}{q}\|_{0.75}$	$\triangle\%$	$\frac{K_T}{q}\|_{0.25}$	$\frac{K_T}{q}\|_{0.50}$	$\frac{K_T}{q}\|_{0.75}$	$\triangle\%$	$\frac{K}{q}\|_{0.25}$	$\frac{K}{q}\|_{0.50}$	$\frac{K}{q}\|_{0.75}$	$\triangle\%$
1	10.00	10.00	10.00		74.75	74.79	74.84		5.53	5.57	5.59		90.34	90.37	90.39	
2	10.00	10.00	10.00	0.00	75.36	75.39	75.42	0.79	10.39	10.41	10.43	87.03	95.78	95.80	95.81	6.01
4	10.00	10.00	10.00	0.00	75.95	75.99	76.02	1.59	19.96	19.99	20.03	259.02	105.97	105.97	105.98	17.26
6	10.00	10.00	10.00	0.00	76.51	76.53	76.55	2.32	29.35	29.37	29.39	427.54	115.89	115.90	115.90	28.25
10	10.00	10.00	10.00	0.00	77.01	77.03	77.07	2.99	48.27	48.30	48.32	767.58	135.32	135.33	135.34	49.75

Total cost per ton as well as its cost type distribution across all size ranges. $\triangle\%$ denotes the change of the median value $\frac{\cdot}{q}|_{0.50}$ compared to $\tau = 1$. Source: Own computation.

Figure 5: Spatial distribution in the long-run



Source: Own computation.

How does this affect the validity of the inferred results? A plausible hypothesis is that the relevance of transport costs decreases with the rising degree of product refinement. If the share of highly refined products is in addition higher in the product mix of smaller dairies then these gain a cost advantage relative to the results presented. This gain will be larger the higher the assumed increase in transport costs. The optimal average dairy size would then be smaller compared to the results presented. If, however, highly refined products are predominantly included in the mix of large dairies then their competitiveness increases compared to the results above, in particular in the case of a relative increase of transport costs. But the depicted trends are robust to changes in this parameter as a sensitivity analysis by use of modified processing cost functions has shown.

Similarly, we test the plausibility of the assumption of constant regional dairy farm output. If the milk density in a region increases, *ceteris paribus*, because, for instance, of a liberalization of the dairy quota trading scheme, then the average dairy size will increase in this region. In the opposite case of reduced regional milk density, smaller dairies will tend to become more efficient (regarding the consequences of changing regional milk densities see in particular Weindlmaier, 2001, 2004a,b).

Furthermore, we have assumed a uniform producer price to dairy farmers. If, however, e.g., larger dairies have to pay higher payout prices to minimize their risk of expensive, idle capacities then this would *ceteris paribus* lead to a deterioration of their cost situation relative to other dairy sizes and thus to a likely decrease in the optimal average dairy size. In the case that smaller dairies have a worse bargaining position and thus pay higher payout prices then the structural change towards fewer but larger dairy plants would be accelerated.

Previous, rather qualitatively-oriented studies on the structural change of the dairy industry are based on similar plausibility considerations, see, e.g., Weindlmaier (2001, 2004a,b); Hülsemeyer (1991, 1994); Nickel (1991). When transport costs rise moderately, these studies also predict a simultaneous reduction in the number of dairies and an increase in average capacity. In this regard, this paper can be seen as complementary to those more qualitative studies.

Finally, the diseconomies in transport might be offset by potential economies of scale. For instance, larger dairies are able to choose better collection routes for their tankers as their contracted dairy farms are located more fully area-covering and less fragmented than those of smaller dairies. By virtue of the sector-wide approach, such fragmented collection areas cannot emerge in our analysis so that, in the solutions generated, the partitioning of areas is already optimal and such economies of scale are already exploited. Choosing a two-day cycle for the collection interval is another potential way to save milk collection costs (compare, e.g., Weindlmaier, 2001). Also this optimization option is already exploited in our model.

5 Summary and Future Research Directions

Given the current situation, which structural path can we expect for the German dairy sector? How many dairies will remain in operation, do different trends emerge for different dairy sizes, and how sensitive are the results to the evolution of the transport and processing costs relationship? The preceding sections attempt to answer these questions by analyzing a simulation of a capacitated facilitation location problem which is based on representative data for regional dairy farm production in Germany as well as cost and capacity data for dairies.

