Catching up or falling behind in Eastern European agriculture – the case of milk production

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Paper prepared for presentation for the 142nd EAAE Seminar
Growing Success? Agriculture and rural development in an enlarged EU

May 29-30, 2014
Corvinus University of Budapest
Budapest, Hungary

Abstract:

The paper deals with the analysis of catching up and falling behind processes in European agricultural sector using a stochastic frontier multiple output distance function for 24 EU Member States in the period 2004 – 2011. The metafrontier estimates reveal that there are considerable productivity differences in milk production across the EU at the NUTS 2 level. Productivity is the highest in the Old Member States, especially in those regions located in the Northwest of the EU. The lowest productivity is observed in Eastern Europe. The same structure as for TFP was found for TFP development. Moreover, the results for technical change suggest that farm sizes are not optimal in many regions in Central and Eastern Europe from a dynamic perspective. The comparative analysis suggest that in the New compared to the Old Member States fewer farms could benefit from the movement on the frontier. Moreover, there are no signs that poor performing farms are catching up to the best performing farms in the regions/countries.

Key words: *Productivity, efficiency, New Member States, metafrontier analysis, SFA.*

JEL Classification: *D 24, O 12, P 27*

1 INTRODUCTION

The recent accession of the New Member States (NMS) to the European Union (EU) has been a mammoth task, accompanied by many side distortions for themselves as well as for the old member states. Nevertheless, the economic theory of integration suggests that deeper integration among new and old member states would net-benefit mutually their domestic economies. Steps taken towards a deeper integration have been the abolishment of border controls, the creation of common, congruent policies regarding competition, state aid, and food safety and environmental standards as well as regulations, and the establishment of an integrated capital market. These policy actions tried to set the foundations for prosperity via enhancing cross-border activities.

One of the main challenges of the integration process has been hitherto the adoption of the CAP for the NMS. A successful introduction of the CAP is of high significance to the entire integration process, since it has been the EU’s main financial reallocation channel of the past six decades and the economies of the NMS have been orientated largely towards the primary sector.

Several attempts to study these effects have already been carried out (Bakucs et al. 2010, Csáki and Jámbor 2010 and 2013). However, the researchers predominantly focused on one or a related group of countries (Latruffe et al. 2012a and b, Cechrua 2012). Moreover, if the comparison was done among countries, it was usually based on country specific model estimates which do not provide conclusive results or can be misleading respectively.

In this paper we will concentrate on the agricultural sector, in particularly on the milk production, and investigate whether the integration processes have had the benefits mentioned above. We will measure the benefits in terms of TFP development and the impact of technical change in agriculture. In particular, we will address the following research questions:

- How has regional agriculture benefited from the adoption of innovations? Is there an indication that regional scarcity of resources was the source of technical progress?
- Is there an indication that technical change (and other sources of adjustment) have led to a convergence of the regions in terms of TFP?

- What are the causes of the regional convergence or divergence? How did farm structure, market structure, and credit constraints affect the adoption of innovations?
- Given the significant duality of farm structures in some countries can the same patterns for large agricultural companies and small farmers be observed or can we identify idiosyncratic developments?

The structure of the paper is as follows. Chapter 2 contains the theoretical framework and presents the estimation strategy. Chapter 3 describes the data set. Chapter 4 presents descriptive analysis of dairy production. Chapter 5 contains estimation results, compares and discusses the estimated technology, technological change, trends in technical efficiency and TFP developments, and provides the results of the metafrontier analysis. Chapter 6 contains a discussion of the results and concluding remarks, including policy recommendations.

2 THEORETICAL FRAMEWORK AND ESTIMATION STRATEGY

The theoretical background is given by neoclassical production economics, especially productivity and efficiency analysis (Fried et al., 2008). The research questions will be dealt with (1) estimation of country specific multiple output distance function for farms specializing on milk production using the FADN database. (2) Based on the estimated parameters the efficient output level will be calculated. These will be used in a metafrontier approach to determine the TFP level and development.

In order to produce coherent results, all models (the country specific models in (1) as well as the metaproduction models in (2)) will make use of the same procedure: The models are formulated as output distance functions with three outputs and five inputs. In all models it is considered explicitly that agricultural production possibilities are affected by firm heterogeneity, which affects the level as well as on the shape of the production possibilities.

2.1 Multiple output distance function

We assume that production possibilities can be well approximated by the output distance function introduced by Shephard (1970):

$$D_O(\boldsymbol{x},\boldsymbol{y}) = min\left\{\theta : (\frac{y}{\theta}) \in P(\boldsymbol{x})\right\}, \tag{1}$$

where $\boldsymbol{y}$ stands for the output vector, $\boldsymbol{y} \in R_+^M$, and $\boldsymbol{x}$ denotes the input vector, $\boldsymbol{x} \in R_+^K$, $P(\boldsymbol{x})$ represents the output set, such as:

$$P(\boldsymbol{x}) = \{\boldsymbol{y} \in R_+^M : \boldsymbol{x}\ can\ produce\ \boldsymbol{y}\}. \tag{2}$$

As provided by Coelli et al. (2005), $D_O(\boldsymbol{x},\boldsymbol{y})$ exhibits the following properties. It is non-decreasing, positively linearly homogenous and convex in $\boldsymbol{y}$, and decreasing and convex in $\boldsymbol{x}$. Moreover, it holds that $D_O(\boldsymbol{x},\boldsymbol{y}) \leq 1$ if $\boldsymbol{y} \in P(\boldsymbol{x})$ and $D_O(\boldsymbol{x},\boldsymbol{y}) = 1$ if $\boldsymbol{y} \in Isoq\ P(\boldsymbol{x})$.

In our application we use a translog functional form, since it is flexible and provides a good approximation of the production process. In addition, it permits the imposition of homogeneity (Coelli and Perelman, 1996). The translog output distance function for 3 outputs and 5 inputs, as it is the case in our empirical application, is:

$$\begin{aligned} D_{Oit} = {} & \alpha_0 + \sum_{m=1}^{3} \alpha_m ln\, y_{mit} + \frac{1}{2}\sum_{m=1}^{3}\sum_{n=1}^{3} \alpha_{mn} lny_{mit} lny_{nit} + \sum_{k=1}^{5} \beta_k ln\, x_{kit} + \\ & + \frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5} \beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{n=1}^{3} \gamma_{km} lnx_{kit} lny_{mit} \end{aligned} \tag{3}$$

where subscripts i, with i=1,2,…,N, and t, with t =1,…,T, refer to a certain producer and time (year), respectively. $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, and $\boldsymbol{\gamma}$ are vectors of parameters to be estimated.

Output distance function is homogenous of degree 1 in outputs. This requires:

$$\begin{aligned}&\textstyle\sum_{m=1}^{3}\alpha_m = 1,\\ &\textstyle\sum_{n=1}^{3}\alpha_{mn} = 0, \text{ for } m = 1,\dots,3, \text{ and} \qquad (4)\\ &\textstyle\sum_{m=1}^{3}\gamma_{km} = 0, \text{ for } k = 1,\dots,5.\end{aligned}$$

Symmetry restrictions are as follows:

$$\alpha_{mn} = \alpha_{nm}, \text{ and } \beta_{kl} = \beta_{kl}. \qquad (5)$$

Following Lovell at al. (1994) the homogeneity is imposed by choosing one output and dividing the other outputs by it. Thus, we get:

$$\begin{aligned}lnD_{Oit} - lny_{1it} = \quad & \alpha_0 + \textstyle\sum_{m=2}^{3}\alpha_m ln\, y_{mit}^{*} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3}\alpha_{mn} lny_{mit}^{*} lny_{nit}^{*} + \sum_{k=1}^{5}\beta_k ln\, x_{kit}\\ & + \tfrac{1}{2}\textstyle\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3}\gamma_{km} lnx_{kit} lny_{mit}^{*}\end{aligned} \qquad (6)$$

where $y_{mit}^{*} = \frac{y_{mit}}{y_{1it}}$.

If we introduce statistical noise, v_{it}, and associate $-lnD_{Oit}$ with inefficiency term, $u_{it} = -lnD_{Oit}$, we get a stochastic frontier multiple output distance function:

$$\begin{aligned}-lny_{1it} = \quad & \alpha_0 + \textstyle\sum_{m=2}^{3}\alpha_m ln\, y_{mit}^{*} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3}\alpha_{mn} lny_{mit}^{*} lny_{nit}^{*} + \sum_{k=1}^{5}\beta_k ln\, x_{kit}\\ & + \tfrac{1}{2}\textstyle\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3}\gamma_{km} lnx_{kit} lny_{mit}^{*} + u_{it} + v_{it}\end{aligned}, \qquad (7)$$

where we assume that $v_{it} \sim N(0,\sigma_v^2)$, $u_{it} \sim \mathrm{N}^{+}(0,\sigma_s^2)$, and they are distributed independently of each other and of the regressors (Kumbhakar and Lovell, 2000).

