Efficient Innovation in Dairy Production -

Empirical Findings for Germany

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Contributed Paper prepared for presentation at the 87th Annual Conference of the Agricultural Economics Society, University of Warwick, United Kingdom

8th – 10th April 2013

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Abstract

This empirical study aims to shed light on the dynamic linkages between innovation and efficiency at individual farm level. We use a comprehensive dataset for dairy farms in Germany for the period 1995 to 2010. Based on a directional distance function framework we estimate the changes in efficiency, technical change and productivity over the period considered. In a second step we then investigate possible factors for technically efficient milk production at farm level before we finally try to identify those farms that are capable of translating investments in innovative technologies into actual efficiency gains over time applying a multi-nomial logit approach. Our empirical findings reveal that investments in innovative dairy technologies are only reflected in higher profitability if sufficient Know-How for the efficient use of these innovations is available.

Key words: Innovation, Efficiency, Dairy Farming, Microeconometrics

JEL codes: Q12, D24, C23

1. Introduction

The German dairy sector remains under immense pressure with respect to a restructuring towards more efficient production units. The agreed abolishment of the EU milk production quotas in 2015 and the fundamental revision of the Common Agricultural Policy framework require an ongoing re-orientation of the milk production and processing industry. Further consolidation of the processing stage, more effective strategies for internationalisation of operations, reliable price forecasting tools, efficient milk procurement mechanisms as well as serious consideration of sustainable production, processing and distribution practices are the main challengies for the dairy industry in 2012 and beyond (see e.g. MIV 2011).

The primary stage of milk production in Germany has been still subject to profound structural change in the last years. In 2011 there were about 90,000 dairy farms with a growing number of cows per farmer and an increasing average milk production per cow (Statistisches Bundesamt 2011). Beside a diversification of the production focus at individual farm level, such increases in productivity and efficiency are essential in the short- to mid-term to sustainably compensate increasingly volatile farm gate milk prices. Subject to the degree of liquidity of the individual dairy farm, beside the optimisation of existing production capacities the aim should be to invest in new and innovative technologies (as e.g. barn and milking techniques) in order to secure a profitable and competitive milk production in the future.

This research contribution, hence, aims to shed empirical light on the dynamic linkages between investment and productivity/efficiency at the individual dairy farm level. We use a comprehensive dataset for dairy farms in Germany for the period 1995 to 2010. Based on a directional distance function framework we estimate the yearly changes in productivity and efficiency over the period considered. In a second step we then investigate possible factors for a technically efficient milk production at farm level before we finally try to identify those farms that are capable of translating investments in innovative technologies into actual efficiency gains over time. The next section briefly describes the current state of milk production in Germany and relevant recent research findings. This is followed by section 3 outlining the theoretical framework for the analysis whereas section 4 discusses the empirics of the study. Finally, section 5 presents and discusses the most important findings so far.

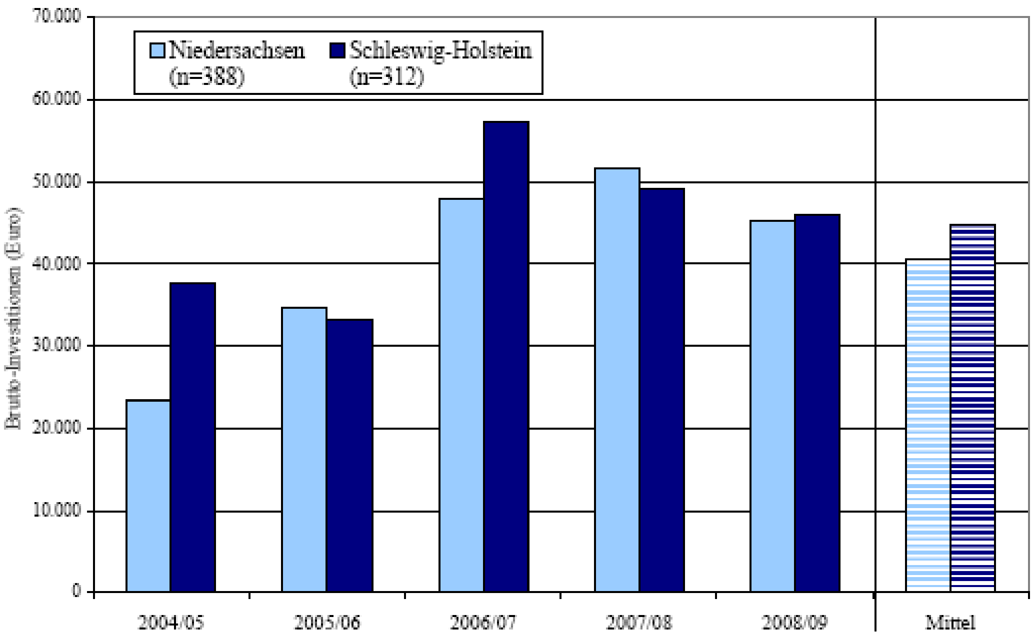
2. German Dairy Sector

The number of cows used for milk production in Germany has continually declined over the last 50 years. Whereas there were more than 5.5 Mio cows in 1980, in 2011 only about 4 Mio cows are used for production. Related is the constant decrease in the number of dairy farmers totalling to about 90,000 farmers in 2011 with a clear trend to bigger production units. The largest dairy farm operations are run in Eastern Germany where we find at average about 150 to 200 cows per farm. Consequently, the average productivity per cow has significantly increased in the last years with one cow producing at average about 7,000 kg raw milk per year (compared to an average of about 3,800 kg milk p.a.) In total about 29 Mio tonnes of milk have been produced on German dairy farms in the year 2011 (Statistisches Bundesamt 2011, Fahlbusch et al. 2011).

