International comparison of product supply chains in the agri-food sector:
determinants of their competitiveness and performance on EU and international markets

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Total Factor Productivity in European Agricultural Production

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Abstract

The paper provides the findings and conclusions regarding TFP development in agriculture in EU member states. We estimated the multiple output distance function to assess the exploitation of economies of scale and production possibilities and the impact of technical change for cereal, milk and pork production in 24 EU member countries. Moreover, we conducted a metafrontier analysis for the comparative assessment of TFP differences. The results show that we can observe a positive trend in TFP in majority of EU member countries. Moreover, technical change was identified as the important factor that contributed predominantly positively to TFP development. Finally, we did not observed catching up process from between the regions. The metafrontier analysis showed that despite a period of almost 10 years after accession the productivity differences in the agricultural among as well as within countries are substantial.

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1 Introduction

Competiveness seems to be one of the most important topics for research and publication in the field of business and management in the world today. New developments and ongoing negotiations have raised governments' interest in evaluating their country's competitiveness. These are related to general developments such as globalization of economic systems, an increase in competition in the world and EU markets, and changes of national (CAP) and international (WTO) agricultural and trade policies.

The Lisbon Agenda states the very ambitious goal of making the EU "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion". This goal was further developed within the EUROPE 2010 Framework where policy objectives and instruments were formulated that contribute to the improvement of competitiveness, like fostering research and development and improving the education level of young people. In this context, the EU has also recognized the significance of competitiveness of the food industry and has already announced several policy initiatives in this field and is committed to maintaining a constructive dialogue with all stakeholders in the food supply chain.

However, competitiveness is a complex, multi dimensional, and relative concept. It is linked to a large number of interdependent variables thus making it difficult to make sense of it and to define it. In this deliverable, we consider competiveness from the viewpoint of productivity.

Productivity is generally defined as the relation of output to inputs, and thus, gives information about the efficacy of factor input. Productivity is not only determined by the ability to use efficiently inputs in the production of outputs but also by the technology in use and economies of scale. Given this perception, it is obvious that productivity is often used as an indicator of competitiveness. Moreover, the European Commission regards it as the most reliable indicator for competitiveness over the long term. Productivity can be measured at different levels. The simplest are rather disaggregated and include yield per hectare or milk per cow. More aggregated are partial productivity measures where total output of a firm, sector or economy is related to one input. Prominent examples include labour and land productivity. The most comprehensive measure is total factor productivity (TFP), which is a ratio of aggregated outputs and inputs. Thus, TFP and its changes are important indicators of firm or sector performance and will play a central role in our analysis.

Productivity and efficiency as important factors determining the overall competitiveness of agricultural producers have received special attention in the European agricultural research in the last two decades (e.g. Bureau and Butault (1992), Gopinath et al. (1997), Ball et al. (2001), Brümmer et al. (2002), Davidova et al. (2003), Mulder et al. (2004), Thorne (2005), Kleinhans et al. (2007), Wijnands et al. (2008), Fogarasi and Latruffe (2009), Zhu and Lansink (2010), Latruffe et al. (2012a)). The authors addressed research questions on adjustment processes connected with competitiveness, CAP changes and EU enlargement in old as well as new member countries. The results on CAP role in productivity growth were often contradictory (e.g. Kumbhakar, Lien (2010), Backus et al. (2010), Latruffe et al. (2012b)) and a systematic overall assessment of the whole of the EU is missing. We would like to complement this research in the COMPETE Project Work Package 6 "Technology, specialisation, productivity", by conducting a metafrontier analysis of the comparative assessment of TFP differences among EU member countries. In particular, these deliverable addresses the following research questions:

(i) The first relates to the impacts of technological change (TCH) and technical efficiency (TE). The aim is to assess whether there is indication that the countries follow a sustainable development path characterized by the development and adoption of innovation and reduced waste of resources due to inefficient input use.

(ii) The second question concerns country specific development, especially whether the challenges and adjustments are systemic, or whether idiosyncratic developments occurred.

(iii) The third question relates to catching-up and falling-behind processes. In particular, if the development is stable and driven by strong competitive farmers or if leapfrogging occurs.

(iv) The last question concerns regional developments. In particular, we investigate regional differences in the suitability of regions for agricultural production and how the regions perform in term of TFP. Moreover, we analyze the presence of an indication that technical change (and other sources of adjustment) have led to a convergence of the regions in terms of TFP.

The deliverable is organized as follows: Chapter 2 contains the theoretical framework and presents the estimation strategy. Chapter 3 describes the data set. Chapter 4 presents results of multiple output distance function estimates and results of metafrontier analysis. The comparison and discussion of estimated technology, technological change and trends in technical efficiency and TFP developments will be provided. Chapter 5 contains a discussion and concluding remarks, including policy recommendations.

2 Theoretical framework and estimation strategy

The research questions will be dealt with (1) estimation of country specific multiple output distance function for the three agricultural sectors (cereals, dairy and pork) using the FADN database. (2) Based on the 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 impacts on 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):

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

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

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

As provided by Coelli et al. (2005), DO(x,y) exhibits the following properties. It is non-decreasing, positively linearly homogenous and convex in y, and decreasing and convex in x. Moreover, it holds that DO(x,y) ≤ 1 if y ϵ P(x) and DO(x,y) = 1 if y ϵ Isoq P(x).

In our application we use a translog functional form since it is flexible and provides well approximation of the production process. Moreover, 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:

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

where subscripts *i*, with *i*=1,2,…,N, and *t*, with *t =1,…,T*, refer to a certain producer and time (year), respectively. ***α***, ***β*** and ***γ*** are vectors of parameters to be estimated.

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

(4) $\sum_{m=1}^{3} \alpha_m = 1$,

$\sum_{n=1}^{3} \alpha_{mn} = 0$, for *m = 1,…, 3*, and

$\sum_{m=1}^{3} \gamma_{km} = 0$, for *k = 1,…,5*.

Symmetry restrictions are as follows:

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

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

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

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:

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

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 (***α, β, γ***). 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 for 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:

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

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:

(9) $$\ln TE_{it} = \ln f\left(\mathbf{y}^*_{it}, \mathbf{x}_{it}, t, m_i; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right) - \ln f\left(\mathbf{y}^*_{it}, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right) \le 0 \quad ,$$

$$\ln TE_{it} = -u_{it} \quad ,$$

and

(10) $-lny_{1it} = \alpha_0 + \sum_{m=2}^{3} \alpha_m ln\, y_{mit}^{*} + \frac{1}{2}\sum_{m=2}^{3}\sum_{n=2}^{3} \alpha_{mn} lny_{mit}^{*} lny_{nit}^{*} + \sum_{k=1}^{5} \beta_k ln\, x_{kit}$

$$+\frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} lnx_{kit} lnx_{lit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{m=2}^{3}\gamma_{km} lnx_{kit} lny_{mit}^{*}$$

$$+\delta_t t + \frac{1}{2}\delta_{tt} t^2 + \sum_{m=2}^{3}\alpha_{mt} t lny_{mit}^{*} + \sum_{k}^{5}\beta_{kt} t ln\, x_{kit}$$

$$+\alpha_{m*} m_i^{*} + \frac{1}{2}\alpha_{m*m*} m_i^{*2} + \delta_{tm*} m_i^{*} t + \sum_{k=1}^{5}\beta_{km*} m_i^{*}\, lnx_{kit} + u_{it} + v_{it} \quad .$$

Technical efficiency, $TE_{i(t)}$, with $0 < TE_{i(t)} < 1$, captures deviations from the maximum achievable output. $m_i^{*} \sim \bullet(0,1)$ represents unobservable fixed management. The symbol $\bullet$ expresses that m_i^{*} might possess any distribution with zero mean and unit variance. The difference between the real (m_i) and optimal (m_i^{*}) management determines the level of technical efficiency. Technical efficiency is defined by:

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

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 – management – γ_0,

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

(iii) interaction of m^{*} with inputs quantity and quality – scale effect – γ_x.

Álvarez et al. (2004) showed that uit can be estimated according to Jondrow at al. (1982) as (12) with simulated mi* according to the relation (13).

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

where $\lambda = \frac{\sigma_u}{\sigma_v}$, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\varepsilon_{it} = v_{it} + u_{it}$.

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

Fixed Management model is fitted by maximum simulated likelihood in SW NLOGIT 5.0.

2.3 TFP calculation and decomposition

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

(14)

$$\ln \iota_{it}^{VRS} = \frac{1}{2}\sum_{j=1}^{K}\left[\left(\varepsilon_{it,j_0} + \bar{\varepsilon}_j\right)\left(\ln x_{it,j} - \overline{\ln x_j}\right) + \bar{\varepsilon}_j \overline{\ln x_j} - \overline{\varepsilon_{it,j_0} \ln x_{it,j}}\right],$$

$$\text{with} \quad \varepsilon_{it,j_0} = \frac{\partial \ln f\left(\mathbf{y}_{mit}^*, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\partial \ln \mathbf{x}_{it,j}}$$

resp.