Productivity finds its expression in the shape of (7), and thus in the parameter vectors ($\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$). Since the coefficients depend on the quality of the individual inputs and input quality is determined by the embedded knowledge, i.e. human capital for labour, technological knowledge for capital, and embedded innovation in materials (Barro and Sala-I-Martin, 1995), technology improves over time due to technological progress and learning by doing. This will not only induce shifts in the output distance function but will also affect the productivity of individual inputs. Moreover, it can be assumed that the various improvements in quality have rather different direct and indirect effects on the individual inputs. However, due to limitations in data availability, the impacts of the various improvements cannot be estimated separately. Instead, it is commonly assumed that a trend variable (t) can be incorporated which captures the joint effects in input quality improvements. Proceeding this way, the resulting function is:

$$\begin{aligned}-lny_{1it} = \quad & \alpha_0 + \textstyle\sum_{m=2}^{3}\alpha_m ln\, y_{mit}^{*} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3}\alpha_{mn} lny_{mit}^{*} lny_{nit}^{*} + \sum_{k=1}^{5}\beta_k ln\, x_{kit}\\ & + \tfrac{1}{2}\textstyle\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3}\gamma_{km} lnx_{kit} lny_{mit}^{*}\\ & + \delta_t t + \tfrac{1}{2}\delta_{tt} t^2 + \textstyle\sum_{m=2}^{3}\alpha_{mt} t lny_{mit}^{*} + \sum_{k}^{5}\beta_{kt} t ln\, x_{kit} + u_{it} + v_{it}\end{aligned} \qquad (8)$$

Here δ_t and δ_{tt} captures the global effect while the α_{mt} and β_{kt} measure the bias of technical change. Stochastic frontier output distance function in (8) will play a central role in our empirical application.

2.2 Heterogeneity in technology

Heterogeneity in technology is captured using a fixed management model. Álvarez et al. (2003 and 2004) specified the fixed management model as a special case of random parameters model in the following form. The technology is given by the consideration of a firm specific factor (m_i*) which enters the distance function in the same way as technical change (8):

$$\begin{aligned} -lny_{1it} = \quad & \alpha_0 + \sum_{m=2}^{3} \alpha_m ln\, y^*_{mit} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3} \alpha_{mn} lny^*_{mit} lny^*_{nit} + \sum_{k=1}^{5} \beta_k ln\, x_{kit} \\ & + \frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5} \beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3} \gamma_{km} lnx_{kit} lny^*_{mit} \\ & + \delta_t t + \frac{1}{2}\delta_{tt} t^2 + \sum_{m=2}^{3} \alpha_{mt} t lny^*_{mit} + \sum_{k}^{5} \beta_{kt} t ln\, x_{kit} \\ & + \alpha_{m*} m_i^* + \frac{1}{2}\alpha_{m*m*} m_i^{*2} + \delta_{tm*} m_i^* t + \sum_{k=1}^{5} \beta_{km*} m_i^*\, lnx_{kit} + u_{it} + v_{it} \end{aligned} \tag{9}$$

With m_i* the firm uses is productive capacities optimally. However, the realisation of the firm specific factor may be suboptimal (m_i). The difference between the real (m_i) and optimal level of m_i^* determines technical efficiency. Technical efficiency, TE_{it}, with $0 < TE_i < 1$, captures deviations from the maximum achievable output. Using the definition of the distance function in (9) provides:

$$\begin{aligned} lnTE_{it} \quad & = -\, u_{it} \\ & = lny_{1it|m} - lny_{1it|m*} \leq 0 \end{aligned} \tag{10}$$

Substituting (9) into (10) and rearranging terms provids:

$$\ln TE_{it} = \gamma_0 + \gamma_t t + \boldsymbol{\gamma}_{\mathbf{x}}{}' \ln \mathbf{x}_{it}\,, \tag{11}$$

where
$$\gamma_0 = \beta_m (m_i - m_i^*) + \frac{1}{2}\beta_{mm}\left(m_i^2 - m_i^{*2}\right)$$

$$\gamma_t = \beta_{tm}\left(m_i - m_i^*\right)$$

$$\boldsymbol{\gamma}_{\mathbf{x}} = \boldsymbol{\beta}_{xm}\left(m_i - m_i^*\right)$$

Thus, technical efficiency consists of three components:

(i) time invariant firm specific effect – pure heterogeneity– γ_0,

(ii) interaction of m^* with time – technological change – γ_t,

(iii) interaction of m^* with inputs– scale effect – γ_X.

The model (9) cannot be estimated by maximum likelihood since m_i* is not observable. Álvarez et al. (2004) propose a maximum simulated likelihood approach where m_i* is simulated by several draws for the standard normal distribution, e. g. $m_i^* \sim N(0,1)$.

The m_i* can be fitted according to (Álvarez et al. 2004):

$$\hat{E}\left[m_i^* \middle| \mathbf{y}_i, \mathbf{X}_i, \boldsymbol{\delta}\right] = \frac{\frac{1}{R}\sum_{r=1}^{R} m^*_{i,r}\, \hat{f}\left(\mathbf{y}_{1i} \middle| \mathbf{y}^*_{mit}, \mathbf{x}_{it}, t, m^*_{i,r}; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\frac{1}{R}\sum_{r=1}^{R} \hat{f}\left(\mathbf{y}_{1i} \middle| \mathbf{y}^*_{mit}, \mathbf{x}_{it}, t, m^*_{i}; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}, \tag{13}$$

where R denotes the number of repetitions $\hat{f}$ denotes the value of the right term in (9).

Moreover, once the m_i* are determined, the u_{it} can be estimated with Jondrow at al. (1982) formula:

$$E\left[u_{it}\left|\varepsilon_{it}, m_i^*\right.\right] = \frac{\sigma\lambda}{\left(1+\lambda^2\right)}\left[\frac{\phi\left(-\left(\varepsilon_{it}\left|m_i^*\right.\right)\lambda/\sigma\right)}{\Phi\left(-\left(\varepsilon_{it}\left|m_i^*\right.\right)\lambda/\sigma\right)} - \frac{\left(\varepsilon_{it}\left|m_i^*\right.\right)\lambda}{\sigma}\right], \tag{14}$$

where $\lambda = \frac{\sigma_u}{\sigma_v}$, $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\varepsilon_{it} = v_{it} + u_{it}$ and ϕ and Φ denote the density and distribution of the standard normal. The software NLOGIT 5.0 was used in the application.

2.3 TFP calculation and decomposition

Total factor productivity is calculated in the form of the Törnqvist-Theil index (TTI) (see, e.g. Čechura and Hockmann, 2010). The TTI exactly determines the changes in production resulting from input adjustments if a function has the translog form (for proof see Diewert, 1976). Furthermore, Caves et al. (1982) present a TTI extension for multilateral consistent comparisons.

The index is constructed as the deviation from the sample means. The input index for variable returns to scale (VRS), or constant returns to scale (CRS), respectively, is given by:

$$\ln \iota_{it}^{VRS} = \frac{1}{2}\sum_{j=1}^{K}\left[\left(\zeta_{it,j_0} + \bar{\zeta}_j\right)\left(\ln x_{it,j} - \overline{\ln x_j}\right) + \bar{\zeta}_j\,\overline{\ln x_j} - \overline{\zeta_{it,j_0}\ln x_{it,j}}\right],$$
$$\text{with} \quad \zeta_{it,j_0} = \frac{\partial \ln f\left(\mathbf{y}_{mit}^*, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\partial \ln \mathbf{x}_{it,j}} \tag{15}$$

resp.

$$\ln \iota_{it}^{CRS} = \frac{1}{2}\sum_{j=1}^{K}\left[\left(\frac{\zeta_{it,j_0}}{\sum_{i=1}^{K}\zeta_{it,j_0}} + \frac{\bar{\zeta}_j}{\sum_{i=1}^{K}\bar{\zeta}_{j_0}}\right)\left(\ln x_{it,j} - \overline{\ln x_j}\right) + \frac{\bar{\zeta}_j}{\sum_{i=1}^{K}\bar{\zeta}_{j_0}}\overline{\ln x_j} - \overline{\frac{\zeta_{it,j_0}}{\sum_{i=1}^{K}\zeta_{it,j_0}}\ln x_{it,j}}\right]. \tag{16}$$

A bar over a variable specifies the arithmetic mean over all observations. That is, the output index and the efficiency index are defined as:

$$\ln\psi_{it} = \ln y_{it} - \overline{\ln y_{it}} \quad \text{and} \quad \ln\upsilon_{it} = \ln TE_{it} - \overline{\ln TE_{it}}\;. \tag{17}$$

Since TFP is a combination of scale effect, technical efficiency, technological change and management effect, the required indices are defined as:

$$\ln\tau_{it} = \frac{1}{2}\left[\left(\zeta_t + \bar{\zeta}_t\right)\left(t - \bar{t}\right) + \bar{\zeta}_t\bar{t} - \overline{\zeta_t t}\right], \quad \textit{with} \quad \zeta_t = \frac{\partial \ln f\left(\mathbf{y}_{mit}^*, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\partial t}\;, \tag{18}$$

$$\ln\mu_{it} = \frac{1}{2}\left[\left(\zeta_{m_0} + \bar{\zeta}_m\right)\left(m_i - \bar{m}_i\right) + \bar{\zeta}_m\bar{m}_i - \overline{\zeta_m m_i}\right]$$
$$\textit{with} \quad \zeta_m = \frac{\partial \ln f\left(\mathbf{y}_{mit}^*, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\partial m_i}\;. \tag{19}$$

Using these definitions, TFP and its breakdown is given by:

$$\ln TFP_{it} = \ln\psi_{it} - \ln\iota_{it}^{CRS} = \underset{SE}{\ln\iota_{it}} + \underset{TE}{\ln\upsilon_{it}} + \underset{TCH}{\ln\tau_{it}} + \underset{MAN}{\ln\mu_{it}}, \quad \textit{with} \quad \ln\iota_{it} = \ln\iota_{it}^{VRS} - \ln\iota_{it}^{CRS}\;. \tag{20}$$

Changes in TFP can be expressed either as a ratio (on the mean) of the output and input index (for CRS) or as a multiplication of TFP components, i.e., scale effect (SE), technical efficiency effect (TE), technological change effect (TCH) and management effect (MAN).