With respect to the milk processing industry in Germany the number of dairy processing operations has continually decreased as a consequence of mergers and acquisitions. A steady increase in the amount of milk processed is accompanied by a decline in the number of processing plants: Of about 3,400 milk processing plants in 1950 only about 165 were still in operation in 2011. The main factors for this profound consolidation in the dairy processing industry are the aspiration to increase the efficiency of operations and the use of more effective marketing tools on the one hand, but also significant investments in innovation as needed by an increasingly globalised and competitive market. This process will continue in the next decade (see MIV 2011).

The negative impacts for dairy farms' profits by an increasingly volatile farm gate milk price and as a consequence of diminishing policy support can be addressed by significantly diversifying the output structure but also by significantly increasing the productivity and efficiency of milk production. Such increases in productivity and efficiency are essential in the short- to mid-term to sustainably compensate increasingly volatile farm gate milk prices in Europe. Subject to the degree of liquidity of the individual dairy farm, beside the further optimisation of existing production capacities the aim should be to invest in new and innovative technologies (as e.g. barn and milking techniques) in order to secure a profitable and competitive milk production in the future (Lohmann und Hemme, 2009).

Graph 1: Annual Gross Investment by German Dairy Farms



Quelle: BMELV, Testbetriebe.

Graph 1 shows e.g. the yearly gross investment in milk production for farms located in the German regions Lower Saxony and Schleswig-Holstein for the years 2004 to 2009. It gets clear that the gross investment has been decreasing in the last years, however, they are still relatively high compared to the average investment rate for the last 6 to 7 years. Investments in milk production can relate to barn design, milking technology, or feeding systems etc. (see Sauer and

Zilberman 2012). Contrary to gross investment the measure of net investments considers non-cash depreciation. Hence, a farm's net investment gives a sense of how much money is spent on capital items (such as property, plants and equipment) which are used for operations and should ensure dynamic growth to sustain and increase the farm's long-term profit (see e.g. Elton et al. 2009). Net investment can thus be considered as a monetary proxy for innovation activity at the individual dairy farm level.

Only a few academic studies have been investigating the productivity and efficiency of milk production in Germany by empirical tools in the last years. Most recently Kellermann et al. (2011) estimated the relationship between technical efficiency and economic success (proxied by the rate of return on owned production factors) for a sample of dairy farms in Bavaria for the period 2000 to 2008. Using a simple rank correlation test procedure they find a strong link between the two measures as well as significant positive effects e.g. with respect to the level of farmer's education and full-time farming. Lassen et al. (2009) apply a variety of partial indicators to shed light on potential spatial variations in dairy production patterns over time. The authors conclude that no exact forecast can be made based on these methods. Methodologically more advanced studies are those by Abdulai and Tietje (2007) as well as Brümmer et al. (2002): Whereas the former use panel data frontier techniques to examine technical efficiency of individual dairy farms in northern Germany, Brümmer et al. (2002) apply a Shephard's type distance function approach to different European dairy sectors for the period 1991 to 1994. They find that the growth in total productivity for German dairy farms has been mainly driven by technical change.

3. Efficiency, Productivity and Innovation

Dairy farms can be considered as production units converting production inputs as e.g. milking cows, labor, energy, fodder etc. into the primary output milk but also other livestock related - more secondary - output(s). The process of "conversion" is described as milk production using a certain kind of production technology related e.g. to cow housing, feeding technology as well milking and cooling processes. The actually observed performance of this milk production is understood among economists as the productivity of a certain dairy operation at a particular point in time. A milk production function is used to formally analyse and quantify such productivity and an extensive literature exists on productivity measurement issues (see e.g. Coelli et al. 2005 or Morrison-Paul 1999).

A production function represents the maximum of milk output that can be produced given technological conditions and the dairy farmer's optimizing behaviour. Different production inputs are combined in differing proportions along this milk production function, hence, to measure such 'total factor productivity' a multivariate measure has to be used whereas the aggregation over different inputs and outputs appears to be a major methodological challenge (see e.g. Morrison-Paul 1999). Dairy farms that produce with a similar kind of technology but differ in their respective productivity, produce most likely with a differing efficiency. Differences in the efficiency of milk production are essentially a result of individual farm management characteristics but also of such related to the specific production environment. The efficiency of a dairy farm at a particular point in time is a combination of its technical, allocative and scale efficiency (see e.g. Kumbhakar and Knox-Lovell 2001).