Using this model and respecting its side constraints, we generate optimal structures for the dairy sector under three scenarios. The benchmark scenario assumes that all dairy plants remain in operation, all with identical capacity utilization. Here, the only potential for optimization is the minimization of transport costs through the allocation of regional dairy farm output to dairies. In the short-run scenario dairy plants can close down and remaining dairies can adjust their individual capacity utilizations to improve efficiency. The long-run scenario additionally allows dairies to adjust their individual capacities. All scenarios disregard the possibility of greenfield investments.

In comparison to the benchmark scenario, which is characterized by excess capacity and high transport costs, in the short-run scenario, excess capacity is reduced by the closure of dairy plants and also transport mileage is considerably reduced through higher utilization of dairies centrally located close to high-output dairy farming areas. The model results match the empirical trend towards concentration, i.e. fewer dairy plants together with increased average dairy size, as observed over the last years. The results vary depending on what shift of relative weight between transport and processing costs is expected. When transport costs are increased sufficiently, the depicted trend towards concentration can slow down and terminate at an earlier stage. In particular, the number of small dairies is positively correlated with the assumed transport cost level. The results for the long-run are qualitatively similar but the number of closures is even higher. Here, the average dairy capacity does not only increase due to closures of formerly small dairies but also due to the expansions of individual dairies' capacity. Analogous to the short-run, with increasing transport costs a trend towards plant sizes in the range of medium capacities emerges.

Moreover, the short- and long-run optima are characterized by a convergence of average costs per ton between the dairies. In the short-run the convergence is substantial, in the long-run almost complete. The remaining differences can be attributed to the assumptions concerning the immobility of production factors and barriers to entry (no greenfield investments). These restrictions gain importance with increasing transport costs and result in the greater variability of average costs between individual dairies. Structural change ends before individual average costs have completely converged because of the fixed spatial structures.

The cause of the observed structural change lies in differences in individual average costs. In the short-run and at current transport costs, large dairies have competitive advantages over small and medium dairies. Hence, small dairies in particular need to avoid pure price competition through soft factors (e.g. special customer or supplier relations) or the production of special products (e.g. specialties or regional marketing strategies). On the other hand, small and medium dairies can gain a relative advantage when the importance of transport costs relative to other cost types increases because, for instance, of a direct increase in transport costs or cost-decreasing technical progress in milk processing. In the long-run, not even competitive advantages based on economies of scale in processing are sustainable so that geographic location relative to dairy farming areas remains as the sole decisive competition factor.

The explanatory power of the model could be increased through the availability of better data, e.g., data on product mix and cost functions for individual dairies. Moreover, several premises of the model could be replaced by more realistic assumptions. For example, the assumptions of shortest distances (beelines) between dairies or that of a single road type, also implying identical daily mileage limit independent of road types. Despite these simplifying assumptions, we are convinced that the results presented allow a good approximation of the future evolution of the German dairy sector.

An interesting extension of the model would be the inclusion of external effects in transport and dairy processing. But this model could also be applied to other sectors in which a simultaneous trade-off between different cost types and spatial separation between primary production and processing exists. This includes, in particular, many areas of the agricultural sector.

References

Aarts, E., H. B. and Stemne, S. (1997). Melkrijzenonderzoek, *Wageningen University, Netherlands*.

Beasley, D., D. B. and Martin, R. (1993). An overview of genetic algorithms: Part 1, fundamentals, *University Computing* **15**(2): 58–69.

Butler, M., P. H. and Keenan, P. (2005). Integrating information technology and operational research in the management of milk collection, *Journal of Food Engineering*. In press.

Caraveli, H. and Traill, W. B. (1998). Technological developments and economies of scale in the dairy industry, *Agribusiness* **14**(4): 311–319.

Cormen, T. H., Stein, C., Rivest, R. L. and Leiserson, C. E. (2001). *Introduction to Algorithms*, The MIT Press, 2nd Ed.

Dalton, T. J., Criner, G. K. and Halloran, J. (2002). Fluid milk processing costs: Current state and comparisons, *Dairy Science* **85**(4): 984–991.

Deutsche Milchindustrie (2005). Beschaffung und Distribution in der Molkereiwirtschaft, *Milch and Markt, Presse Online*. Accessed online `http://www.milch-markt.de/de/milch/logistik1/beschaffung_distribution.html`, 8 November 2005.

Deutscher Bauernverband (2004). *Situationsbericht 2005. Trends und Fakten zur Landwirtschaft*.