(15)
$$\ln \iota_{it}^{CRS} = \frac{1}{2}\sum_{j=1}^{K}\left[\left(\frac{\varepsilon_{it,j_0}}{\sum_{i=1}^{K}\varepsilon_{it,j_0}} + \frac{\bar{\varepsilon}_j}{\sum_{i=1}^{K}\varepsilon_{j_0}}\right)\left(\ln x_{it,j} - \overline{\ln x_j}\right) + \frac{\bar{\varepsilon}_j}{\sum_{i=1}^{K}\varepsilon_{j_0}}\overline{\ln x_j} - \overline{\frac{\varepsilon_{it,j_0}}{\sum_{i=1}^{K}\varepsilon_{it,j_0}} \ln x_{it,j}}\right].$$

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

(16)
$$\ln \psi_{it} = \ln y_{it} - \overline{\ln y_{it}} \quad \text{and} \quad \ln \upsilon_{it} = \ln TE_{it} - \overline{\ln TE_{it}} .$$

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

(17)
$$\ln \tau_{it} = \frac{1}{2}\left[\left(\varepsilon_t + \bar{\varepsilon}_t\right)\left(t - \bar{t}\right) + \bar{\varepsilon}_t \bar{t} - \overline{\varepsilon_t t}\right], \quad with \quad \varepsilon_t = \frac{\partial \ln f\left(\mathbf{y}_{mit}^*, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\partial t},$$

(18)
$$\ln \mu_{it} = \frac{1}{2}\left[\left(\varepsilon_{m_0} + \bar{\varepsilon}_m\right)\left(m_i - \bar{m}_i\right) + \bar{\varepsilon}_m \bar{m}_i - \overline{\varepsilon_m m_i}\right],$$
$$with \quad \varepsilon_m = \frac{\partial \ln f\left(\mathbf{y}_{mit}^*, \mathbf{x}_{it}, t, m_i^*; \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}\right)}{\partial m_i}.$$

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

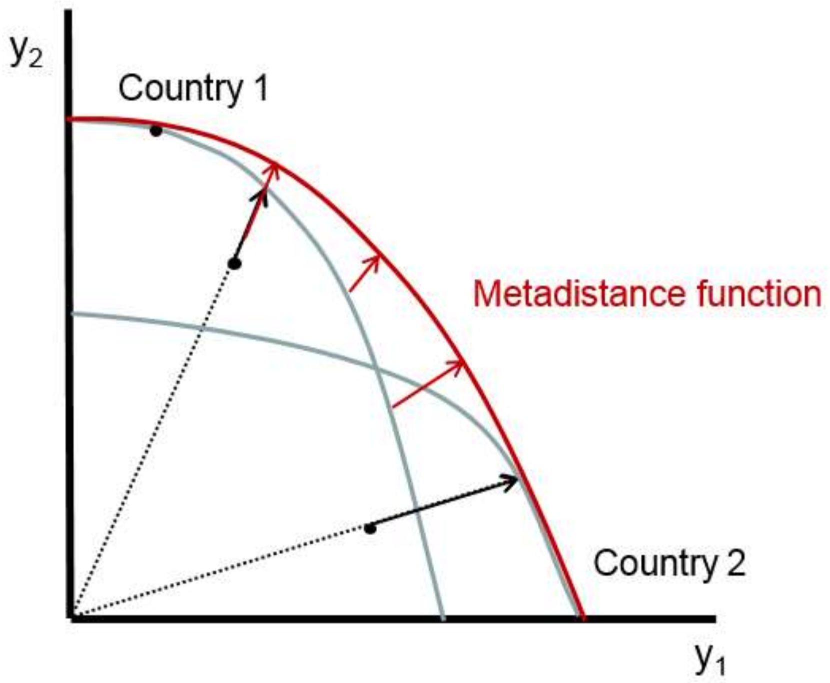
(19)
$$\ln TFP_{it} = \ln \psi_{it} - \ln \iota_{it}^{CRS} = \underset{SE}{\ln \iota_{it}} + \underset{TE}{\ln \upsilon_{it}} + \underset{TCH}{\ln \tau_{it}} + \underset{MAN}{\ln \mu_{it}}, \quad with \quad \ln \iota_{it} = \ln \iota_{it}^{VRS} - \ln \iota_{it}^{CRS}.$$

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 metadistnace function (for illustration see Figure 1) will allow us a coherent comparison of the level of technical efficiency and TFP among the EU member countries.

Figure 1: Metadistance function



Source: own depiction

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 are missing) and covers the period from 2004 to 2011 except for Austria (2005 – 2011), Bulgaria and Rumania (2008 – 2011).

The analysis uses information on three types of production: cereals, milk and pork. The multiple output distance function is estimated for each type of production. In each production we use three outputs and five inputs:

Cereal production: y_1 cereal production, y_2 other plant production, y_3 animal production, x_1 labour, x_2 land, x_3 capital, x_4 specific material and x_5 other material.

Milk production: 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.

Pork production: y_1 pork 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 in cereal production is represented by the costs of seeds, plants, fertilisers and crop protection. Specific material in dairy production creates cost on feed for grazing livestock and in pork production cost on feed for pigs and poultry.

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 of cereal production on total plant production, or 50 % share of dairy production on total animal production or 50 % of pork production on total animal production respectively.

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.

4 Results

4.1 Country multiple output distance function estimates and TFP calculations

In this chapter we first focus on parameter estimates and make a technology comparison among the countries as well as an evaluation of economies of scale. Moreover, the questions related to technological change are addressed. The comparison of trends in TE and TFP is carried out in the second and third part of this chapter. In these sections, we also address the question concerning catching up and falling behind processes. The chapters present the results separately for cereals, milk and pork production.

4.1.1 Parameter estimates

4.1.1.1 Cereals

Tables 1, 2 and 3 provide parameter estimates of the multiple output distance function (relation 10) for 24 EU member countries. 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 cereal 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 1). Then we verify the significance of heterogeneity in production structure. In particular, we evaluate the parameters on unobservable fixed management (Table 2). Finally, we concentrate on technological change and biased technological change.

Table 1 provides the estimated parameters conventionally discussed in the distance function, i.e. first order parameters on outputs and inputs of the multiple output distance function. Almost all parameters are significant even at 1 % significance level. This also holds for the majority of 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: $\beta_{y2} > 0$, $\beta_{y3} > 0$ and $\beta_{y2} + \beta_{y3} < 1$; and for inputs: $\beta_q < 0$ for q= x1, x2, x3, x4, x5. Table 1 shows that these conditions are met. Moreover, convexity in inputs requires $\beta_{qq} + \beta_q^2 - \beta_q > 0$ for q = x1, x2, x3, x4, x5. This condition holds for almost all countries 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, and parameters of inputs can be interpreted as elasticities of production on the sample mean. As far as the shares of outputs are concerned, the countries differ significantly in the production structure. Since we analyse specialized cereals companies (i.e. with the share of cereal production in total plant production exceeding 50 %), the parameters on y_2 are lower than 0.5 except for the Netherlands, where we did not distinguish between specialized and non-specialized due to the low number of observations of specialized companies. The estimates show that agricultural companies in most member countries are highly specialized in cereal

Table 1 First order parameters of the multiple output distance functions – cereal production