To measure the efficiency of individual dairy operations we can make use of a single output type production function to map the technology and performance of the operation. However, avoiding the aggregation over different outputs (i.e. beside milk also other livestock and/or arable products) one could make use of the concept of a multi-input/-output type distance function to map dairy farms' technology and performance (see e.g. Faere and Grosskopf 2000). The set of all technologically feasible input-output combinations is given by the following production technology:

(1) $$T = \{(x, y): x \text{ can produce } y\}$$

where $x \in R_+^N$ is a vector of inputs and $y \in R_+^M$ is a vector of outputs.[1] Production efficiency can be measured using the formal concept of a directional distance function (Chambers et al., 1996; 1998).[2] It measures the distance from a particular observation to the efficient boundary of technology and its value depends on a mapping rule (or a directional vector) by which the direction is determined in which the inputs are to be contracted and the outputs are to be expanded. For a given direction $g = (g_x, g_y)$ with $g_x \in R_+^N$ and $g_y \in R_+^M$ the directional technology distance function (dtdf) is given by

(2) $$\vec{D}_T(x, y; g_x, g_y) = sup\{\varphi: (x - \varphi g_x, y + \varphi g_y) \in T\}$$

and takes values in the interval $[0, +\infty]$. The directional distance function equals zero for technically efficient observations and takes a positive value for inefficient observations.[3] For every observation k, k = 1, …, K

(3) $$\omega_k = \vec{D}_T(x, y; g_x, g_y) + \varepsilon_k$$

where $\omega_k \sim |N(0, \sigma_\omega^2)|$ is a nonnegative error component representing the distance function value and $\varepsilon_k \sim N(0, \sigma_\varepsilon^2)$ is a conventional two-sided disturbance term accounting for specification errors. The translation property of the dtdf allows for its empirical estimation (see Chambers et al 1998)

(4) $$\vec{D}_T(x_k - \lambda g_x, y_k + \lambda g_y; g_x, g_y) = \vec{D}_T(x_k, y_k; g_x, g_y) - \lambda$$

with $\lambda \in R$ as the additive analogue of the homogeneity property for the Shephard distance function (see e.g. Sauer 2010). This property implies that the translation of the input-output

[1] Following Chambers et al (1998, [8]) we assume that: (t1) T is closed; (t2) free disposability: if $(x, y) \in T, x' \geq x$, and $y' \leq y$ then $(x', y') \in$ T; (t3) no free lunch: if $(x, y) \in T$ and $x = 0$ then $y = 0$; (t4) possibility of inaction: $(0,0) \in T$; (t5) T is convex.

[2] The ddf represents a variation of the shortage function (Luenberger 1992, 1995) and is related to the Shephard type distance functions (Shephard 1970).

[3] The technology assumptions (t1) to (t5) imply the following properties of the dtdf: (d1) translation property: $\vec{D}_T(x_k - \lambda g_x, y_k + \lambda g_y; g_x, g_y) = \vec{D}_T(x_k, y_k; g_x, g_y) - \lambda \; for \; all \; \lambda \in R$; (d2) g-homogeneity of degree minus one: $\vec{D}_T(x_k, y_k; \alpha g_x, \alpha g_y) = \alpha^{-1} \vec{D}_T(x_k, y_k; g_x, g_y), \alpha > 0$; (d3) input monotonicity: $x' \geq x \rightarrow \vec{D}_T(x'_k, y_k; g_x, g_y) \geq \vec{D}_T(x_k, y_k; g_x, g_y)$; (d4) output monotonicity: $y' \geq y \rightarrow \vec{D}_T(x_k, y'_k; g_x, g_y) \leq \vec{D}_T(x_k, y_k; g_x, g_y)$; (d5) concavity: $\vec{D}_T(x_k, y_k; g_x, g_y)$ is concave in (x, y) .

vector from (x, y) to $\left(x - \lambda g_x, y + \lambda g_y\right)$ leads to a decrease in the distance function value by the scalar λ. Hence, by substituting (3) into (4) we obtain

(5) $$-\lambda = \vec{D}_T\left(x_k - \lambda g_x, y_k + \lambda g_y; g_x, g_y\right) - \omega_k + \varepsilon_k$$

Input and output oriented distance functions are special cases of the directional technology distance function (see Chambers et al 1998). The directional input distance function (didf) can be obtained by setting $q_y = 0^M$ which gives

(6) $$\vec{D}_I(x, y; g_x, 0^M) = sup\{\varphi: (x - \varphi g_x) \in L(y)\}$$

with $L(y) = \{x: (x, y) \in T\}$ denoting the input sets. The didf implies that the frontier of L(y) is approached by keeping output quantities fixed and by contracting inputs only.[4] As dairy production in Germany and Europe has been subject to quota regulations the assumption of cost minimizing production behaviour seems the most appropriate modelling choice in this context (see also Sauer 2010). The described didf is estimated in a frontier type specification outlined below to empirically measure the individual dairy farms' efficiency.