Domschke, W. and Drexl, A. (2005). *Einführung in Operations Research*, Springer, Berlin, 6th Edition.

Drescher, K. and Maurer, O. (1999). Competitiveness in the European dairy industries, *Agribusiness* **15**(2): 163–177.

Glover, F. (1989). Tabu Search - Part I, *ORSA Journal on Computing* **1**: 190–206.

Glover, F. (1990). Tabu Search - Part II, *ORSA Journal on Computing* **2**: 4–32.

Günther, H.-O. and Tempelmeier, H. (2005). *Produktion und Logistik*, Springer, Berlin, 6th Edition.

Grünert, T. (2001). *Lagrangean Tabu Search, In: Ribeiro, C. and P. Hansen (Eds.): Essays and Surveys in Metaheuristics.*, Kluwer Academic Publishers, Boston, pp. 21–39.

Görtz, S. and Klose, A. (2004). *Das kapazitierte Standortproblem: Branch–and–Price und die Wahl der Verzweigungsvariable*, Arbeitsbericht der Bergischen Universität Wuppertal and der Universität Zürich.

Hülsemeyer, F. (1991). Die Milch– und Molkereiwirtschaft in Deutschland – Perspektiven und Anpassungserfordernisse, *DLG* **2**: 19–35.

Hülsemeyer, F. (1994). Deutsche Molkereiwirtschaft im strukturellen Wandel, *Die Molkereizeitung, Welt der Milch* **13**: 496–497.

Höper, U., Jürgensen, M., Hargens, R., Groß, K.-U. and Hülsemeyer, F. (2000). *Unternehmensgrössenabhängige ökonomische und ökologische Auswirkungen bei Erfassung, Be- und Verarbeitung und Distribution von Milch und Milchprodukten,* In: Regionale Vermarktungssysteme in der Land-, Forst- and Ernährungswirtschaft. Chancen, Probleme und Bewertung, Dachverband Agrarforschung, Schriftenreihe agrarspektrum, Band 30, DLG-Verlag, Frankfurt am Main: 115-129.

Irish Farmers Journal (1997). Craig Gardiner milk price audit.

Janz, C. U. (2002). *Unternehmenszusammenschlüsse in der Milch- und Zuckerindustrie unter wettbewerbsrechtlichen und ökonomischen Gesichtspunkten*, PhD thesis, Fakultät für Agrarwissenschaften der Georg-August-Universität Göttingen, Göttingen.

Keane, M. (1998a). Structural change and economies of scale and international competitiveness in dairying, *25th I.D.F. Congress in Aarhus, Denmark.*

Keane, M. (1998b). *Economies of Scale and Dairy Product Manufacturing Enterprises*, Agribusiness Discussion Paper No. 17, Department of Food Economics, University College, Cork, Ireland.

Klose, A. and Drexl, A. (2005). Facility location models for distribution system design, *European Journal of Operational Research* **162**(1): 4–29.

Michalewicz, Z. and Fogel, D. (2000). *How to Solve It: Modern Heuristics*, Springer-Verlag, Berlin.

Milchindustrieverband (2004). Geschäftsbericht des Milchindustrieverbands, 2003/04.

Nickel, O. (1991). *Die deutsche Milchbranche im EG–Binnenmarkt*, Behr's–Verlag, Hamburg.

Reeves, C. (2003). *Genetic Algorithms, In: F. Glover, and G. Kochenberger (Eds.), Handbook of Metaheuristics*, Kluwer Academic Publishers, Norwell.

Thiele, H. (2004). Zukünftige Strukturentwicklungen and Unternehmenszusammenschlüsse in der deutschen Molkereiwirtschaft, *Kieler Milchtage, Mini–Report.*

Weindlmaier, H. (2001). Strukturwandel in der deutschen Molkereiwirtschaft, *Deutsche Milchwirtschaft* **52**(2): 51–54.

Weindlmaier, H. (2002). Die Wertschöpfungskette Milch: Konzept, Optimierungsmöglichkeiten und Konfliktfelder, *dmz* **22**: 14–15.

Weindlmaier, H. (2004a). The consequences of changing conditions of the European dairy sector for the strategies of dairy companies, *Acta Agriculturae Slovenica* **84**(1): 63–80.

Weindlmaier, H. (2004b). Milchwirtschaft vor tiefgreifendem Strukturwandel, *Agrarwoche* **13**: 3–4.