EU member country		Other plant production	Animal productio n	Labour	Land	Capital	Specific material	Other material	RTS
		y2	y3	x1	x2	x3	x4	x5	
Austria	Coeff.	0.0862	0.6522	-0.0752	-0.1303	-0.0497	-0.1506	-0.6982	-1.1039
		***	***	***	***	***	***	***	
Belgium	Coeff.	0.1072	0.7871	-0.1413	-0.0001	-0.0489	-0.1246	-0.6471	-0.9620
		***	***	***		***	***	***	
Bulgaria	Coeff.	0.3340	0.1036	-0.0632	-0.2879	-0.0704	-0.3247	-0.2064	-0.9526
		***	***	***	***	***	***	***	
Czech Republic	Coeff.	0.3278	0.1769	-0.0923	-0.1369	-0.0302	-0.3891	-0.3673	-1.0159
		***	***	***	***	***	***	***	
Germany	Coeff.	0.2132	0.3979	-0.0489	-0.2032	-0.0471	-0.2012	-0.6076	-1.1081
		***	***	***	***	***	***	***	
Denmark	Coeff.	0.1909	0.2343	-0.0959	-0.5992	-0.0273	-0.0653	-0.3208	-1.1085
		***	***	***	***	**	***	***	
Estonia	Coeff.	0.2108	0.0895	-0.0625	-0.2843	-0.0673	-0.3188	-0.2648	-0.9976
		***	***	***	***	***	***	***	
Spain	Coeff.	0.0265	0.2152	-0.1453	-0.1308	-0.0269	-0.2686	-0.3644	-0.9361
		***	***	***	***	***	***	***	
Finland	Coeff.	0.0781	0.4491	-0.1436	-0.2580	-0.0261	-0.1061	-0.6117	-1.1455
		***	***	***	***	***	***	***	
France	Coeff.	0.0775	0.5255	-0.0970	-0.1494	-0.1148	-0.1766	-0.5538	-1.0916
		***	***	***	***	***	***	***	
United Kingdom	Coeff.	0.1695	0.2661	-0.1924	-0.1202	-0.0335	-0.4099	-0.4360	-1.1920
		***	***	***	***	***	***	***	
Greece	Coeff.	0.0604	0.3934	-0.2360	-0.0911	0.0333	-0.1994	-0.3078	-0.8010
		***	***	***	***	***	***	***	
Hungary	Coeff.	0.2345	0.1174	-0.0416	-0.2732	-0.0542	-0.2090	-0.3915	-0.9696
		***	***	***	***	***	***	***	
Ireland	Coeff.	0.1743	0.3398	-0.0355	-0.4049	-0.1057	-0.3256	-0.2745	-1.1462
		***	***	**	***	***	***	***	
Italy	Coeff.	0.2057	0.1199	-0.0470	-0.3779	-0.0712	-0.2140	-0.2060	-0.9161
		***	***	***	***	***	***	***	
Lithuania	Coeff.	0.1915	0.1017	-0.0833	-0.2413	-0.0765	-0.3776	-0.2151	-0.9937
		***	***	***	***	***	***	***	
Latvia	Coeff.	0.1828	0.1362	-0.0070	-0.2077	-0.0948	-0.2743	-0.4082	-0.9920
		***	***		***	***	***	***	
Netherlands	Coeff.	0.6746	0.0754	-0.1216	-0.2544	-0.1066	-0.2947	-0.5124	-1.2898
		***	***	***	***	***	***	***	
Poland	Coeff.	0.1243	0.4206	-0.0597	-0.2655	-0.0485	-0.1469	-0.5359	-1.0565
		***	***	***	***	***	***	***	
Portugal	Coeff.	0.0660	0.2362	-0.0626	-0.1225	-0.0372	-0.2416	-0.3481	-0.8120
		***	***		***	**	***	***	
Romania	Coeff.	0.3563	0.1209	-0.0203	-0.4598	0.0260	-0.2004	-0.1856	-0.8402
		***	***	***	***	***	***	***	
Sweden	Coeff.	0.1180	0.2388	-0.0720	-0.2028	-0.0159	-0.0184	-0.8786	-1.1876
		***	***	***	***			***	
Slovenia	Coeff.	0.1153	0.5050	-0.0158	-0.2384	-0.0582	-0.1084	-0.6908	-1.1116
		***	***		***	***	***	***	
Slovakia	Coeff.	0.2407	0.0912	-0.2036	-0.0454	-0.0464	-0.4551	-0.2791	-1.0295
		***	***	***	**	***	***	***	

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

production with the share exceeding 40 % of the total production. Austria, Belgium, Germany, France, the Netherlands and Slovenia are exceptions. In these countries animal production is more pronounced. As far as the structure of plant production is concerned, specialized crop companies have a share of cereal production higher than 70% in most of cases. Other production types play a more significant role in Belgium, Bulgaria, the Czech Republic, Germany, the Netherlands and Romania.

The production elasticities of the individual countries share some common patterns. The highest elasticity is for material inputs, i.e. specific and other materials, and the lowest for capital. However, the differences among the countries are highly pronounced in the value of all elasticities. The sum of material inputs elasticity is in the interval -0.4 to -0.9. The interval of labour elasticity is from -0.04 to -0.24. The lowest land elasticity is in Slovakia (-0.05) and the highest in Denmark (-0.60). Capital elasticity in the majority of countries does not exceed -0.1. Moreover, the estimates of capital elasticity are quite low (lower than 0.05) in some countries, which can be connected with capital market imperfections, including limited access to capital and the use of old machinery by many farmers in these countries. Thus, we can already conclude that technology significantly differs among the countries.

As far as the economies of scale are concerned, there is no indication of economies of scale (the sum of the elasticities is about one) for the average farm in the Czech Republic, Estonia, Lithuania, Latvia, Sweden and Slovakia. Returns to scale increase for the average farm in Austria, Germany, Denmark, France, the United Kingdom, Ireland, the Netherlands, Poland and Slovakia. On the contrary, decreasing returns to scale were estimated for the average farm in Belgium, Bulgaria, Spain, Greece, Hungary, Italy, Portugal and Romania. That is, these results already suggest that the impact of scale efficiency (SE) on productivity change will be quite large in most member countries.

Table 2 provides the parameter estimates on unobservable management. Since the coefficients on unobservable management are highly significant in the majority of cases, we can conclude that the chosen specification well approximates the estimated relationship and that heterogeneity among companies is an important characteristic of farmers with cereal specialisation in almost all member countries. Unobservable management contributes positively to production in all member countries (positive Alpha_m). However, the positive impact of unobservable management accelerates for some countries (negative Alpha_mm) and decelerates for others (positive Alpha_mm). Unobservable management has also a different impact on production elasticities in individual countries. That is, if the coefficient is positive, the increasing management leads to an increase in production elasticity and vice versa. In terms of the relation between unobservable management and technical efficiency, the positive coefficient means the positive impact of a given input on technical efficiency and vice versa. Since the impact of unobservable management on production elasticities differs among the countries and no common pattern can be identified, we concentrate only on the role of technological change. Technological change has a positive impact on technical efficiency in almost half of the analysed countries, namely in Denmark, Spain, Finland, the United Kingdom, Greece, Ireland, Italy, Lithuania, the Netherlands, Romania and Slovenia. In the other countries, technological change has a negative contribution to technical efficiency development.

Table 2 Parameters on unobservable fixed management – cereal production

EU member country		Alpha_m	Time	Labour	Land	Capital	Specific material	Other material	Alpha_mm
			t	x1	x2	x3	x4	x5	
Austria	Coeff.	-0.2754	-0.0019	0.0119	0.0105	-0.0485	0.0006	0.0751	-0.0668
		***		*		***		***	***
Belgium	Coeff.	-0.1920	-0.0083	0.1298	-0.0377	-0.0949	0.0117	0.0664	0.0768
		***	***	***	***	***		***	***
Bulgaria	Coeff.	-0.0959	-0.0052	-0.0010	-0.1935	-0.0570	0.2111	-0.0034	0.2898
		***			***	***	***		***
Czech Republic	Coeff.	-0.0309	-0.0080	-0.0732	-0.2059	-0.0762	0.0675	0.2417	-0.1914
		***	***	***	***	***	***	***	***
Germany	Coeff.	-0.2377	-0.0028	-0.0150	-0.0778	-0.0152	0.0413	0.0901	0.0397
		***	***	***	***	***	***	***	***
Denmark	Coeff.	-0.1044	0.0032	-0.0893	-0.1377	0.0760	0.0313	0.1432	-0.3931
		***	*	***	***	***	***	***	***
Estonia	Coeff.	-0.1769	-0.0105	0.0388	-0.0525	0.0128	-0.0081	0.0226	0.0067
		***	**	**	**				
Spain	Coeff.	-0.3758	0.0159	-0.0645	-0.0818	0.0011	0.0718	-0.0108	-0.0953
		***	***	***	***		***	**	***
Finland	Coeff.	-0.0032	0.0068	-0.0686	0.0534	0.0258	0.0079	-0.2230	-0.4836
			***	***	***	***		***	***
France	Coeff.	-0.2246	-0.0044	-0.0324	-0.0150	-0.0032	0.0080	0.0632	0.0494
		***	***	***	***		***	***	***
United Kingdom	Coeff.	-0.2389	0.0091	-0.0340	-0.0288	-0.0471	0.0632	0.0544	-0.0346
		***	***	***	***	***	***	***	***
Greece	Coeff.	-0.3394	0.0124	-0.1157	-0.1071	0.0418	0.1692	-0.1031	0.0734
		***	***	***	***	***	***	***	***
Hungary	Coeff.	-0.2094	-0.0122	-0.0185	-0.0485	0.0072	0.0563	-0.0091	-0.0499
		***	***	***	***		***		***
Ireland	Coeff.	-0.1844	0.0051	-0.0621	0.0138	0.0022	0.0358	0.0550	0.0055
		***		***			**	***	
Italy	Coeff.	-0.2163	0.0065	-0.0420	-0.1488	-0.0137	0.1425	0.0076	0.0084
		***	***	***	***	**	***	*	
Lithuania	Coeff.	-0.1420	0.0109	-0.0213	-0.1637	-0.0524	0.1372	0.0549	0.0221
		***	***		***	***	***	***	**
Latvia	Coeff.	-0.0349	-0.0136	0.0883	0.2044	-0.0326	0.0122	-0.1520	-0.2586
		***	***	***	***	***		***	***
Netherlands	Coeff.	-0.0722	0.0099	0.1844	-0.2183	-0.1071	-0.0037	-0.0666	0.3714
		***	***	***	***	***		***	***
Poland	Coeff.	-0.1336	-0.0068	0.0092	-0.0345	-0.0529	-0.0497	0.0407	0.2232
		***	***	***	***	***	***	***	***
Portugal	Coeff.	-0.0741	-0.0311	0.2429	0.0316	-0.0770	0.0719	0.0457	0.2240
		***	***	***	**	***	***	**	***
Romania	Coeff.	-0.2142	0.0234	-0.0353	-0.0281	0.0212	0.0075	0.0122	0.0362
		***	***	***	***	***		**	***
Sweden	Coeff.	-0.2560	-0.0065	0.0934	-0.1440	-0.0061	-0.0039	0.0844	-0.0871
		***	**	***	***			***	***
Slovenia	Coeff.	-0.1820	0.0174	0.0155	-0.0678	-0.0257	0.0770	0.0342	0.0186
		***	***		***		***	**	
Slovakia	Coeff.	-0.0959	-0.0212	-0.0111	-0.3302	0.0362	0.2205	0.0756	-0.1704
		***	***		***	***	***	***	***