Changes in the level of a dairy farm's productivity are not only a result of improvements in efficiency but also due to process innovations e.g. with respect to housing, feeding and/or milking technology. Such technical innovations often involve an increase in milk production to reap economies of scale. Hence, process innovations lead to a non-parallel outward movement of the production frontier which means an expansion of the dairy farm's output level. Furthermore, such innovations can lead to a change in the relative input ratios and/or a change in the relative production level. The total effect equals the marginal change in total factor productivity by technical change through the adoption of innovative technologies (see e.g. Furtan and Sauer 2008).

The adoption of new technologies in primary production has been at the centre of agricultural economics for the last 50 years. The economic literature on technology adoption started with the seminal work by Griliches (1957) who viewed adoption as a process of imitation. An alternative approach, the threshold model of adoption, was introduced by Davis (1979). This approach is based on the assumptions of explicit micro level behaviour, heterogeneity among individual units and a dynamic process of individual learning leading to a gradual diffusion of technology adoption over time. Feder et al (1985) emphasized that the introduction of discrete choice modelling allows the identification of sources of such heterogeneity affecting the timing and extent of adoption. Another strand of early contributions to the literature (see e.g. the survey by Feder and Umali, 1993) makes use of expected utility modelling focusing on the identification of size effects, risk preferences and variations in human capital as potential factors for technology adoption choices. Later studies (Sunding and Zilberman, 2001) emphasized the importance of considering the timing of adoption, investment irreversibility and input quality improvements with respect to adoption choices. The study by Feder et al. (1985) suggested that technology adoption choices are part of packages of different changes including also the introduction of new inputs as well as the expansion of the scale of operations.

[4] Likewise, the directional output distance function is obtained by setting $q_x = 0^N$. Note, that the dtdf is dual to the profit function, whereas the didf and the dodf are dual to the cost and revenue functions, respectively (see Faere and Grosskopf 2000 for a more detailed discussion).

One stream of studies empirically investigates technology adoption and diffusion taking into account farmers' perceptions with respect to the risk of future yield (e.g. Yaron et al. 1992 or Kim an Chavas 2003) and conclude that technological progress significantly contributes to reducing the exposure to risk and downside risk over time. Different contributions point to the crucial importance of risk for production and technology decisions also at dairy farm level (see e.g. Gardebroek 2006, Schaper et al 2009). These studies find that the most important risks that dairy farmers perceive are various market risks followed by policy and production risks as e.g. animal diseases. As outlined above animal health related risk is especially relevant with respect to the adoption of a new milking technology. Survey results show that dairy farmers operate in a risk conscious but not risk averse way and selectively apply risk management strategies (Schaper et al 2009). Given the current changes in the overall EU dairy market regime, market related risk (i.e. price volatility related risk) can be expected to increase in the future (see Peerlings et al 2010, Gorton et al. 2012). Sauer and Zilberman (2012) finally simultaneously model the effects of risk, social interaction, past innovation experiences by considering also the sequential implementation structure of the adoption decision related to automatic milking systems (AMS). Their findings confirm previous studies according to which education based peer-group behaviour, technology density and a positive impact of previous innovation experiences have a significant positive effect on the innovation process at farm level. Using relevant peer-groups to spread adoption-related information can induce a faster technology diffusion.

4. Empirical Analysis

To empirically map the multi-input/-output production structure of a dairy farm we estimate a directional input distance function (didf) parameterized via a flexible quadratic functional form, a second-order Taylor series approximation which is linear in parameters and yet flexible enough to provide a good approximation of the true production technology.[5] We proxy technical change by a trend variable and non-neutral technical change by several trend interaction terms. Based on (5) and (6) above the parameterized didf takes the form

(7) $$\vec{D}_I(x, y; g_x, 0^M) = \sum_{i=1}^{N}\sum_{j=1}^{N}\alpha_{ij}x_i\,x_j + \sum_{k=1}^{M}\sum_{l=1}^{M}\beta_{kl}y_k\,y_l + \sum_{i=1}^{N}\sum_{k=1}^{M}\gamma_{ik}x_i\,y_k + \delta_{tt}tt + \sum_{i=1}^{N}\delta_{it}\,x_i t + \sum_{k=1}^{M}\delta_{kt}\,y_k t + \varepsilon$$

with $\theta = (\alpha, \beta, \gamma, \delta)$ as a vector of parameters to be estimated and ε is a random error assumed to be independently and identically distributed with mean zero and variance σ_ε^2. To obtain the didf specification we use the mapping rule: $(x - \lambda g_x, y)$, i.e. $(g_x, g_y) = (1{,}0)$ with $\lambda =$ number of cows. The input vector **x** includes cows, labor, fodder, land, veterinary expenses, intermediate expenses, and depreciation costs whereas the number of cows are used as the scalar following (5) above. The output vector **y** includes milk revenue, arable revenue, livestock related revenue, and other revenue. Further a time trend and other trend interaction terms are incorporated and all monetary values are deflated as is common practice.