2.4 Metafrontier analysis

The metafrontier analysis will be conducted using the same model specification as for the individual countries. We will calculate the efficient output based on the parameter estimates of country multiple output distance function and will use them in the estimation of stochastic metafrontier multiple output distance function. We use again 3 outputs and 5 inputs. Moreover, we will employ again the Fixed Management model to capture the heterogeneity. The estimated metadistance will allow a coherent comparison of TFP levels among the EU member countries.

3 DATA

The panel data set is drawn from the FADN database provided by the European Commission. The data set contains data on 24 EU member countries (Cyprus, Malta and Luxemburg were excluded) and covers the period from 2004 to 2011 except for Austria (2005 – 2011), Bulgaria and Rumania (2008 – 2011).

The analysis focuses on milk production and uses the following data: y_1 milk production, y_2 other animal production, y_3 plant production, x_1 labour, x_2 land, x_3 capital, x_4 specific material and x_5 other material. Labour is represented by the total labour measured in AWU. Land is the total utilised land. Capital is a sum of contract work and depreciation. Specific material creates cost on feed for grazing livestock. Outputs as well as inputs (except for labour and land) are deflated by country price indexes on each individual output and input (2005 = 100). The country price indexes are taken from the EUROSTAT database.

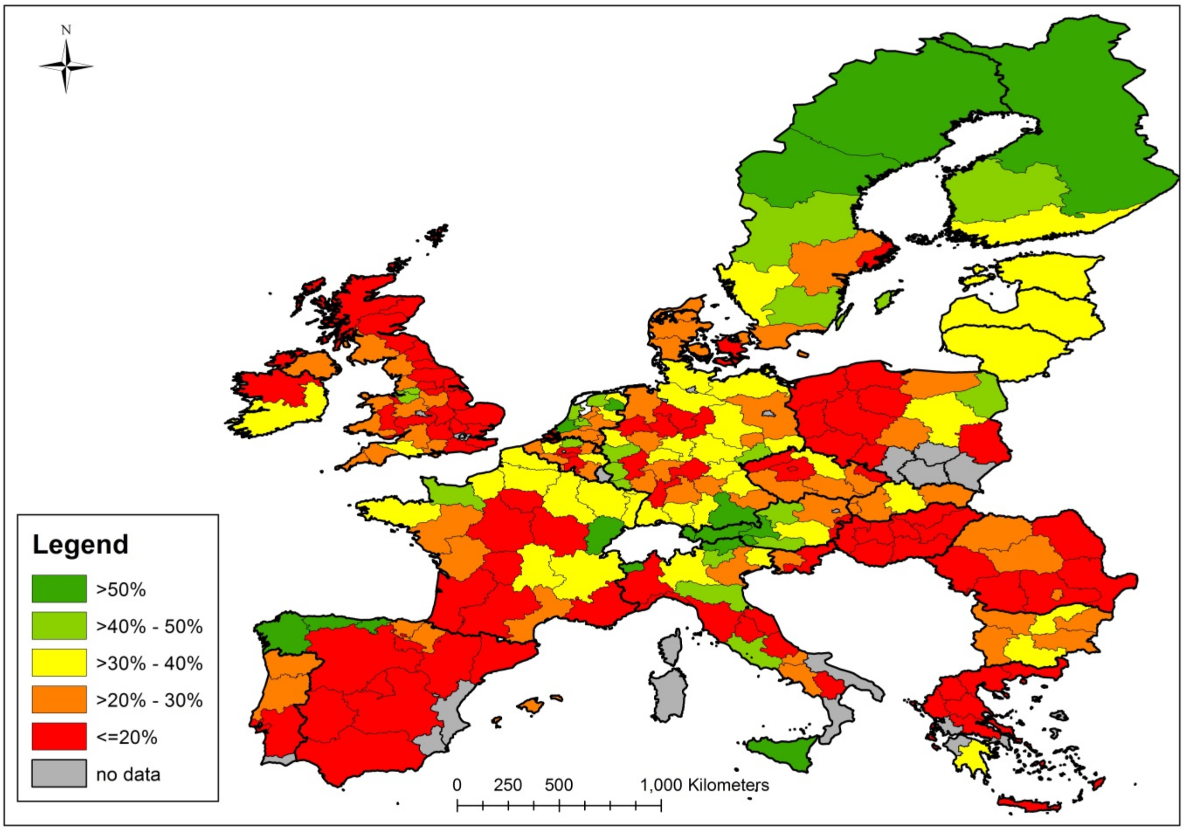
The multiple output distance function is estimated only for specialized producers. The specialization is defined as at least 50 % share milk production on total animal production.

Since not all information can be found in the database, only those producers having non-zero and positive values are used for the variable of interest. Moreover, we rejected producers with less than five observations to decrease the problem with entry and exit of the producers from the database. The country sample descriptive statistics are provided in the Appendix – Table A1.

4 DISTRIBUTION OF DAIRY PRODUCTION

Figure 1 provides information on the importance of milk production for agricultural holdings in form of its shares in total agricultural income. The highest share of milk production in total agricultural production is observed in the area ranging from the Scandinavian and Baltic countries to Northern France. Here milk production accounted for more than 30% of agricultural gross production. The regions in the South of Europe specialization towards milk production is less pronounced. The same holds for the new EU member states.

Figure 1: Share of dairy gross production in total agricultural gross production, NUTS2 level

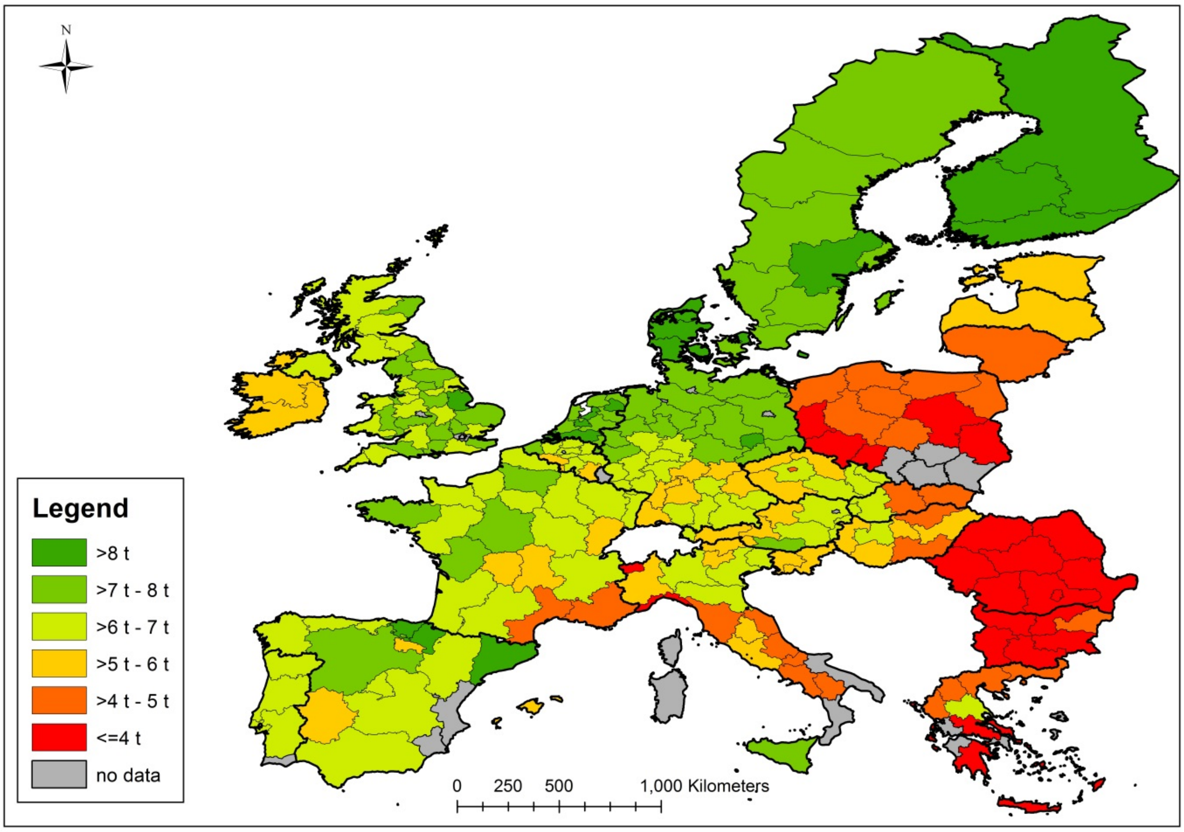


Source: own calculation

The specialisation is measured considering all farms in the data set. However, it does not provide information about the intensity of milk production. Figure 2 gives information on the intensity, measured by the milk delivery per cow on NUTS2 level. The highest milk production per cow is observed in the Northwest of the EU, especially Denmark, Finland and the Netherland. Moreover, the old member states have a higher intensity as the NMS. Exceptions are the Czech Republic and some regions in Hungary and Slovakia, which reach intensity levels comparable with the medium performing regions in the old member states.