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

Table 3 provides the parameter estimates on technological change and biased technological change. Technological change has a significant positive contribution ($\beta_T < 0$) to the production possibilities in the majority of countries. Only Estonia, Spain, Latvia, Poland and Sweden are exceptions. The positive impact of technical change accelerates over time ($\beta_{TT} < 0$) in some countries, namely in Austria, Belgium, the Czech Republic, Greece, Hungary, Ireland, Romania and Slovenia. The others experienced a decelerating ($\beta_{TT} > 0$) positive contribution of technological change. The negative impact of technological change accelerates over time in Estonia, Spain, Latvia and Sweden. Only in Poland the negative contribution of technological change decelerates over time.

The biased technical change is pronounced in almost all countries (Table 3). However, the direction of biased technical change differs again among countries and no common patterns can be identified. In Austria, capital-using and material-saving impact can be observed. Labour-using and material-saving biased technical change was estimated for Bulgaria. The Czech Republic is characterized by material-using and labour- and capital- saving technical change. Germany experienced capital-using and material-saving biased technical change. The biased technical change is labour-using in Denmark, land-using in Finland, capital-using and material-saving in France, labour- and land-saving and material- using in the United Kingdom, land-saving and material-using in Greece, labour-using and land-saving in Hungary, land- ,capital-saving and material-using in Lithuania, land-using in the Netherlands, labour-using and material-saving in Portugal, capital-saving, land- and material-using in Romania, land-using, labour- and material-saving in Slovenia, and land-saving and labour- and material-using in Slovakia.

Since the period under investigation begins in 2004, it could be expected that at this stage of the European agricultural development, labour would become scarcer while capital would become more abundant. That is, labour-saving and capital-using technical changes could be expected. The fact that we revealed capital-using technical change only for Austria, Germany and France and even capital-saving for the Czech Republic, Lithuania and Romania together with negative technical change in five European countries indicates that serious adjustment problems exist, including problems in the capital market.

Table 3 Technological change and biased technological change – cereal production

EU member country		t	tt	x1*t	x2*t	x3*t	x4*t	x5*t
Austria	Coeff.	-0.0088	-0.0085	-0.0020	0.0005	-0.0179	0.0084	0.0101
		***	***			***	***	***
Belgium	Coeff.	-0.0109	-0.0092	-0.0017	0.0028	-0.0003	-0.0048	0.0032
		***	***					
Bulgaria	Coeff.	-0.0635	-0.0063	0.0002	-0.0250	-0.0148	-0.0020	0.0318
		***			*			***
Czech Republic	Coeff.	-0.0066	-0.0039	0.0069	-0.0026	0.0044	0.0002	-0.0083
		**	**	**		**		**
Germany	Coeff.	-0.0149	-0.0001	0.0002	-0.0013	-0.0032	-0.0005	0.0022
		***				***		*
Denmark	Coeff.	-0.0263	0.0039	-0.0122	0.0016	0.0070	-0.0005	-0.0026
		***	**	**				
Estonia	Coeff.	0.0311	0.0078	-0.0112	0.0160	-0.0048	-0.0105	-0.0028
		***	*					
Spain	Coeff.	0.0113	0.0114	0.0233	0.0227	-0.0054	-0.0303	-0.0001
		***	***	***	***	***	***	
Finland	Coeff.	-0.0170	0.0233	0.0067	-0.0176	0.0041	0.0055	-0.0063
		***	***		***			
France	Coeff.	-0.0131	0.0016	0.0009	0.0007	-0.0059	0.0103	-0.0068
		***	***			***	***	***
United Kingdom	Coeff.	-0.0363	0.0117	0.0075	0.0095	-0.0002	-0.0120	0.0002
		***	***	***	***		***	
Greece	Coeff.	-0.0038	-0.0079	-0.0054	0.0105	0.0007	-0.0086	-0.0022
		*	***		***		***	
Hungary	Coeff.	-0.0026	-0.0181	-0.0053	0.0087	0.0015	-0.0007	-0.0026
			***	*	**			
Ireland	Coeff.	-0.0170	-0.0222	0.0006	0.0215	-0.0116	0.0051	-0.0053
		***	***					
Italy	Coeff.	-0.0403	0.0024	-0.0015	-0.0033	0.0029	0.0010	-0.0002
		***						
Lithuania	Coeff.	-0.0075	0.0062	-0.0042	0.0198	0.0085	-0.0043	-0.0185
		**	*		**	**		**
Latvia	Coeff.	0.0144	0.0161	-0.0121	0.0030	-0.0115	-0.0076	0.0266
		***	***			*		***
Netherlands	Coeff.	-0.0208	0.0109	0.0082	-0.0106	0.0037	0.0018	-0.0030
		***	***		*			
Poland	Coeff.	0.0117	-0.0161	-0.0072	0.0170	-0.0004	-0.0023	-0.0091
		***	***	***	***		**	***
Portugal	Coeff.	-0.0265	0.0303	-0.0395	-0.0012	-0.0021	0.0194	-0.0029
		***	***	*			*	
Romania	Coeff.	-0.0652	-0.0208	0.0018	-0.0155	0.0102	-0.0202	0.0063
		***	***		**	***	***	
Sweden	Coeff.	0.0009	0.0123	0.0180	0.0135	-0.0106	-0.0134	-0.0025
			***	**	*	*	**	
Slovenia	Coeff.	-0.0163	-0.0385	0.0222	-0.0924	0.0086	0.0380	0.0361
		*	***	*	***		***	**
Slovakia	Coeff.	-0.0190	0.0036	-0.0185	0.0247	0.0070	0.0051	-0.0261
		***		***	***			***

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

4.1.1.2 Milk

The results of parameter estimates of the multiple output distance function for milk production are presented in the same way as the parameter estimates of cereals production. Tables 4, 5 and 6 provide parameter estimates for 23 EU member countries (the multiple output distance function for Greece could not be estimated due to the low number of observations).

Table 4 provides the first order parameters on output and inputs of the multiple output distance function and returns to scale. From the statistical point of view, almost all estimated parameters are significant with 1% significance level. The estimated parameters also met the theoretical properties of the output distance functions – the monotonicity of outputs and inputs and convexity in inputs. This holds for almost all the countries evaluated on the sample mean.

The first order parameters of outputs (y2 and y3) point to the production structure differences among EU member countries. Since we analysed farms specialized in milk production with the share of milk production on total animal production exceeding 50 %, the share of other animal production on 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 y2 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 on their total output is lower than 10 %.

The production elasticities of the individual countries have some common patterns. As in the case of cereals, 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. It is the case of Slovakia where 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.

Table 4 *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
		***	***	***	***	***	***	***	
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
		***	***	***	***	**	***	***	
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
		***	***	***	***	*	***	***	
Estonia	Coeff.	0.0805	0.3111	-0.1513	-0.1282	-0.0800	-0.4832	-0.2333	-1.0760
		***	***	***	***	***	***	***	
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
		***	***	***	***	***	***	***	
United Kingdom	Coeff.	0.0697	0.1186	-0.0835	-0.0827	-0.0676	-0.4118	-0.3771	-1.0227
		***	***	***	***	***	***	***	
Greece	Coeff.	LNO	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Hungary	Coeff.	0.0852	0.3410	-0.1149	-0.0706	-0.0501	-0.3641	-0.3732	-0.9729
		***	***	***	***	***	***	***	
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
		***	***	***	***	***	***	***	
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
		***	***	***		***	***	***	
Netherlands	Coeff.	0.0293	0.0117	-0.0873	-0.3180	-0.0864	-0.3305	-0.1684	-0.9907
		***	***	***	***	***	***	***	
Poland	Coeff.	0.0946	0.3221	-0.1081	-0.2439	-0.1321	-0.2133	-0.3725	-1.0701
		***	***	***	***	***	***	***	
Portugal	Coeff.	0.0575	0.1726	-0.1410	-0.0556	-0.0205	-0.4821	-0.2510	-0.9503
		***	***	***	***	***	***	***	
Romania	Coeff.	0.1829	0.4990	-0.0741	-0.3282	-0.0117	-0.2655	-0.2184	-0.8979
		***	***	***	***	**	***	***	
Sweden	Coeff.	0.0223	0.3663	-0.1025	-0.2230	-0.0438	-0.3808	-0.2602	-1.0102
		***	***	***	***	***	***	***	
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; LNO – Low Number of Observations

Source: own calculation

Moreover, Table 4 reveals other differences in technology among the analysed countries. The sum of material inputs elasticity is in the interval -0.43 (Slovakia) to -0.80 (Denmark) and the elasticity of capital is in interval -0.01 (Spain) to -0.13 (Poland). The elasticity of labour is the lowest in Austria (-0.04). Furthermore, labour elasticity is the lowest among individual elasticities in France and Slovenia where the impact of capital on production is more pronounced than in other countries. Thus, the technology of milk producers in these countries is characterized by high mechanization. This also suggests that milk producers do not face capital market imperfections and have access to capital. On the other hand, countries like Belgium, the Czech Republic, Denmark, Spain, Portugal, Romania and Sweden have a capital elasticity lower than 0.05. The low capital intensity is substituted by other inputs, especially by labour. This suggests that there may some capital market imperfections. Finally, we can conclude that the estimates revealed significant differences in t technology among the countries.