[5] Färe et al. (2010) illustrate that the quadratic functional form has global approximation properties compared to the translog function when used in parametric directional distance function models.

To measure individual farms' efficiency we use a parametric stochastic frontier approach in a panel data specification applying the Battese and Coelli (1995) random effects estimator. The corresponding likelihood function and efficiency derivations are given in Coelli et al. (2005). The technical inefficiency effects part of ε, u_{it}, in (7) is specified as

(8) $$u_{it} = \boldsymbol{Z}_{it}\delta + w_{it}$$

with the following components of the vector $\boldsymbol{Z}_{it}$: yearly indicators, institutional characteristics, financial indicators, environmental characteristics, innovation proxies, location related as well as socioeconomic variables. Innovation in terms of technical change can be measured by different input or output oriented measures (see e.g. Rogers 1998). Process related investments in milk production can relate to barn design, milking technology, or feeding systems etc. (see Sauer and Zilberman 2012). A dairy farm's net investment gives a sense of how much money is spent on innovative capital items used for operations and ensuring dynamic growth to sustain and increase the farm's long-term profit (see e.g. Elton et al. 2009). Net investment can thus be considered as a monetary proxy for innovation activity at the individual dairy farm level. Hence, the relative efficiency effect of a dairy farm's innovation activity can be proxied by the estimate for the proxy net investment as an input oriented measure for innovation on dairy operations.

The level of technical efficiency and the rate of technical change per year is estimated for each dairy farm based on the distance frontier oultined above. In a next step the change in total factor productivity per farm is measured by using the Luenberger index formula as the directional distance function has an additive structure (Chambers et al 2000):[6]

(9) $$L(x^t, x^{t+1}, y^t, y^{t+1}) = \tfrac{1}{2}\big[\vec{D}_I^{t+1}(x^t, y^t; g_x, g_y) - \vec{D}_I^{t+1}(x^{t+1}, y^{t+1}; g_x, g_y) + \vec{D}_I^{t}(x^t, y^t; g_x, g_y) - \vec{D}_I^{t}(x^{t+1}, y^{t+1}; g_x, g_y)\big]$$

This productivity indicator compares period t and period t+1 with the first of the four distance functions in square parentheses representing an artificially constructed measure that assumes a t+1 period dairy technology, but t-period input and output quantities. Negative (positive) values of the indicator L(.) imply a decrease (increase) in productivity between the two periods. As we estimate an didf our productivity index is an input-based one (see Chambers et al. 1996).[7]

Having estimated the marginal effect of innovation in dairy technology on individual farm's technical efficiency we then aim to investigate the factors for a variation in this effect over different farms. Specifically we ask the questions: What are characteristics of those farms that are capable of translating innovative activity into marginal efficiency gains. Hence, we estimate a multinomial logit model in a random effects specification to more accurately describe those farms that can be labelled as 'efficient dairy innovators'.

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[6] The latter is the additive counterpert of the more well-known Malmquist productivity index defined in terms of ratios of values of the Shephard distance functionn and is multiplicative in natur.

[7] It is well known that the econometric estimation of distance functions is complicated by the fact that the function values are unobservable. Despite the exploitation of the homogeneity properties of e.g. the translog function still problems of endogeneity remain (see also Sauer and Morrison-Paul 2011). Faere and Grosskopf (2000) acknowledge that this transformation may induce correlation between the regressors and residuals but dismiss the resulting simultaneity problem as insignificant. Atkinson et al. (2003) use instrumental variable techniques to address this problem, whereas Guarda et al. (2011) estimate the model in a two-step procedure.

As we have longitudinal data where there are multiple observations for the same farm, unobserved heterogeneity is likely to be present. Hence, we specify a random effects multinomial logit model where the probability P_{ijt} of a farm being part of a certain class of innovators j is

$$(10) \quad P_{ijt} = \frac{\exp(\alpha_j + u_{ij} + X_{it}\beta_j)}{\sum_{k=1}^{J} \exp(\alpha_k + u_{ik} + X_{it}\beta_k)}, \quad j = 1,2,\ldots,n$$

where α_j represents the specific constant terms of the class of innovators, and X_{it} is a set of individual specific characteristics. If we assume that the individual specific random effects are the same in every period and are uncorrelated and independent across periods, then, conditional on unobserved factors u_{ij}, the observations from the ith farm are assumed to be independent (see e.g. Hartzel and Agresti 2001)[8].

We use an extensive panel data set for the German dairy sector for the years 1996 to 2010 with more than 40,000 observations for about 2,700 farms. Summary statistics can be obtained from the authors upon request and are not reported here because of space limitations. The data has been collected and prepared by Land Data and is based on verified financial accounts for a representative sample of German farms.

5. Results and Discussion

Efficiency, Technical Change and Total Factor Productivity

Table 1 summarizes the results for the change in efficiency, technical change and change in total factor productivity for the total period investigated (1996 to 2010) as well as per year. Whereas dairy farms have experienced a relatively high increase with respect to technical change (about 5.8% p.a.), the increase in technical efficiency appears as relatively modest (about 0.5% p.a.). Hence, the change in total factor productivity amounts to about 19% for the total period with an average increase of about 1.4% per year.