However, milk production per cow is only a poor indicator of the productivity of dairy production, since it is a partial indicator not considering the other factors of production. In order to provide a more comprehensive measure these have to be taken into account. This leads to the calculations of total factor productivity as shown in the next chapter.

Figure 2: Productivity of dairy gross production (milk yield per cow), NUTS2 level



Source: own calculation

5 ESTIMATION RESULTS

5.1 Metafrontier analysis

Table 1 provides the parameter estimates of the stochastic metafrontier model for milk production using an output distance function. Almost all parameters are significant even at 1 % significance level. This also holds for the majority of the other fitted parameters. As far as theoretical consistency is concerned, the estimated model implies that the estimation should inherit the properties of an output distance function. According to Coelli et al. (2005), the output distance function should be non-decreasing, positively linearly homogenous and convex in outputs, as well as decreasing and quasi convex in inputs. That is, the monotonicity requirements for outputs imply: $\beta y_2 > 0$, $\beta y_3 > 0$ and $\beta y_2 + \beta y_3 < 1$; and for inputs: $\beta x_q < 0$ for $q = 1, 2, 3, 4, 5$. Table 1 shows that these conditions are met. Moreover, convexity in inputs requires $\beta x_{qq} + \beta x_q^2 - \beta x_q > 0$ for $q = 1, 2, 3, 4, 5$. This condition holds evaluated on the sample mean.

Since all variables are normalised in logarithm by their sample mean, the first-order parameters of outputs represent the shares of outputs y_2 and y_3 in the total output. Since we analysed farms specialized in milk production it is natural that the shares of plant production and other animal production is relatively small ($\beta y_3 = 0.2172$ and $\beta y_2 = 0.0726$).

The parameters of inputs can be interpreted as elasticities of production on the sample mean. The highest production elasticity exists for material inputs (x_4 and x_5) and the lowest for capital (x_3). The estimates further show that heterogeneity is an important determinant of dairy production in the EU. It contributes positively to the production and the impact is accelerating. The increase in heterogeneity (suitability of dairy production) has a positive impact on production elasticities of material inputs and a negative one on labour, land, and capital. The effect of technological change on technical efficiency is negative with increasing management.

The sum of production elasticities is 0.889. Thus, decreasing returns to scale were estimated for the EU member countries. The estimates reveal that the scale efficiency will have a significant impact on productivity change, evaluated on the sample mean. However, this also holds for most individual EU member countries (see next section).

Table 1: Parameter estimates –metafrontier for dairy

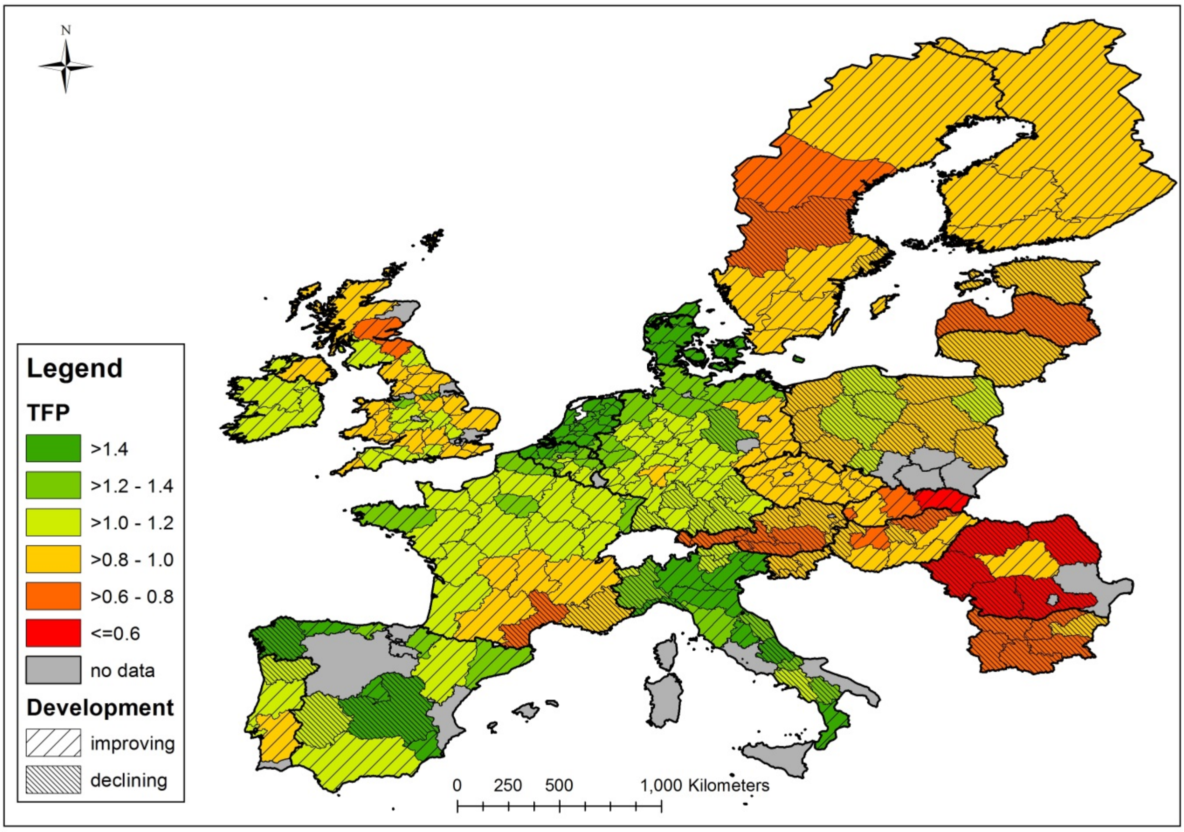
Means for random parameters				**Coefficient on unobservable fixed management**			
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
Const.	-0.1156	0.0010	0.0000	**Alpha_m**	-0.3815	0.0006	0.0000
Time	-0.0076	0.0002	0.0000	**Time**	-0.0052	0.0002	0.0000
X1	-0.0725	0.0011	0.0000	**X1**	-0.0607	0.0010	0.0000
X2	-0.1398	0.0008	0.0000	**X2**	-0.0386	0.0006	0.0000
X3	-0.0659	0.0008	0.0000	**X3**	-0.0082	0.0008	0.0000
X4	-0.3215	0.0006	0.0000	**X4**	0.0871	0.0006	0.0000
X5	-0.2893	0.0011	0.0000	**X5**	0.0554	0.0010	0.0000
				Alpha_mm	-0.0575	0.0007	0.0000
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
TT	-0.0009	0.0002	0.0000	**X13**	-0.0039	0.0011	0.0003
Y2	0.0726	0.0005	0.0000	**X14**	0.0489	0.0010	0.0000
Y3	0.2172	0.0004	0.0000	**X15**	0.0232	0.0015	0.0000
Y2T	-0.0015	0.0002	0.0000	**X23**	-0.0090	0.0007	0.0000
Y3T	0.0005	0.0001	0.0001	**X24**	0.0344	0.0007	0.0000
Y22	0.0350	0.0005	0.0000	**X25**	0.0020	0.0009	0.0297
Y33	0.0791	0.0003	0.0000	**X34**	0.0220	0.0008	0.0000
Y23	-0.0024	0.0003	0.0000	**X35**	0.0111	0.0009	0.0000
X1T	0.0013	0.0003	0.0000	**X45**	0.0097	0.0009	0.0000
X2T	0.0029	0.0002	0.0000	**Y2X1**	-0.0066	0.0008	0.0000
X3T	-0.0051	0.0002	0.0000	**Y2X2**	0.0068	0.0006	0.0000
X4T	-0.0034	0.0002	0.0000	**Y2X3**	0.0024	0.0006	0.0002
X5T	0.0029	0.0003	0.0000	**Y2X4**	0.0062	0.0005	0.0000
X11	-0.0444	0.0021	0.0000	**Y2X5**	-0.0099	0.0008	0.0000
X22	-0.0230	0.0011	0.0000	**Y3X1**	-0.0056	0.0006	0.0000
X33	-0.0180	0.0005	0.0000	**Y3X2**	0.0083	0.0005	0.0000
X44	-0.1252	0.0007	0.0000	**Y3X3**	-0.0049	0.0005	0.0000
X55	-0.0723	0.0016	0.0000	**Y3X4**	0.0049	0.0003	0.0000
X12	-0.0033	0.0014	0.0157	**Y3X5**	-0.0022	0.0006	0.0006
Sigma	0.1418	0.0004	0.0000				
Lambda	1.2265	0.0136	0.0000				

Note: ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively
Source: own calculation

Figure 3 shows the distribution of total factor productivity for specialized milk producers in the EU at the NUTS 2 level. The highest TFP is observed in Northern Central Europe (Denmark, Belgium, Germany), Northern Italy and France, and some regions in Spain. In Eastern Europe above average TFP is only observed in some Polish regions. In general, the average TFP is Eastern Europe fairly lacking behind the EU average with the lowest TFP levels observed in Romania and Bulgaria.