As far as economies of scale are concerned, the constant returns to scale were estimated (the sum of the elasticities is about one) for the average farm in Germany, the United Kingdom, 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).

Table 5 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 also for milk specialised producers in EU member states. The unobservable management contributes positively to production in all analysed countries (positive Alpha_m). The effect of unobservable management is predominantly decelerating (positive Alpha_mm). The accelerating impact of unobservable management (negative Alpha_mm) can be found in Bulgaria, Germany, Ireland, Italy, Lithuania, the Netherlands, Portugal, Sweden, Slovenia and Slovakia.

The impact of unobservable management on production elasticities differs significantly among the analysed countries. Increasing management leads to an increase especially in specific material elasticity (19 cases), where the effect of management has also the highest power. On the other hand, increasing management leads to the decrease in labour elasticity (17 cases) and land elasticity (16 cases). The impact of management on capital and other material is approximately in half the countries positive and negative in the other half.

Table 5 Parameters on unobservable fixed management – milk production

EU member country		Alpha_m	Time	Labour	Land	Capital	Specific material	Other material	Alpha_mm
			t	x1	x2	x3	x4	x5	
Austria	Coeff.	-0.1266	0.0039	-0.0038	0.2042	0.0778	0.0271	0.0170	0.5735
		***	***		***	***	***	***	***
Belgium	Coeff.	-0.2411	-0.0043	0.0301	0.0011	-0.0078	0.0229	-0.0414	0.0280
		***	***	***			***	***	***
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	0.1000	0.3494
		***	***	***	***	***	**	***	***
Germany	Coeff.	0.2077	0.0051	-0.0035	0.0196	-0.0220	-0.0452	0.0392	0.0390
		***	***		***	***	***	***	***
Denmark	Coeff.	-0.1130	-0.0025	-0.0100	-0.0145	-0.0034	0.0374	0.0345	0.0259
		***	**		**		***	***	***
Estonia	Coeff.	-0.1419	0.0008	0.0190	-0.0793	-0.0062	0.0185	0.0520	0.0461
		***		*	***			***	***
Spain	Coeff.	0.2216	-0.0050	0.0776	0.0210	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	-0.0270	0.0251	0.0487	-0.0153	0.0175
		***	***	***	***	***	***	***	***
United Kingdom	Coeff.	-0.1668	0.0043	-0.0165	-0.0344	0.0083	0.0389	0.0067	0.0095
		***	***	**	***		***		***
Greece	Coeff.	LNO	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Hungary	Coeff.	-0.1553	-0.0010	-0.0033	0.0576	-0.1056	-0.1255	0.1451	0.0999
		***			***	***	***	***	***
Ireland	Coeff.	0.2727	0.0011	0.0627	-0.0489	0.0414	-0.0393	0.1349	0.2374
		***	***	***	***	***	***	***	***
Italy	Coeff.	-0.2831	0.0040	-0.0671	-0.0586	0.0063	0.1370	-0.0073	-0.0369
		***	***	***	***	*	***	***	***
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
		***	***				***		***
Netherlands	Coeff.	0.0784	-0.0004	0.0780	-0.0141	0.0474	0.0762	0.0910	0.2693
		***		***	***	***	***	***	***
Poland	Coeff.	-0.2010	-0.0037	-0.0134	-0.0359	0.0050	0.0227	0.0421	0.0095
		***	***	**	***		***	***	***
Portugal	Coeff.	0.0868	0.0005	0.1090	0.1182	0.0240	-0.1395	0.1295	0.3590
		***	***	***	***	***	***	***	***
Romania	Coeff.	0.2516	0.0065	0.0457	0.0386	0.0001	-0.0243	-0.0379	-0.0608
		***	*	***	***		***	***	***
Sweden	Coeff.	0.2234	-0.0002	-0.0411	0.0412	-0.0183	-0.0107	0.1176	0.1941
		***		***	***	***		***	***
Slovenia	Coeff.	-0.1824	-0.0049	-0.0121	-0.0864	-0.0025	0.0752	0.0497	-0.0270
		***	**		***		***	***	***
Slovakia	Coeff.	0.3191	0.0210	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

Moreover, Table 5 shows the impact of technological change on technical efficiency. This impact is significantly positive in eight countries, namely in Austria, Bulgaria, Spain, Finland, the United Kingdom, Italy, Lithuania and Latvia. Technological change negatively affected technical efficiency development in Belgium, the Czech Republic, Germany, Denmark, France, Ireland, Poland, Portugal, Romania, Slovenia and Slovakia with at least 10 % significance level.

Table 6 provides the parameter estimates on technological change and biased technological change. Technological change contributes positively to production possibilities in 16 countries at 10 % level of significance. The positive impact of technological change accelerates over time for half of the mentioned countries - Austria, Germany, France, Ireland, Netherlands, Romania, Sweden and Slovenia. On the other hand, the positive impact of technological change decelerates over time in Denmark, Estonia, Finland and Italy. Parameter βTT is not significant in Belgium, the Czech Republic, Portugal and Slovakia.

A significant negative contribution of technological change to production possibilities was estimated only for Spain, where the negative contribution accelerates, and in Poland, where the negative contribution to technological change decelerates over time.

The biased technological change is pronounced for almost all analysed countries, except for Hungary and Romania, see Table 6. However, significant 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, the United Kingdom, Italy and Slovakia. The biased technological change is land-saving in Belgium, Estonia, 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 capital elasticity together with the direction of biased technological change suggest that milk producers have better access to capital than to cereals producers, which allows them to innovate their production technology and makes them more competitive in the European market. Considering specific material only, the biased technological change is predominantly material-using, except for the Netherlands.

Table 6 Technological change and biased technological change – milk production

EU member 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
		***			***		***	***
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
		***		**		***		
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
		***	***	***		***	***	**
Estonia	Coeff.	-0.0038	0.0052	0.0001	0.0131	-0.0025	-0.0039	-0.0116
		*	**		*			*
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
		***	***	**	**	***	***	***
United Kingdom	Coeff.	-0.0011	-0.0075	-0.0124	0.0021	-0.0032	-0.0025	0.0125
			***	***				***
Greece	Coeff.	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Hungary	Coeff.	0.0005	-0.0058	0.0086	0.0127	-0.0058	-0.0088	-0.0053
			*					
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
		***	***	***	***	***	***	
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
						**		
Netherlands	Coeff.	-0.0078	-0.0046	-0.0011	-0.0004	-0.0030	0.0070	-0.0084
		***	***				***	**
Poland	Coeff.	0.0155	-0.0112	0.0031	-0.0043	0.0058	-0.0027	-0.0038
		***	***		***	***	**	**
Portugal	Coeff.	-0.0163	0.0022	-0.0019	-0.0020	0.0028	-0.0039	0.0038
		***					*	
Romania	Coeff.	-0.0389	-0.0275	0.0004	-0.0001	0.0001	-0.0047	-0.0072
		***	***					
Sweden	Coeff.	-0.0059	-0.0049	-0.0037	-0.0077	-0.0079	0.0049	0.0124
		***	***		**	***		***
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; LNO – Low Number of Observations

Source: own calculation

4.1.1.3 Pork

Tables 7, 8 and 9 provide parameter estimates of multiple output distance function for pork producers in 23 EU member countries (the multiple output distance function for Ireland could not be estimated due to the low number of observations. For some other countries for instance, Greece and Romania, the multiple output distance function was estimated. However, the low number of observations negatively affected the estimates.