Table 1: Efficiency, Technical Change and Total Factor Productivity

	Productivity Change (Luenberger)	Efficiency Change	Technical Change
total period (1996-2010)	+ 19.211%	+ 6.791%	+ 81.724%
∅ annual	+ 1.372%	+ 0.485%	+ 5.837%

*10%, **5%, ***1% significance; estimates based on random effects directional input distance frontier and Luenberger index formula.

It is clear from these estimates that even small efficiency increases can lead to significant productivity shifts. Hence, the essential question is: How can dairy farms increase their (technical) efficiency more effectively? Therefore, we have investigated potential inefficiency drivers over these years.

[8] The multinomial logit model depends on the assumption of Independence of Irrelevant Alternatives (IIA) which holds conditionally on all covariates and random errors (see McFadden 1980). It has been also shown that the inclusion of random terms in the estimation model partially relaxes the IIA property.

Inefficiency Effects

The individual estimates for these inefficiency effects are summarized by table A1 in the appendix. These estimates suggest that the degree of specialization, running the dairy farm as a full-time business, the price level for land, and the level of education all contribute to an increased technical efficiency. We also found farms located in the North of Germany as producing most efficiently, followed by farms located in the West and those located in the East of Germany. In general, the estimates also confirmed the conjecture that innovative investments lead to significant efficiency gains. We found significant positive efficiency effects by the level of net investments in the same year as well as one year before.

Testing further whether the efficieny effect of innovative activities varies across space we found empirical evidence that dairy farms located in the West and North are able to gain higher efficiency increases as those located in other parts of Germany. These gains show to be sustainable lasting through the first two years of investments. Furthermore, the estimates revealed that the type and length of education of the farm manager has a significant influence on the efficiency effect of innovative activities. We found that the positive efficiency effect is significantly more pronounced for those managers who hold a master craftsman diploma ("Meister, Hoehere Landbauschule, Technikerausbildung or Fachakademie") or those who have a university level degree ("Ingenieurschule, Fachhochschule, Universität"). The latter are most effectively able to translate innovation into sustainable efficiency gains.

Efficient Innovators

Having empirically established the link between innovative activities (proxied by net investments) and the quality of human capital (proxied by the level of education) we now search for those type of farms and farmers that are most successfully apply innovative technologies to increase their dairy operations' efficiency. Table 2 shows the marginal effects of individual characteristics for different groups of innovative farmers based on the multi-nomial logit estimations.

Table 2: Groups of Efficient Innovators - Characteristics

characteristic	*coefficient*	*t-statistics*
***group II** – still in agricultural education (positive but not sustainable efficiency effect)*		
share of milk revenue	0.667**	1.991
age of farmer	-0.048***	-14.554
labor to capital ratio	-0.334***	-5.301
region north	0.999***	4.710
region west	0.636***	4.722
region south	0.107	0.744
region east	-1.821*	-1.793
organic production	-2.948	0.022
***group IV** – master craftsman diploma / Meister, HLS, Techniker, FA (positive and susainable efficiency effect)*		
share of milk revenue	0.585***	5.676
age of farmer	0.005***	4.148
labor to capital ratio	6.545e-04	0.429
region north	0.874***	11.188
region west	0.462***	10.391
region south	-0.208***	-4.154
region east	0.246**	1.967
organic production	-0.582***	-5.901
***group V** – university, applied university (positive and significantly susainable efficiency effect)*		

share of milk revenue	-1.316***	-5.375
age of farmer	-0.045***	-14.938
labor to capital ratio	-0.044	-1.465
region north	-0.327	0.058
region west	0.535***	4.992
region south	-0.224*	-1.933
region east	0.896***	3.691
organic production	0.849***	5.065

*10%, **5%, ***1% significance; estimates based on random effects multi-nomial logit model; group I and III showed no significant efficiency effect by innovation activities.

Our analysis identifies 3 groups/classes of dairy farmers for whom the investment in innovative technologies indeed results in marginal efficiency improvements. The first group of farmers (group II in table 2) consists of such that are still in training with respect to completing a first agricultural related education at various levels. For these farms the investment in innovative technologies results in a direct efficiency gain, however, this positive effect appears to be not sustainable. The second group of farmers are those that hold a master craftsman diploma (group IV in table 2). These farmers manage to translate innovative activities into sustainable efficiency improvements. Farms in this group are relatively large (up to 130 cows), are located in the North or West of Germany and are more likely to be specialized dairy producers. Farmers are of higher age and follow conventional dairy production. The third group of farmers (group V in table 2) consists of organic dairy producers but also less specialized farms led by younger managers with a very high level of education (mostly university level). Those farms are most likely located in the East or West of Germany.