Moreover, most regions in the old memebr states expereinced an above average TFP growth. In Central and Eastern Europe this holds only for the Czech Republic, Hungary and Slovakia. The Baltic countries, Poland, Slovenia, as well as Bulgaria and Romania had an below average TFP growth rate. Given that this group of countries had also below average TFP levels, it can be concluded that TFP in milk production was more and more falling behind those of the old member states. Only in the three earlier mentioned countries there are signs of a catching up process. A TFP only little below the EU average was accompagnied with an above average TFP development.

Figure 3: TFP differences among regions, NUTS2 level



Source: own calculation

5.2 Country multiple output distance function estimates and TFP calculations

Tables 2, 3, and 4 provide parameter estimates of the multiple output distance function (relation 10) for 23 EU member countries (the multiple output distance function for Greece could not be estimated due to the low number of observations). Instead of discussing each country estimate separately, we will evaluate and compare the results for all member countries together. This strategy helps to understand better the common and individual specifics of milk production in EU member countries as far as technology, efficiency, and productivity are concerned.

We start with the discussion of the first order parameters and economies of scale (Table 2). Then we verify the significance of heterogeneity in production structure. In particular, we evaluate the parameters on unobservable fixed management (Table 3). Finally, we concentrate on technological change and biased technological change (Table 4).

5.2.1 *Parameter estimates*

Table 2 provides selected estimated parameters of the output distance function, i.e. first order parameters on outputs and inputs. Almost all parameters are significant, even at 1 % significance level. This also holds for the majority of the other fitted parameters. Moreover, the monotonicity and convexity conditions holds for all countries at the sample mean.

Table 2: First order parameters of the multiple output distance functions – milk production

EU member country		Other Animal production	Plant production	Labour	Land	Capital	Specific material	Other material	RTS
		y2	y3	x1	x2	x3	x4	x5	
Austria	Coeff.	0.1619 ***	0.0565 ***	-0.0436 ***	-0.2823 ***	-0.1149 ***	-0.2885 ***	-0.1715 ***	-0.9008
Belgium	Coeff.	0.0863 ***	0.0931 ***	-0.0776 ***	-0.1939 ***	-0.0439 ***	-0.2227 ***	-0.2800 ***	-0.8181
Germany	Coeff.	0.1129 ***	0.2188 ***	-0.1121 ***	-0.2373 ***	-0.0986 ***	-0.2648 ***	-0.3063 ***	-1.0190
Denmark	Coeff.	0.0370 ***	0.2161 ***	-0.0749 ***	-0.1577 ***	-0.0159 *	-0.5123 ***	-0.2892 ***	-1.0500
Spain	Coeff.	0.0354 ***	0.0849 ***	-0.1639 ***	-0.0390 ***	-0.0132 ***	-0.4243 ***	-0.1825 ***	-0.8229
Finland	Coeff.	0.0130 ***	0.0907 ***	-0.0979 ***	-0.1931 ***	-0.0933 ***	-0.2809 ***	-0.2351 ***	-0.9003
France	Coeff.	0.0864 ***	0.1325 ***	-0.0924 ***	-0.1951 ***	-0.1181 ***	-0.2195 ***	-0.3011 ***	-0.9262
Great Britain	Coeff.	0.0697 ***	0.1186 ***	-0.0835 ***	-0.0827 ***	-0.0676 ***	-0.4118 ***	-0.3771 ***	-1.0227
Ireland	Coeff.	0.1394 ***	0.1062 ***	-0.0960 ***	-0.2210 ***	-0.0574 ***	-0.2563 ***	-0.3052 ***	-0.9360
Italy	Coeff.	0.0906 ***	0.4018 ***	-0.1075 ***	-0.1689 ***	-0.0897 ***	-0.5525 ***	-0.1050 ***	-1.0236
Netherlands	Coeff.	0.0293 ***	0.0117 ***	-0.0873 ***	-0.3180 ***	-0.0864 ***	-0.3305 ***	-0.1684 ***	-0.9907
Portugal	Coeff.	0.0575 ***	0.1726 ***	-0.1410 ***	-0.0556 ***	-0.0205 ***	-0.4821 ***	-0.2510 ***	-0.9503
Sweden	Coeff.	0.0223 ***	0.3663 ***	-0.1025 ***	-0.2230 ***	-0.0438 ***	-0.3808 ***	-0.2602 ***	-1.0102
Bulgaria	Coeff.	0.1476 ***	0.3648 ***	-0.1932 ***	-0.1222 ***	-0.0909 ***	-0.3779 ***	-0.2466 ***	-1.0308
Czech Republic	Coeff.	0.0901 ***	0.4207 ***	-0.1467 ***	-0.1801 ***	-0.0134 **	-0.2836 ***	-0.3455 ***	-0.9693
Estonia	Coeff.	0.0805 ***	0.3111 ***	-0.1513 ***	-0.1282 ***	-0.0800 ***	-0.4832 ***	-0.2333 ***	-1.0760
Hungary	Coeff.	0.0852 ***	0.3410 ***	-0.1149 ***	-0.0706 ***	-0.0501 ***	-0.3641 ***	-0.3732 ***	-0.9729
Lithuania	Coeff.	0.1505 ***	0.4192 ***	-0.1013 ***	-0.2052 ***	-0.0896 ***	-0.3193 ***	-0.3249 ***	-1.0404
Latvia	Coeff.	0.1163 ***	0.4493 ***	-0.1069 ***	-0.0292	-0.1109 ***	-0.4290 ***	-0.3269 ***	-1.0029
Poland	Coeff.	0.0946 ***	0.3221 ***	-0.1081 ***	-0.2439 ***	-0.1321 ***	-0.2133 ***	-0.3725 ***	-1.0701
Romania	Coeff.	0.1829 ***	0.4990 ***	-0.0741 ***	-0.3282 ***	-0.0117 **	-0.2655 ***	-0.2184 ***	-0.8979
Slovenia	Coeff.	0.1269 ***	0.2168 ***	-0.0880 ***	-0.2877 ***	-0.1135 ***	-0.3994 ***	-0.2422 ***	-1.1310
Slovakia	Coeff.	0.0650 ***	0.3043 ***	-0.3331 ***	-0.2020 ***	-0.0570 ***	-0.2055 ***	-0.2270 ***	-1.0246

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively.
Source: own calculation

The first order parameters of outputs (y_2 and y_3) point out the production structure differences among EU member countries. Since we analysed farms specialized in milk production with the share of milk production in total animal production exceeding 50%, the share of other animal production in total output is lower than 50% for all analyzed countries. Specialized milk farms with a higher share of other animal production can be found in Romania, Austria, and Lithuania, where the parameter of y_2 exceeds 0.15. Agricultural companies in Romania can be characterized also by the highest share of plant production, almost 50%, pointing to the high production diversification on Romanian farms as well as to a high proportion of own feed production. The share of plant production is higher than 40 % also in the Czech Republic, Italy, Lithuania, and Latvia. On the other hand, farms in Austria, Spain, Finland, and the Netherlands are highly specialized in animal production. The share of plant production in their total output is lower than 10 %.

The production elasticities of the individual countries have some common patterns. The elasticities for materials inputs (specific and other materials) have the highest values and the elasticities for capital the lowest. However, some exceptions can be found. In the case of Slovakia, surprisingly labour has the highest elasticity. This suggests low capital intensity in dairy cows breeding in Slovakia. Romania is another exception, where the prevailing pasture breeding leads to the high impact of land on milk production. On the other hand, land has the lowest impact in Spain where land elasticity is -0.04.

As far as economies of scale are concerned they are slightly deviating from 1. Constant returns to scale were estimated (the sum of the elasticities is about one) for the average farm in Germany, Great Britain, Hungary, Italy, Latvia, the Netherlands, Sweden, and Slovakia. On the contrary, the impact of scale efficiency on productivity change can only be assumed in other EU member states, where the returns to scale are either increasing (Bulgaria, Denmark, Estonia, Lithuania, Poland, and Slovenia) or decreasing (Austria, Belgium, the Czech Republic, Spain, Finland, France, Ireland, Portugal, Romania). This suggests that in most countries the average farm operates almost at optimal (static) farm size. This implies that optimal farm size is a function of many different determinants as heterogeneous as the conditions in the countries.

Table 3 provides the parameter estimates on unobservable management. The coefficients on unobservable management are highly significant in the majority of cases. This suggests that the estimated relationship is appropriately approximated by chosen specification and that heterogeneity among farms is an important characteristic for milk specialized producers in EU member states.

The effect of unobservable management is positive ($\alpha_m < 0$) and predominantly decelerating ($\alpha_{mm} > 0$). The impact of unobservable management on production elasticities differs significantly among the analysed countries. In general, better suitability for milk production goes hand in hand with a more productive use of in specific materials (fodder) ($\beta_{mx4} > 0$). On the other hand, suitability for milk production leads to the decrease in labour, land, and capital elasticity ($\beta_{mx1} < 0$, $\beta_{mx2} < 0$, and $\beta_{mx3} < 0$).