As in the previous chapters, we start the discussion on the first order parameters and economies of scale. The parameter estimates of the first order parameters on output and inputs of the multiple output distance function and returns to scale are listed in Table 7. The majority of estimated parameters are significant with 1 % significance level. The parameter estimates of output distance function meet monotonicity requirements for all output and inputs. The land in Belgium, the United Kingdom, Slovakia and capital in Bulgaria are exceptions. However, these parameters are not, except for Belgium, significant with 5 % significance level. In addition, the convexity in inputs holds for almost all countries evaluated on the sample mean.

The first order parameters of outputs represent the share of outputs y2 and y3 in the total output. Pork producers with a higher share of other animal production can be found in the Czech Republic and Finland, where the parameter of y2 exceeds 0.15. Pork specialized producers in the majority of the analysed countries can be characterized also by a considerable high share of plant production. The share is higher than 30 % in 15 countries, namely in Austria, the Czech Republic, Germany, Denmark, Estonia, Finland, Hungary, Italy, Lithuania, Latvia, Poland, Portugal, Sweden and Slovenia. On the other hand the share of plant and other animal production in total output is around 10 % in the United Kingdom and the Netherlands pointing to the high specialization of English and Dutch farms.

Despite the pronounced differences in technology among the countries some common patterns can be found. As in the case of cereals and milk production, the elasticities for materials inputs (specific and other materials) have the highest values and the elasticities for capital are the lowest. Estonia is an exception. In Estonia the land has the highest elasticity (-0.60) and the sum of material elasticities (specific and other) is the lowest (-0.47) of all countries. The elasticity of capital is the highest in Italy (-0.17). The high value of capital elasticity can be also found in France (-0.15), Finland (-0.13), Portugal (-0.12) and in Austria (-0.11). However, there are no similarities in impacts of other inputs (land, labour) in these five countries. For example, labour elasticity in Portugal is the highest of the analysed countries (-0.26) while labour elasticity in France (-0.06) has the second lowest value. Italian farms, on the other hand, are characterized by the highest impact of land (-0.28).

As far as economies of scale are concerned, no indication of economies of scale (the sum of the elasticities is about one) was estimated for the average farm in the Czech Republic, Finland, France, Hungary, Lithuania and Slovenia. The other pork producers experienced an increasing returns to scale. Thus the impact of scale efficiency on productivity change is large in most member states, such as in the case of cereal production.

Table 7 First order parameters of the multiple output distance functions – pork 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.	0.0745	0.3501	-0.1042	-0.1024	-0.1107	-0.4625	-0.3224	-1.1022
		***	***	***	***	***	***	***	
Belgium	Coeff.	0.0527	0.0503	-0.0685	0.0350	-0.0228	-0.7355	-0.2311	-1.0229
		***	***	***	***	**	***	***	
Bulgaria	Coeff.	0.5691	0.5314	-0.3705	-0.2626	0.0008	-0.2067	-0.0676	-0.9066
		***	***	***	***		***	**	
Czech Republic	Coeff.	0.2370	0.4817	-0.1283	-0.0689	-0.0327	-0.2509	-0.5340	-1.0147
		***	***	***	***	***	***	***	
Germany	Coeff.	0.0623	0.3970	-0.0981	-0.1568	-0.0991	-0.3459	-0.3873	-1.0871
		***	***	***	***	***	***	***	
Denmark	Coeff.	0.0562	0.3455	-0.1440	-0.1920	-0.0783	-0.4752	-0.1992	-1.0886
		***	***	***	***	***	***	***	
Estonia	Coeff.	0.0071	0.5598	-0.1449	-0.6041	-0.0714	-0.2617	-0.2079	-1.2900
			***	***	***	*	***	**	
Spain	Coeff.	0.0953	0.1563	-0.2572	-0.0362	-0.0062	-0.5104	-0.2341	-1.0440
		***	***	***	***		***	***	
Finland	Coeff.	0.1771	0.3882	0.0301	-0.1049	-0.1320	-0.4082	-0.4126	-1.0275
		***	***		*	***	***	***	
France	Coeff.	0.0990	0.1194	-0.0610	-0.0006	-0.1472	-0.5450	-0.2505	-1.0043
		***	***	***		***	***	***	
United Kingdom	Coeff.	0.0571	0.0565	-0.1089	0.0107	-0.0117	-0.7051	-0.3102	-1.1251
		***	***	***			***	***	
Greece	Coeff.	-0.0257	0.3061	-0.8309	-0.0842	0.0855	-0.4056	0.0554	-1.1798
Hungary	Coeff.	0.0755	0.4339	-0.0933	-0.1040	-0.0710	-0.4551	-0.3014	-1.0247
		***	***	***	***	***	***	***	
Ireland	Coeff.	LNO	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Italy	Coeff.	0.0370	0.5059	-0.0797	-0.2811	-0.1678	-0.2976	-0.2196	-1.0458
		***	***	***	***	***	***	***	
Lithuania	Coeff.	0.1228	0.5280	-0.1934	-0.0585	-0.0026	-0.2226	-0.5319	-1.0090
		***	***	***	**		***	***	
Latvia	Coeff.	0.0430	0.5233	0.0185	-0.1065	-0.0803	-0.3121	-0.4632	-0.9436
		***	***		***	***	***	***	
Netherlands	Coeff.	0.0908	0.0229	-0.1314	0.0099	-0.0631	-0.6608	-0.2471	-1.0925
		***	***	***		***	***	***	
Poland	Coeff.	0.0737	0.4916	-0.0769	-0.2064	-0.0862	-0.3507	-0.3596	-1.0799
		***	***	***	***	***	***	***	
Portugal	Coeff.	0.1124	0.3536	-0.2601	-0.0201	-0.1209	-0.3104	-0.3715	-1.0829
		***	***	***		***	***	***	
Romania	Coeff.	44.6418	-10.8183	-55.7818	49.9886	-14.1476	-44.5424	48.0238	-16.4594
		*							
Sweden	Coeff.	0.0715	0.3171	-0.0489	-0.1378	-0.0539	-0.4539	-0.4186	-1.1130
		***	***	***	***	***	***	***	
Slovenia	Coeff.	0.0950	0.4430	-0.0455	-0.0633	-0.0465	-0.3445	-0.4881	-0.9879
		***	***		*	*	***	***	
Slovakia	Coeff.	0.0932	0.6521	-0.2931	0.0602	-0.0357	-0.2094	-0.5695	-1.0477
		***	***	***	*		***	***	

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively; LNO – Low Number of Observations; The parameter estimates for some countries were negatively influenced by low number of observations.

Source: own calculation

Table 8 provides the parameter estimates on unobservable management. The coefficients on unobservable management are highly significant in the cases of the Czech Republic, Germany, the United Kingdom, Denmark, Spain, Italy, Poland and Slovenia. For these countries we can conclude that the chosen specification well approximates the estimated relationship and that heterogeneity among farms is an important characteristic of agricultural companies specialized in pork production. The unobservable management contributes positively to production in all analysed countries (positive Alpha_m). This effect is significantly accelerating (Alpha_mm has a positive value) in eight countries, namely in Austria, Estonia, Spain, Latvia, the Netherlands, Poland, Portugal and Sweden. The decelerating impact of unobservable management (negative Alpha_mm) can be observed in the Czech Republic, Germany, Denmark, the United Kingdom, Italy, Lithuania and Slovenia.

The impact of unobservable management on production elasticities differs among analysed countries. Increasing management leads to an increase especially in specific material elasticities (14 cases), where the effect of management has also the highest power. On the other hand increasing management leads to a decrease in labour elasticities (12 cases). A similar impact of unobservable management was estimated in milk production. This can be again reinterpreted for the relation between unobservable management and technical efficiency through a given input.

Finally, technological change has a significantly positive impact on technical efficiency in five countries, namely in Spain, the United Kingdom, Italy, Latvia and Slovenia. On the other hand, the contribution of technological change to technical efficiency development is significantly negative in eight countries: Austria, Czech Republic, Germany, Denmark, Finland, Lithuania, Poland and Portugal.