The empirical results impressively highlight the following evidence: (i) The quality of human capital in terms of educational training is crucial for a lasting increase in efficiency as a result of innovation. (ii) Individual learning of how to efficiently use new technologies (i.e. learning-by-using and learning-by-doing) is crucially linked to the level of education. (iii) The analysis of education based peer-group behaviour might be essential to fully understand the links between knowledge, technology and efficiency. Effective learning by using new dairy technologies appears to be inherently linked to the educational based background and behaviour (see also Foster and Rosenzweig 1995).

6. Conclusions

The main conclusions resulting from this research are obvious: Sustainably higher profits from dairy production are possible by increasing the efficiency of operations through the investment in innovative technologies. Given ongoing structural challenges in the European milk sectors and highly volatile raw milk prices investment in education and technology seems to be the key for competitive and economically sustainable dairy production. Our empirical findings imply that investments in innovative dairy technologies are only reflected in higher profitability if sufficient Know-How for the efficient use of these innovations is available. Technology suppliers have to focus those efficient dairy innovators by providing complementary knowledge and support with respect to technology usage. Policy actors have to realize that investment in (higher) agricultural education is as crucial as supporting technology acquisition at farm level with respect to a successful structural change in the dairy sector. Finally, dairy farmers have to accept that investment in innovative technologies and investment in education are the keys for a profitable dairy production in the mid- and long-term future.

References

ABDULAI, A. AND H. TIETJE 2007. Estimating Technical Efficiency Under Unobserved Heterogeneity with Stochastic Frontier Models: Application to Northern German Dairy Farms. *European Review of Agricultural Economics* 34, 3: 393-416.

ATKINSON, S.E., R. FÄRE, D. PRIMONT 2003. Stochastic Estimation of Firm Inefficiency using Distance Functions. *Southern Economic Journal* 69: 596 – 611.

BATTESE AND COELLI 1995. A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics* 20, 2: 325 - 332.

BRUEMMER, B., T. GLAUBEN AND G. THIJSSEN 2002. Decomposition of Productivity Growth Using Distance Functions: The Case of Dairy Farms in Three European Countries. *American Journal of Agricultural Economics* 84, 3: 628 - 644.

CHAMBERS, R.G., Y. CHUNG, R. FAERE 1996. Benefit and Distance Functions. *Journal of Economic Theory* 70: 407 - 419.

CHAMBERS, R.G., Y. CHUNG, R. FÄRE 1998. Profit, Directional Distance Functions and Nerlovian Efficiency. *Journal of Optimization Theory and Application* 98, 2: 351 - 364

COELLI, T., BATTESE, G. AND T. RAO 2005. *An Introduction to Efficiency and Productivity Analysis*. Springer.

DAVIS, S.W. 1979. Interfirm Diffusion of Process Innovations. *European Economic Review* 12: 299 - 317.

ELTON, E.J., M.J. GRUBER, AND S.J. BROWN (2009). *Modern Portfolio Theory and Investment Analysis*. Wiley.

FAHLBUSCH, M., N. STEFFEN, B. BRUEMMER, AND A. SPILLER 2011. Der Markt fuer Milch und Milcherzeugnisse. *German Journal of Agricultural Economics* 60: 52 – 71.

FÄRE, R. AND S. GROSSKOPF 2000. Theory and Application of Directional Distance Functions. *Journal of Productivity Analysis* 13: 93 - 103.

FÄRE, R., C. MARTINS-FILHO, M. VERDANYAN 2010. On Functional Form Representation of Multi-Output Production Technologies. *Journal of Productivity Analysis* 33: 81 – 96.

FEDER, G. AND UMALI, D.L. 1993. The Adoption of Agricultural Innovations: A Review. *Technological Forecasting and Social Change* 43: 215-239.

FEDER, G., JUST, R.E., AND ZILBERMAN, D. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change* 33: 255-298.

FOSTER, A. AND ROSENZWEIG, M. 1995. Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture. *Journal of Political Economy* 103: 1176-1209.

FURTAN, H. AND J. SAUER 2008. Determinants of Food Industry Performance - Empirical Evidence for Denmark. *Journal of Agricultural Economics* 59: 555 - 573.

GARDEBROEK, C. 2006. Comparing Risk Attitudes of Organic and Non-organic Farmers with a Bayesian Random Coefficient Model. *European Review of Agricultural Economics* 33: 485 – 510.

GORTON, M., SAUER, J., WHITE, J. 2012. Marketing, Cooperatives and Price Heterogeneity: Evidence from the CIS Dairy Sector. *Agricultural Economics* 43, 2.

GRILICHES, Z. 1957. Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrics* 25: 501 - 523.

GUARDA, P., A. ROUABAH, M. VERDANYAN 2011. A Directional Distance Function Approach to Identifying Bank Output. *Unpublished Manuscript*.

HARTZEL J, AND A., AGRESTI 2011. Multinomial logit random effects models. *Statistical Modelling* 1, 2: 81 – 102.