Table 3: Parameters on unobservable heterogeneity – milk production

EU country		α_m	Time	Labour	Land	Capital	Specific material	Other material	α_{mm}
			t	x1	x2	x3	x4	x5	
Austria	Coeff.	-0.1266 ***	0.0039 ***	-0.0038	0.2042 ***	0.0778 ***	0.0271 ***	0.017 ***	0.5735 ***
Belgium	Coeff.	-0.2411 ***	-0.0043 ***	0.0301 ***	0.0011	-0.0078	0.0229 ***	-0.0414 ***	0.028 ***
Germany	Coeff.	-0.2077 ***	-0.0051 ***	0.0035	-0.0196 ***	0.022 ***	0.0452 ***	-0.0392 ***	0.039 ***
Denmark	Coeff.	-0.113 ***	-0.0025 **	-0.01	-0.0145 **	-0.0034	0.0374 ***	0.0345 ***	0.0259 ***
Spain	Coeff.	-0.2216 ***	0.005 ***	-0.0776 ***	-0.021 ***	-0.0054 **	0.1191 ***	0.0174 ***	-0.0337 ***
Finland	Coeff.	-0.0912 ***	0.0064 ***	-0.0962 ***	-0.0533 ***	-0.0243 ***	-0.0839 ***	0.0002	0.3363 ***
France	Coeff.	-0.2012 ***	-0.0036 ***	-0.0278 ***	-0.027 ***	0.0251 ***	0.0487 ***	-0.0153 ***	0.0175 ***
Great Britain	Coeff.	-0.1668 ***	0.0043 ***	-0.0165 **	-0.0344 ***	0.0083	0.0389 ***	0.0067	0.0095 ***
Ireland	Coeff.	-0.2727 ***	-0.0011 ***	-0.0627 ***	0.0489 ***	-0.0414 ***	0.0393 ***	-0.1349 ***	0.2374 ***
Italy	Coeff.	-0.2831 ***	0.004 ***	-0.0671 ***	-0.0586 ***	0.0063 *	0.137 ***	-0.0073 ***	-0.0369 ***
Netherlands	Coeff.	-0.0784 ***	0.0004	-0.078 ***	0.0141 ***	-0.0474 ***	-0.0762 ***	-0.091 ***	0.2693 ***
Portugal	Coeff.	-0.0868 ***	-0.0005 ***	-0.109 ***	-0.1182 ***	-0.024 ***	0.1395 ***	-0.1295 ***	0.359 ***
Sweden	Coeff.	-0.2234 ***	0.0002	0.0411 ***	-0.0412 ***	0.0183 ***	0.0107	-0.1176 ***	0.1941 ***
Bulgaria	Coeff.	-0.1623 ***	0.0271 ***	-0.0255 **	-0.0166 **	-0.0563 ***	0.0196 **	0.1093 ***	-0.0916 ***
Czech Republic	Coeff.	-0.0466 ***	-0.0033 ***	0.1081 ***	-0.2099 ***	0.0344 ***	0.0109 **	0.1 ***	0.3494 ***
Estonia	Coeff.	-0.1419 ***	0.0008	0.019 *	-0.0793 ***	-0.0062	0.0185	0.052 ***	0.0461 ***
Hungary	Coeff.	-0.1553 ***	-0.001	-0.0033	0.0576 ***	-0.1056 ***	-0.1255 ***	0.1451 ***	0.0999 ***
Lithuania	Coeff.	-0.0593 ***	0.0076 ***	0.0074	0.0814 ***	0.0343 ***	-0.0657 ***	-0.0489 ***	0.2855 ***
Latvia	Coeff.	-0.0852 ***	0.0161 ***	-0.0075	0.0204	-0.0021	0.0476 ***	-0.0342	0.0417 ***
Poland	Coeff.	-0.201 ***	-0.0037 ***	-0.0134 **	-0.0359 ***	0.005	0.0227 ***	0.0421 ***	0.0095 ***
Romania	Coeff.	-0.2516 ***	-0.0065 *	-0.0457 ***	-0.0386 ***	-0.0001	0.0243 ***	0.0379 ***	-0.0608 ***
Slovenia	Coeff.	-0.1824 ***	-0.0049 **	-0.0121	-0.0864 ***	-0.0025	0.0752 ***	0.0497 ***	-0.027 ***
Slovakia	Coeff.	-0.3191 ***	-0.021 ***	-0.1206 ***	-0.0418 ***	-0.0237 ***	0.0721 ***	0.0881 ***	0.0189 **

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively; LNO – Low Number of Observations

Source: own calculation

Given the assumption regarding the unobservable component, $m_i^* \sim N(0,1)$, the value of the constant term can be regarded as the standard deviation of the determinant in the sample. In general, there is no pronounced difference betwen the average value of this determinant between Old and New Member States. This shows that the country groups have similar distributions or the suitability of milk production, however, on a different levels (see Figure 3). Moreover, there is indication that in countries which have a high TFP, like Denmark and Netherlands, the suitablility of milk produktion is relatively homogenously distributed. The same effect is observarble for the New Member States (e.g. Czech Republic).

Table 4: Technological change and biased technological change – milk production

EU country		t	tt	x1*t	x2*t	x3*t	x4*t	x5*t
Austria	Coeff.	-0.0070 ***	-0.0080 ***	-0.0090 ***	0.0026 **	-0.0120 ***	-0.0018	0.0041 *
Belgium	Coeff.	-0.0043 ***	0.0003	0.0038	0.0163 ***	0.0024	-0.0081 ***	-0.0162 ***
Germany	Coeff.	-0.0132 ***	-0.0011 **	-0.0015	-0.0085 ***	-0.0017 *	-0.0034 ***	0.0155 ***
Denmark	Coeff.	-0.0143 ***	0.0075 ***	0.0149 ***	0.0002	0.0186 ***	-0.0207 ***	-0.0135 **
Spain	Coeff.	0.0038 ***	0.0025 **	0.0137 ***	0.0019 *	0.0052 ***	-0.0279 ***	-0.0022
Finland	Coeff.	-0.0158 ***	0.0098 ***	0.0025	0.0044	-0.0092 ***	-0.0115 ***	0.0033
France	Coeff.	-0.0100 ***	-0.0047 ***	0.0024 **	-0.0026 **	-0.0037 ***	-0.0041 ***	0.0076 ***
Great Britain	Coeff.	-0.0011	-0.0075 ***	-0.0124 ***	0.0021	-0.0032	-0.0025	0.0125 ***
Ireland	Coeff.	-0.0163 ***	-0.0091 ***	0.0044	0.0071	-0.0023	0.0048	-0.0185 ***
Italy	Coeff.	-0.0248 ***	0.0051 ***	-0.0078 ***	0.0051 ***	0.0067 ***	-0.0085 ***	0.0006
Netherlands	Coeff.	-0.0078 ***	-0.0046 ***	-0.0011	-0.0004	-0.0030	0.0070 ***	-0.0084 **
Portugal	Coeff.	-0.0163 ***	0.0022	-0.0019	-0.0020	0.0028	-0.0039 *	0.0038
Sweden	Coeff.	-0.0059 ***	-0.0049 ***	-0.0037	-0.0077 **	-0.0079 ***	0.0049	0.0124 ***
Bulgaria	Coeff.	-0.0061	-0.0029	0.0244 **	-0.0180 ***	-0.0042	0.0058	-0.0063
Czech Republic	Coeff.	-0.0209 ***	-0.0006	0.0063 **	0.0007	-0.0073 ***	-0.0028	0.0025
Estonia	Coeff.	-0.0038 *	0.0052 **	0.0001	0.0131 *	-0.0025	-0.0039	-0.0116 *
Hungary	Coeff.	0.0005	-0.0058 *	0.0086	0.0127	-0.0058	-0.0088	-0.0053
Lithuania	Coeff.	0.0021	-0.0018	-0.0024	0.0084	0.0156 ***	-0.0020	-0.0141
Latvia	Coeff.	0.0063	0.0070	0.0039	0.0039	-0.0161 **	0.0062	0.0071
Poland	Coeff.	0.0155 ***	-0.0112 ***	0.0031	-0.0043 ***	0.0058 ***	-0.0027 **	-0.0038 **
Romania	Coeff.	-0.0389 ***	-0.0275 ***	0.0004	-0.0001	0.0001	-0.0047	-0.0072
Slovenia	Coeff.	-0.0108 ***	-0.0094 ***	0.0078	-0.0158 **	0.0058	-0.0043	0.0072
Slovakia	Coeff.	-0.0296 ***	-0.0003	-0.0165 ***	-0.0090	-0.0216 ***	0.0040	0.0347 ***

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively
Source: own calculation

Table 4 provides the parameter estimates on technological change and biased technological change. The impact is significant at 10 % level for almost all countries. It is significantly positive in most of the Old Member States ($\beta_t < 0$) while in the New Member States deterioration of production possibilities dominates ($\beta_t > 0$). A significant positive impact of technical change occurred especially in those countries, which are catching up (the Czech Republic and Slovakia).