Table 8 Parameters on unobservable fixed management – pork production

EU member country		Alpha_m	Time	Labour	Land	Capital	Specific material	Other material	Alpha_mm
			t	x1	x2	x3	x4	x5	
Austria	Coeff.	0.2140	0.0112	0.0379	-0.0200	0.0095	-0.0645	-0.0181	0.0438
		***	***	**	*		***		***
Belgium	Coeff.	-0.1131	-0.0016	0.0211	0.0474	-0.0081	0.0391	-0.0260	0.0239
		***			***		***		***
Bulgaria	Coeff.	-0.0047	-0.3240	0.5191	0.1635	-0.2122	-0.1247	-0.0618	-0.3102
			***	***	***	***	***	***	***
Czech Republic	Coeff.	-0.0621	-0.0275	0.0313	-0.1235	0.0221	-0.0323	0.0775	0.2640
		***	***	***	***	***	***	***	***
Germany	Coeff.	-0.1555	-0.0029	0.0909	0.0331	-0.0180	0.0614	-0.0142	0.1196
		***	***	***	***	***	***	***	***
Denmark	Coeff.	-0.0708	-0.0094	-0.0934	0.0247	-0.0503	0.1107	0.0184	0.1115
		***	***	***	***	***	***		***
Estonia	Coeff.	-0.1451	0.0087	0.0325	0.0233	0.0432	0.0139	-0.0380	-0.1903
		***				*			***
Spain	Coeff.	-0.2037	0.0373	-0.1119	-0.0340	0.0043	0.0862	0.0249	-0.1083
		***	***	***	***		***	*	***
Finland	Coeff.	0.0624	0.0124	0.0905	-0.0108	0.1397	-0.1313	0.0057	-0.0206
		***	*	**		***	***		
France	Coeff.	0.1238	0.0014	0.0356	-0.0073	0.0239	-0.1034	0.0198	0.0067
		***		***		**	***	*	
United Kingdom	Coeff.	0.0647	-0.0251	0.1758	-0.0674	-0.0070	-0.2034	0.1403	-0.1569
		***	***	***	***		***	***	***
Greece	Coeff.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hungary	Coeff.	0.1337	0.0026	0.0565	-0.0594	-0.0163	-0.0148	0.0397	0.0085
		***		***	***		**	**	
Ireland	Coeff.	LNO	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Italy	Coeff.	0.2500	-0.0110	0.1175	0.1218	0.1003	-0.0897	-0.0156	-0.2234
		***	**	***	***	***	***		***
Lithuania	Coeff.	-0.0236	-0.0679	-0.3660	0.0053	-0.0072	-0.0258	0.0202	0.1532
		**	***	***			***		***
Latvia	Coeff.	0.0072	-0.0180	0.0303	-0.2239	0.0103	-0.0402	0.2604	0.3398
			***		***		***	***	***
Netherlands	Coeff.	0.0960	0.0035	0.0543	-0.0068	0.1315	-0.1615	0.0180	0.0722
		***		***		***	***		***
Poland	Coeff.	-0.1512	-0.0014	-0.0270	-0.0350	-0.0158	0.0380	0.0228	-0.0087
		***	**	***	***	***	***	***	***
Portugal	Coeff.	0.1981	0.0562	-0.0222	0.0150	0.0830	0.0046	-0.1336	0.0792
		***	***			***		***	**
Romania	Coeff.	-7.6128	-0.0063	-0.0130	0.0181	-0.0043	0.0140	-0.0613	-0.0409
								**	***
Sweden	Coeff.	0.1731	0.0005	0.0212	0.0062	-0.0168	-0.0721	0.0512	0.0306
		***				*	***	***	***
Slovenia	Coeff.	0.0974	-0.0824	0.3291	0.0935	-0.0609	-0.1042	-0.0377	-0.1443
		***	***	***	**	**	***		***
Slovakia	Coeff.	0.0326	0.0554	-0.1827	0.0572	-0.0081	0.0391	0.1091	0.2477
		**	***	***	**		***	***	***

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively; LNO – Low Number of Observations; The parameter estimates for some countries were negatively influenced by low number of observations – as it is the case of e.g. Romania and Greece.

Source: own calculation

Table 9 provides the parameter estimates on technological change and biased technological change. Technological change has a significant positive contribution to the production possibilities in the majority of the countries. A significant negative contribution can be observed only in Poland and in Sweden. The positive impact of technological change accelerates over time in the Czech Republic, Lithuania, the Netherlands and Slovenia. On the other hand, the positive impact of technological change decelerates over time in Denmark, the United Kingdom and Portugal. Parameter β_{TT} is not significant in Germany, France and Latvia. In Poland, the negative impact of technological change decelerates over time and this result is similar as in the case of Polish milk production. In Sweden, on the other hand, the negative contribution of technological change accelerates over time.

The biased technological change is pronounced in almost all analysed countries. However, the direction of biased technological change differs among countries and there are no common patterns. In most of cases, biased technological change can be observed for land and capital. However, the frequencies of these inputs using or saving technological change are more or less balanced. That is, the biased technological change is land-using in Austria, the Czech Republic, Germany, Finland and Portugal and land-saving in Denmark, Lithuania, Latvia and Poland. The capital-using biased technological change can be found in the Czech Republic, Germany, Italy, the Netherlands and Slovenia. On the other hand, the capital-saving technological change is typical for France, the United Kingdom, Lithuania and Poland. Austria, the United Kingdom, Poland and Portugal can be characterized by labour-saving technological change. Estonia and France experienced labour-using biased technological change. The biased technological change is material-saving in the majority of cases. There can also be found substitution between specific and other materials. It is the case of the Czech Republic, France and the United Kingdom.

The presumption of labour saving and capital using biased technological change cannot be confirmed.

Table 9 Technological change and biased technological change - pork production

EU member country		t	tt	x1*t	x2*t	x3*t	x4*t	x5*t
Austria	Coeff.	0.0078	-0.0095	0.0262	-0.0293	-0.0129	0.0058	0.0135
			**	***	***			
Belgium	Coeff.	0.0068	0.0053	0.0034	0.0033	0.0226	-0.0105	-0.0263
		***	**			***	**	***
Bulgaria	Coeff.	-0.0385	-0.0454	-0.0220	0.0291	0.1625	-0.1273	-0.0334
		***	***		**	***	***	*
Czech Republic	Coeff.	-0.0056	-0.0120	0.0034	-0.0150	-0.0068	-0.0109	0.0317
		***	***		***	***	***	***
Germany	Coeff.	-0.0432	-0.0001	0.0040	-0.0054	-0.0060	0.0004	0.0128
		***			**	***		***
Denmark	Coeff.	-0.0544	0.0052	-0.0002	0.0298	0.0064	-0.0294	-0.0069
		***	**		***		***	
Estonia	Coeff.	-0.0363	0.0300	-0.0850	-0.0484	-0.0215	0.0342	0.0663
			**	***				
Spain	Coeff.	0.0064	0.0137	0.0183	0.0001	0.0008	-0.0086	-0.0100
			**	*			**	
Finland	Coeff.	-0.1555	-0.0315	-0.0681	-0.2027	-0.0313	0.1645	0.0804
		***			***		**	
France	Coeff.	-0.0071	0.0023	-0.0104	0.0024	0.0159	0.0218	-0.0242
		***		**		**	***	***
United Kingdom	Coeff.	-0.0134	0.0116	0.0223	0.0027	0.0211	0.0197	-0.0630
		***	***	***		***	***	***
Greece	Coeff.	-0.0259	0.0757	0.4330	-0.1107	-0.0438	0.0611	0.0708
Hungary	Coeff.	-0.0105	-0.0004	-0.0066	-0.0058	0.0030	-0.0094	0.0175
		*						
Ireland	Coeff.	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Italy	Coeff.	-0.0035	-0.0019	-0.0172	0.0033	-0.0221	0.0056	0.0156
						***		**
Lithuania	Coeff.	-0.0297	-0.0295	0.0367	0.0367	0.0610	-0.0002	-0.0738
		***	***		**	***		***
Latvia	Coeff.	-0.0161	0.0050	-0.0058	0.0236	-0.0078	0.0019	0.0003
		**			*			
Netherlands	Coeff.	-0.0137	-0.0073	-0.0046	0.0003	-0.0247	0.0268	-0.0122
		***	**			***	***	
Poland	Coeff.	0.0218	-0.0163	0.0040	0.0081	0.0026	-0.0116	0.0008
		***	***	**	***	*	***	
Portugal	Coeff.	-0.0507	0.0455	0.0669	-0.0203	-0.0320	-0.0104	0.0511
		**	***	*	***			***
Romania	Coeff.	-10.3885	-0.0165	-0.0272	0.0127	0.0283	0.0247	-0.0311
						*		
Sweden	Coeff.	0.0072	0.0050	0.0053	0.0000	-0.0061	0.0037	-0.0072
		***	**					
Slovenia	Coeff.	-0.0257	-0.0267	-0.0268	0.0040	-0.0284	0.0347	-0.0083
		***	***			**	***	
Slovakia	Coeff.	-0.0135	0.0048	0.0021	0.1050	-0.0045	0.0293	-0.1411
					***		**	***

Note: ***, **, * denotes significance at the 1%, 5%, and 10% levels respectively; LNO – Low Number of Observations; The parameter estimates for some countries were negatively influenced by low Number of observations – as it is the case of. Romania.

Source: own calculation

4.1.2 Technical efficiency

This chapter provides the technical efficiency estimates for cereal, milk and pork production in the analysed EU member countries. Since the technical efficiency estimates are country specific we concentrate predominantly on discussing the significance of technical efficiency and its distribution, and on comparing trends in technical efficiency developments and their components. The overall comparison of the level of technical efficiency among EU member states will be carried out using metafrontier analysis (chapter 4.2).

4.1.2.1 Cereals

Table 10 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}.