KELLERMAN, M., K. SALHOFER, W. WINTZER AND C. STOCKINGER 2011. The Relationship between Technical Efficiency and Economic Success: The Case of Bavarian Dairy Farms. *German Journal of Agricultural Economics* 60, 4: 230 - 242.

KIM, K. AND CHAVAS, J.-P. 2003. Technological Change and Risk Management: An Application to the Economics of Corn Production. *Agricultural Economics* 29: 125 - 142.

KUMBHAKAR, S. AND C.A., KNOX LOVELL 2003. *Stochastic Frontier Analysis*. Cambridge University Press.

LASSEN, B.J., F. ISERMEYER AND C. FRIEDRICH 2009. Regional Changes in German Dairy Production. *German Journal of Agricultural Economics*, 58, 5/6: 238-247.

LATACZ-LOHMANN, U. AND T. HEMME 2009. Milcherzeugung nach der Quote. *Unpublished Manuscript*. Kiel.

MCFADDEN D. 1980. Qualitative response models. In: Hildenbrand W, editor. *Advances in Econometrics*. Cambridge, UK: Cambridge University Press, pp. 1 – 37.

MIV 2011. *Milch und Mehr - Die Deutsche Milchwirtschaft auf einen Blick*. Berlin.

MORRISON-PAUL, C. 1999. *Performance: Productivity, Utilization, Cost Economies, and Related Performance Indicators*. Kluwer.

PEERLINGS, J., POLMAN, N., AND KROL, N. 2010. *Structural Change in the EU Dairy Sector*, Paper Presented at the 114th EAAE Seminar, Berlin/Germany.

ROGERS, E.M. 1983. *Diffusion of Innovations*, New York: Free Press.

SAUER, J. 2010. Deregulation and Dairy Production Systems - A Bayesian Distance Function Approach. *Journal of Productivity Analysis* 34, 3.

SAUER, J. AND D. ZILBERMAN 2012. Sequential Technology Implementation, Network Externalities and Risk: The Case of Automatic Milking Systems. *Agricultural Economics* 43, 3.

SCHAPER, C., LASSEN, B., AND THEUVSEN, L. 2009. *Risk Management in Milk Production: A Study in Five European Countries*, Paper Presented at the 113th EAAE Seminar, Chania/Greece.

STATISTISCHES BUNDESAMT 2011. Genesis-Online Datenbank. Wiesbaden.

SUNDING, D. AND ZILBERMAN, D. 2001. The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector, in: *Handbook of Agricultural Economics*. Eds. Gardner, B.L., and Rausser, G. New York: Elsevier.

YARON, D., DINAR, A., AND VOET, D. 1992. Innovations on Family Farms: The Nazareth Region in Israel. *American Journal of Agricultural Economics* 74: 361 - 370.

Appendix

Table A1: Determinants of Inefficiency

determinant	*coefficient*	*t-statistics*
share of milk revenue	-2.165***	-51.534
debt	5.463e-09***	2.333
full-time business	-0.415***	-7.816
organic production	-0.035	-0.081
altitude 2 (300-600m nn)	0.755***	-30.241
altitude 3 (>600m nn)	0.292***	-8.097
pasture days	0.097	0.951
region - south (BW, BY)	0.187***	8.078
region - west (NW, H, RP, SL)	0.137***	8.798
region - east (BE, BB, MV, SA, S, TH)	0.0936**	2.532
age of farmer	5.791e-05*	1.832
price of land	-8.263e-04***	-35.376
education farmer 1 (in education)	-0.275***	-5.060
education farmer 2 (skilled worker - Facharbeiter)	-0.103***	-6.652
education farmer 3 (master craftsman diploma - Meister, HLS, Techniker, FA)	-0.0916***	-5.181
education farmer 4 (university, applied university - IngSchule, FH, Universität)	-0.056***	-5.282
net investment	-2.142e-06***	-16.732
net investment (year-1)	-6.944e-07***	-4.140
net investment (year-2)	-8.159e-08	-0.808
net investment * region south	2.193e-06***	24.376
net investment * region west	-1.560e-06***	-17.240
net investment * region east	6.241e-06***	9.887
net investment (year-1) * region south	1.009-e-06***	5.331
net investment (year-1) * region west	-6.358e-07***	-3.224
net investment (year -1) * region east	7.416e-07***	13.661
net investment * education 1	-1.621e-05***	-11.869
net investment * education 2	6.417e-07***	5.134
net investment * education 3	-4.429e-07***	-3.787
net investment * education 4	-2.689e-06***	-4.736
1996	0.167***	8.691
1997	-0.893***	-40.813
1998	-1.212***	-46.776
1999	-1.538***	-57.207
2000	-1.943***	-60.103
2001	-1.216***	-28.419
2002	-1.841***	-36.398
2003	-1.980***	-60.165
2004	-2.299***	-43.359
2005	-2.537***	-40.962
2006	-3.577***	-38.205
2007	-1.669***	-33.119
2008	-1.961***	-34.536
2009	-1.697***	-32.214
_cons	-2.602***	-28.950

*10%, **5%, ***1% significance; estimates based on random effects directional input distance frontier.