The biased technological change is pronounced for almost all analysed countries, except for Hungary and Romania. However, distinct differences in the direction of biased technological change can be observed. The labour-saving technological change can be found in Bulgaria, the Czech Republic, Denmark, Spain, and France, and labour-using technological change in Austria, Great Britain, Italy, and Slovakia. The biased technological change is land-saving in Belgium, Estonia, and Spain, and land-using in Bulgaria, Germany, France, Poland, Sweden, and Slovenia. The capital-using biased technological change is pronounced in most EU member countries. It is capital-saving only in Denmark, Spain, Italy, Lithuania, and Poland. The estimates of the capital elasticity together with the direction of the biased technological change suggest that milk producers do not face capital market imperfections, what allows them to upgrade their production technology and makes them more competitive on the European Common market.

Table 5: Technical efficiency – milk production

EU country	σ	λ	Statistical characteristics of technical efficiency					
			Mean	Std.Dev	Min.	Max	1st Decile	10th Decile
Austria	0.1149***	0.8607***	0.8817	0.0709	0.5159	0.9909	0.7828	0.9531
Belgium	0.1484***	1.8004***	0.9055	0.0495	0.4954	0.9882	0.8475	0.9526
Germany	0.1451***	1.2857***	0.9146	0.0367	0.5244	0.9839	0.8700	0.9523
Denmark	0.1176***	1.9259***	0.9223	0.0420	0.5163	0.9842	0.8696	0.9634
Spain	0.2248***	1.3685***	0.8702	0.0564	0.3758	0.9760	0.7991	0.9259
Finland	0.1426***	1.4201***	0.8690	0.0723	0.5605	0.9840	0.7630	0.9452
France	0.1353***	1.8293***	0.9129	0.0456	0.4495	0.9879	0.8569	0.9576
Great Britain	0.1329***	1.3153***	0.9208	0.0346	0.6142	0.9800	0.8757	0.9561
Ireland	0.1256***	1.5678***	0.9085	0.0507	0.5565	0.9813	0.8490	0.9560
Italy	0.2320***	0.8560***	0.8900	0.0318	0.6156	0.9734	0.8515	0.9228
Netherlands	0.1001***	1.0222***	0.9268	0.0367	0.7084	0.9914	0.8780	0.9634
Portugal	0.1748***	0.8438***	0.8958	0.0394	0.6890	0.9746	0.8453	0.9381
Sweden	0.1566***	1.7901***	0.8870	0.0585	0.5149	0.9795	0.8104	0.9467
Bulgaria	0.3658***	2.1998***	0.7886	0.1080	0.2662	0.9466	0.6343	0.9011
Czech Republic	0.1340***	1.0643***	0.8904	0.0535	0.5885	0.9802	0.8181	0.9482
Estonia	0.2046***	1.7752***	0.8704	0.0640	0.4275	0.9743	0.7824	0.9379
Hungary	0.2105***	1.7663***	0.8650	0.0653	0.5935	0.9656	0.7706	0.9343
Lithuania	0.1796***	0.7746**	0.8984	0.0379	0.7124	0.9673	0.8487	0.9381
Latvia	0.2336***	0.0000	-	-	-	-	-	-
Poland	0.2066***	1.4176***	0.8776	0.0539	0.4274	0.9745	0.8064	0.9333
Romania	0.2232***	0.7307***	0.9030	0.0241	0.7558	0.9590	0.8732	0.9292
Slovenia	0.2247***	2.2508***	0.8577	0.0768	0.3264	0.9719	0.7602	0.9344
Slovakia	0.2594***	3.8655***	0.8304	0.0998	0.3086	0.9761	0.6949	0.9364

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively
Source: own calculation

5.2.2 Technical efficiency and TFP

Table 5 provides the estimates of parameter σ, λ, and the statistical characteristics of technical efficiency. The parameter σ provides information about the joint variation of u_{it} and v_{it}. λ is the relation between the variance of u_{it} and v_{it}. Thus, the parameter indicates the significance of TE in the residual variation. A value smaller than one suggests that variation in u_{it} is less pronounced than variation in the random component v_{it}. Since λ is highly significant in all EU member countries except for Latvia and in majority of countries higher than one, the estimates indicate that efficiency differences among milk producers are important reasons for variation in production.

The countries' λ are on average lower in the Old than the New Member States. This suggests that firm performance in milk production in accession countries is more heterogeneous. This conclusion is reinforced when looking in more detail at the distribution of inefficiencies. The 1st decile of farmers in most New Member States have efficiency scores which were lower than in the other EU member states. At the same time the best decile of farmer in the Old Member States reaches higher efficiency values than in NMS, so more farms are lacking behind and fewer farms are at the national frontiers in the New Member States.

Finally, the Spearman's rank correlations of technical efficiency (Table A1 in the appendix) points out that leapfrogging in technical efficiency appears to be a common phenomenon in majority of member countries. However, the Spearman's rank correlation for TFP suggests that the order of milk producers is stable over time. That is, leapfrogging can be excluded as far as TFP development is considered. Structural change seems to occur in such a way that the most successful producers strengthen their positions. Producers with poor performance will not be able to catch up with the developments of the sector leaders, and therefore are expected to fall more and more behind.

6 CONCLUSIONS

This section summaries the results and will discuss them in light of the research questions asked in the introduction, in detail:

- How has regional agriculture benefited from the adoption of innovations? Is there an indication that regional scarcity of resources was the source of technical progress?
- Is there an indication that technical change (and other sources of adjustment) have led to a convergence of the regions in terms of TFP?
- What are the causes of the regional convergence or divergence? How did farm structure, market structure, and credit constraints affect the adoption of innovations?
- Given the significant duality of farm structures in some countries can the same patterns for large agricultural companies and small farmers be observed or can we identify idiosyncratic developments?

The metafrontier estimates reveal that there are considerable productivity differences in milk production across the EU at the NUTS 2 level. Productivity is the highest in the Old Memeber States, especially in those regions located in the Northwest of the EU. The lowest producticity generaly could be observed in Eastern Europe. The same strucure as for TFP we found for TFP development. We found an above average increase in the Old and a below average development in the New Member States. This implies that positive economic effects expected from the economic integration have not been realized yet. Moreover, only few regions mainly located in Slowakia, the Czech Republic, and Hungary could keep pace with the developments in the Old Member States and thus are catching up. However, most regions in Eastern Europe were falling more and more behind during the first years of EU acession.

The determinants for this development were further investigated by analysing the sources of TFP development using the national production frontiers. In particular, we investigated how the scale, technical change, and technical efficiency contributed to TFP levels and growth.

The analyses suggest that on average in all countries specialized producers operate at almost constant returns to scale, i.e. optimal farm sizes from a static point of view. This in turn implies that there is no pure technical definition of optimal farm size , rather it depends on many mutally related determinants.

However, the results for technical change suggest that farm sizes are not optimal in many regions in Central and Eastern Europe from a dynamic prespective. The impact of technical change in Eastern Europe on milk production was lower than in the rest of the EU. Moreover, there appears to be a strong correlaton between larger farms and the adoption of technical changes, since countries, whose milk production is large scaled, were able to generate above average effects of technical change (Slowakia, the Czech Republic and Hungary). The correlation of technical change and size also implies that technical change was highly indivisible and could be adopted by those farms which operate beyond a size-specific threshold with improved machinary, adequate animal housing etc. or do not face other constraints (credit market imperfections).

Furthermore, the effects, discussed so far, occur on the frontier of the country specific producton possibilites. The comparative analysis suggest that despite it was explicitly accounted for farm heterogeniety, milk production has a wider more left skewed distribution for technical efficieny in Central Europe than in other regions of the EU. This implies that in the New compared to the Old Member States fewer farms could benefit from the movement on the frontier. Moreover, since technical effiency remains relatively stable in the peroid under examinatoin there are no signs that poor performing farms are catching up to the best performing farms in the regions/countries.

The results discussed so far have important implications for the efficiency of the CAP. One of the declared targets of EU policy intervention is the improvement of productivity and competitiveness in European agriculture. The fact that several regions in Eastern Europe are falling behind suggests a policy failure at the EU level. The largest part of EU agricultural funds is centrally planned at the EU level. However, the redistribution does not appear to contribute positively to some policy objectives. From this it follows that it is important to reallocate funds from pillar 1 to pillar2, where the member states have larger decision-making power regarding the distribution of funds, as it was foreseen by the last CAP reform. Our analysis recommends that the member states should foster the axis „competiveness“ in pillar 2 and should, in addition to investment aids to farmers, provide some means for related and supporting industries of the dairy sector.

Acknowledgements

This paper was created within the project COMPETE – “International comparisons of product supply chains in the agro-food sectors: determinants of their competitiveness and performance on EU and international markets”. The project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no 312029 (www.compete-project.eu).

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Appendix

Table A1 - Sample descriptive statistics – milk production

EU member country	y1		y2		y3		x1		x2		x3		x4		x5		
	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Cases
Austria	36.92	25.19	11.46	7.83	3.59	9.10	1.80	0.57	36.56	28.68	20.71	10.68	9.89	8.00	26.39	14.15	5452
Belgium	100.32	54.61	23.67	24.95	29.25	45.37	1.80	0.62	60.15	34.84	32.00	19.63	28.21	19.91	51.86	31.55	2310
Bulgaria	51.39	110.57	9.64	26.51	81.15	202.28	10.56	30.59	268.08	549.45	16.47	41.27	35.43	81.61	61.96	132.07	2430
Czech Republic	512.62	463.51	186.00	235.80	526.47	568.70	40.49	35.90	1099.36	915.59	177.14	173.11	265.04	234.04	736.44	726.12	2600
Germany	154.81	279.48	25.36	38.22	28.34	107.03	2.72	6.05	104.28	228.65	44.92	79.73	41.55	109.53	101.09	223.73	8676
Denmark	393.23	250.81	54.59	70.15	103.04	84.24	2.68	1.49	144.63	81.11	36.51	19.34	176.03	132.78	184.70	117.45	1656
Estonia	136.30	264.80	17.41	44.49	68.97	138.00	7.25	12.48	335.82	509.19	37.11	81.94	72.45	142.51	85.53	167.57	1275
Spain	125.01	121.24	7.60	20.11	12.44	18.18	1.90	0.94	30.97	38.83	10.76	16.04	57.34	61.42	28.61	34.35	6093
Finland	102.15	73.50	9.07	12.62	7.92	11.43	2.33	0.92	64.81	39.59	46.11	40.50	29.19	23.25	65.48	41.35	2580
France	105.76	62.10	26.86	25.62	37.97	53.03	2.10	1.00	117.52	79.58	52.15	34.13	27.49	20.43	83.79	55.41	9811
Great Britain	208.14	163.90	34.27	35.23	27.15	50.29	2.63	1.43	116.95	97.35	43.36	36.24	80.41	67.59	101.82	82.78	3276
Greece	98.18	108.54	25.56	36.53	15.92	12.62	2.34	1.19	18.33	13.50	8.90	6.57	60.62	88.37	15.08	12.67	86
Hungary	374.37	792.68	67.12	230.61	270.90	553.88	22.43	44.54	656.95	1178.69	95.12	199.33	212.56	380.68	399.94	1130.36	688
Ireland	91.21	61.77	28.84	22.13	8.14	10.97	1.70	0.71	61.54	32.95	22.29	14.29	29.13	22.87	43.19	26.40	1972
Italy	142.57	256.69	20.10	48.54	42.25	91.71	2.55	2.24	43.24	74.41	19.84	28.17	84.84	152.81	20.69	55.05	6748
Lithuania	61.38	168.71	10.81	36.59	49.68	161.29	5.17	14.63	192.21	481.73	16.04	48.11	25.32	72.08	49.54	166.95	1179
Latvia	59.48	122.73	14.37	50.15	48.32	171.29	7.51	17.03	237.71	457.79	18.83	43.41	32.57	64.96	63.92	170.46	619
Netherlands	215.79	145.60	20.04	25.97	17.68	76.91	1.87	1.11	56.57	36.12	53.56	40.96	40.13	30.02	102.94	75.74	2571
Poland	29.95	69.35	6.89	18.36	15.84	77.08	2.48	5.37	45.38	137.76	8.32	21.95	8.82	22.21	23.94	101.63	11130
Portugal	51.31	46.93	5.17	5.67	8.61	11.30	1.80	0.74	23.71	20.83	6.14	6.07	23.55	24.19	17.39	17.04	1879
Romania	19.49	81.85	5.22	21.55	31.04	155.16	3.84	12.61	78.98	385.86	8.33	51.79	8.55	30.44	27.01	156.84	2231
Sweden	130.86	159.98	15.31	25.93	34.39	44.68	2.18	1.57	106.47	113.89	47.17	57.53	64.11	75.07	88.89	102.64	2388
Slovenia	39.22	38.57	7.61	9.30	13.93	18.20	2.43	0.93	24.94	18.60	13.78	10.67	18.87	19.71	18.63	14.88	2107
Slovakia	432.41	434.90	148.84	188.88	562.98	622.65	54.88	40.76	1583.84	1048.62	387.01	380.45	263.94	280.64	784.61	736.11	1447

Note: y1 – milk production (ths. EUR), y2 – other animal production (ths. EUR), y3 – plant production (ths. EUR), x1 – labour (AWU), x2 – land (ha), x3 – capital (ths. EUR), x4 – specific material (ths. EUR) and x5 – other material (ths. EUR).

Source: FADN and own calculations

Table A2: Spearman’s rank correlation coefficients of technical efficiency in milk production

	Spearman’s rank correlation coefficients of technical efficiency						
EU country	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2011/2010
Austria	NA	0.8514	0.8299	0.8063	0.8092	0.8270	0.8382
Belgium	0.2746	0.1130	0.0804	-0.1172	0.0971	0.0150	0.1300
Bulgaria	NA	NA	NA	-0.1301	-0.0435	-0.0767	0.1380
Czech Republic	0.6577	0.6419	0.6229	0.5600	0.5404	0.5759	0.6221
Germany	0.2585	0.1194	0.0870	-0.0299	-0.0657	0.1483	0.1726
Denmark	0.1539	-0.1244	0.1554	0.1175	0.0176	0.1690	0.2783
Estonia	-0.1435	0.0824	-0.0393	-0.0104	0.1357	0.1485	0.1092
Spain	0.2128	0.0517	0.0670	0.1374	0.0535	0.0968	0.1784
Finland	0.6492	0.5894	0.6542	0.6203	0.6141	0.5337	0.5058
France	0.2371	0.1300	0.0003	-0.0476	-0.0546	-0.0047	0.1827
Great Britain	0.0973	0.0758	0.0027	-0.1528	0.1355	-0.0343	0.2454
Greece	-	-	-	-	-	-	-
Hungary	-0.1440	-0.0245	0.0062	-0.0750	-0.1277	-0.0415	0.3697
Ireland	0.3318	0.1514	0.2712	0.0746	0.2369	0.3877	0.2382
Italy	0.0877	0.0759	0.1229	-0.2069	0.0093	-0.0314	0.1259
Lithuania	0.2506	0.4243	0.3003	0.4834	0.2822	0.5280	0.6731
Latvia	0.9660	0.9961	0.9949	0.9846	0.9716	0.9882	0.9888
Netherlands	0.6437	0.6453	0.5838	0.5225	0.4013	0.4451	0.5901
Poland	0.0551	0.0586	0.0363	-0.1087	-0.0503	0.0452	0.1029
Portugal	0.5463	0.5834	0.4461	0.4362	0.3642	0.2517	0.5158
Romania	NA	NA	NA	-0.1976	-0.2371	-0.2710	-0.2272
Sweden	0.4560	0.4500	0.2143	0.0856	0.1221	0.2580	0.0984
Slovenia	0.0278	-0.0259	-0.1281	0.0887	-0.0451	0.2693	-0.0430
Slovakia	-0.0257	-0.0806	0.1907	-0.0435	-0.1566	0.0889	0.2747

Source: own calculation

Table A3: Spearman’s rank correlation coefficients of TFP in milk production

EU country	Spearman’s rank correlation coefficients of TFP						
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2011/2010
Austria	NA	0.8863	0.9059	0.8909	0.9069	0.8892	0.9140
Belgium	0.9551	0.9472	0.9480	0.9451	0.9537	0.9485	0.9530
Bulgaria	NA	NA	NA	0.6248	0.6661	0.5747	0.6368
Czech Republic	0.8700	0.8960	0.8827	0.8594	0.8423	0.8650	0.8892
Germany	0.9719	0.9673	0.9696	0.9558	0.9635	0.9757	0.9598
Denmark	0.8437	0.7163	0.9090	0.9046	0.8601	0.8499	0.9137
Estonia	0.8061	0.8798	0.8684	0.8824	0.9134	0.9273	0.9146
Spain	0.8237	0.8123	0.8246	0.8448	0.8500	0.7955	0.8411
Finland	0.8894	0.8959	0.9158	0.8913	0.9000	0.9108	0.8676
France	0.9411	0.9521	0.9450	0.9279	0.9134	0.9302	0.9482
Great Britain	0.9580	0.9574	0.9556	0.9525	0.9643	0.9349	0.9524
Greece	-	-	-	-	-	-	-
Hungary	0.7057	0.8624	0.7602	0.7128	0.8019	0.8749	0.9072
Ireland	0.9560	0.9515	0.9394	0.9454	0.9613	0.9601	0.9473
Italy	0.9767	0.9799	0.9804	0.9589	0.9761	0.9728	0.9776
Lithuania	0.8998	0.9199	0.9145	0.9258	0.8918	0.8934	0.9357
Latvia	0.7383	0.8045	0.8540	0.8373	0.7692	0.8750	0.8197
Netherlands	0.9501	0.9390	0.9527	0.9556	0.9444	0.9594	0.9392
Poland	0.9143	0.9318	0.9382	0.9280	0.9128	0.9236	0.9346
Portugal	0.9176	0.8927	0.8728	0.8349	0.8353	0.8625	0.8897
Romania	NA	NA	NA	0.9313	0.9617	0.9658	0.9694
Sweden	0.9359	0.9359	0.8799	0.8812	0.8904	0.9043	0.8932
Slovenia	0.8855	0.8793	0.8105	0.8775	0.8679	0.9004	0.8928
Slovakia	0.8818	0.8641	0.9117	0.8786	0.7432	0.8372	0.9260

Source: own calculation