Table 10 Technical efficiency – cereal production

EU member country	Sigma	Lambda	Statistical characteristics of technical efficiency					
			Mean	Std.Dev	Min.	Max	1st Decile	10th Decile
Austria	0.2573***	2.3210***	0.8385	0.0858	0.2865	0.9789	0.7336	0.9200
Belgium	0.1875***	1.7686***	0.8804	0.0583	0.5266	0.9755	0.8074	0.9385
Bulgaria	0.4038***	1.1859***	0.7614	0.0855	0.1685	0.9378	0.6531	0.8621
Czech Republic	0.1960***	0.5382**	0.9233	0.0180	0.8060	0.9696	0.9006	0.9438
Germany	0.2506***	2.6177***	0.8397	0.0854	0.1881	0.9830	0.7318	0.9264
Denmark	0.2191***	1.4762***	0.8246	0.0804	0.4444	0.9798	0.7122	0.9147
Estonia	0.3300***	2.3096***	0.7962	0.1047	0.2648	0.9524	0.6457	0.9099
Spain	0.5053***	2.4878***	0.7137	0.1401	0.0338	0.9579	0.5076	0.8669
Finland	0.3401***	1.8927***	0.7253	0.1290	0.1985	0.9576	0.5441	0.8773
France	0.2182***	2.0856***	0.8617	0.0732	0.2307	0.9861	0.7682	0.9327
United Kingdom	0.2583***	1.7024***	0.8437	0.0696	0.3695	0.9684	0.7545	0.9146
Greece	0.2625***	1.3986***	0.8513	0.0646	0.3552	0.9702	0.7742	0.9121
Hungary	0.3677***	2.0765***	0.7796	0.1061	0.0983	0.9604	0.6395	0.8924
Ireland	0.2583***	2.2338***	0.8367	0.0853	0.4300	0.9665	0.7127	0.9246
Italy	0.3558***	1.7223***	0.7932	0.0917	0.0455	0.9536	0.6689	0.8938
Lithuania	0.4118***	2.3351***	0.7521	0.1221	0.2098	0.9542	0.5790	0.8891
Latvia	0.3851***	2.5535***	0.7293	0.1309	0.2590	0.9508	0.5382	0.8880
Netherlands	0.3386***	1.6873***	0.7560	0.1137	0.2556	0.9575	0.5980	0.8848
Poland	0.2375***	1.2344***	0.8446	0.0643	0.1505	0.9803	0.7606	0.9154
Portugal	0.4276***	3.1661***	0.7207	0.1404	0.2007	0.9706	0.5251	0.8840
Romania	0.2766***	1.2436***	0.8493	0.0559	0.4647	0.9570	0.7762	0.9078
Sweden	0.3712***	2.8722***	0.7706	0.1188	0.0997	0.9638	0.6086	0.9021
Slovenia	0.4490***	7.0269***	0.7250	0.1509	0.2858	0.9690	0.5196	0.9089
Slovakia	0.3476***	2.0530***	0.7697	0.1079	0.3499	0.9572	0.6253	0.8885

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

Thus, the parameter indicates the significance of TE in the residual variation. A value smaller than one suggests that variation in uit is less pronounced than variation in the random component vit. Since λ is highly significant in all EU member countries and higher than one, the estimates indicate that efficiency differences among cereal producers are important reasons for variation in production. Only the Czech Republic is an exception with λ smaller than one, which suggests that the differences in efficiency of inputs use are rather small among Czech cereal producers.

The average technical efficiency in EU member countries is about 0.8 with a variation of approximately +/- 10 %. This suggests that on average farmers do not exploit sufficiently their production possibilities in most EU countries. The table shows that the average technical efficiency in individual countries is the lowest in Spain (0.71) and the highest in the Czech Republic (0.92). However, table 4 provides only country specific estimates of technical efficiency which cannot be used for comparative purposes. This comparison will be done using the metafrontier analysis in chapter 4.2.

The variation of the average technical efficiency is not large for all EU member countries even if huge differences among the best and the worst farmers exist. High technical efficiency of the 10 % best farmers is a common feature in all countries. In particular, the technical efficiency is higher than 0.86 and for most countries exceeds 0.9. That is, the top 10 % producers highly exploit their production possibilities. On the other hand, the worst 10 % significantly differ among countries. In many countries, the worst 10 % farmers have a technical efficiency lower than 0.65. This suggests that these farmers will have problems to keep pace with competitors due to inefficient inputs use (evaluating on the country level).

The spread between 1st and 10th decile is on average 23.4 %. That is, 80 % of the farmers have technical efficiency between 0.67 and 0.9. This interval is significantly smaller for Belgium (13 %), the Czech Republic (4 %), Greece (14 %) and Romania (13 %). On the other hand, there are countries with considerable differences in technical efficiency (Spain 35 %, Finland 33 %, Latvia 35 %, Portugal 36 % and Slovenia 39 %).

Table 11 provides the development of technical efficiency. The developments of technical efficiency are rather stochastic in many EU member countries. The average percentual change is positive for Austria, Belgium, Estonia, France, Hungary, Italy, Lithuania, Latvia, Portugal, Slovenia and Slovakia. However, positive even very weak trends were estimated only for Belgium, Bulgaria, Portugal and Romania. Despite the rather stochastic development of technical efficiency, one common pattern for most countries can be observed. Technical efficiency experienced a drop in most EU member countries in the years 2008 and 2009 and an increase in the years after that. However, the decrease was stronger than the increase. That is, the majority of countries experienced a drop in technical efficiency between 2008 and 2011.

Factors determining technical efficiency development were also rather specific for each member country. The positive impact of technical change on technical efficiency development was pronounced in Spain, the United Kingdom, Greece, Italy, Lithuania, Netherlands, Romania and Slovenia. In other countries, either technical change contributed negatively to technical efficiency development or the impact was rather small. Management and scale effect varied significantly among the countries and contributed mainly to the rather stochastic development of technical efficiency. However, management effect was much more pronounced than the scale effect.

Table 11 Developments of technical efficiency (% change) – cereal production

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	NA	0.461	-1.867	2.717	1.019	-0.723	-2.286	1.622	0.135	y = 0.248 - 0.028t	0.00
Belgium	-0.042	-0.279	0.257	-0.391	-0.237	0.354	-0.046	2.014	0.204	y = -0.653 + 0.191t	0.36
Bulgaria	NA	NA	NA	-0.614	-0.006	-1.004	1.480	-0.105	-0.050	y = -0.801 +0.250t	0.18
Czech Republic	0.108	0.247	-0.196	0.574	-0.968	0.002	0.103	-0.104	-0.029	y = 0.140 - 0.038t	0.04
Germany	3.446	1.668	3.839	-0.550	-2.437	-1.675	-0.603	-6.094	-0.301	y = 4.872 - 1.150t	0.74
Denmark	-1.780	0.504	1.257	3.721	-4.052	-7.060	3.009	0.916	-0.436	y = -0.365 - 0.016t	0.00
Estonia	-0.338	3.911	-6.119	5.208	-4.262	3.622	-1.467	1.106	0.208	y = 0.048 + 0.035t	0.00
Spain	3.280	-14.073	2.290	5.556	1.117	-4.376	0.600	3.879	-0.216	y = -3.062 + 0.632t	0.06
Finland	2.325	0.128	-6.188	6.593	-3.786	-8.878	2.746	3.211	-0.481	y = -0.526 + 0.010t	0.00
France	-0.856	1.029	1.457	1.220	-1.551	-3.224	2.362	-0.152	0.036	y = 0.095 - 0.088t	0.01
United Kingdom	0.145	-0.415	1.068	1.481	-1.941	-5.551	2.449	0.373	-0.299	y = 0.315 - 0.062t	0.01
Greece	-0.672	0.343	-0.450	1.441	1.421	-1.267	-1.718	0.696	-0.026	y = 0.146 - 0.038t	0.01
Hungary	2.437	2.025	-0.393	-2.819	5.684	-2.197	-3.031	-0.519	0.148	y = 2.446 - 0.511t	0.17
Ireland	-0.458	-2.021	3.320	4.927	-4.632	-7.589	2.176	2.498	-0.222	y = -0.190 - 0.007t	0.00
Italy	-0.012	0.195	0.334	5.556	-3.737	-5.658	1.798	2.087	0.070	y = 0.315 - 0.054t	0.00
Lithuania	7.018	3.657	-17.848	6.550	5.270	-0.545	0.992	-0.316	0.597	y = 1.349 - 0.167t	0.00
Latvia	5.836	-0.853	-0.785	2.058	-3.328	1.879	-4.538	1.870	0.267	y = 2.602 - 0.519t	0.15
Netherlands	-2.033	3.726	-0.146	-2.782	-0.862	0.586	4.218	-2.762	-0.007	y = -0.086 + 0.018t	0.00
Poland	0.156	0.009	-0.105	-0.055	-0.895	-0.014	1.762	-1.119	-0.033	y = 0.007 - 0.009t	0.00
Portugal	3.113	-10.765	1.622	0.092	5.628	-2.325	2.763	4.392	0.565	y = -3.200 + 0.837t	0.16
Romania	NA	NA	NA	-0.778	-0.039	-0.796	0.857	-0.285	-0.208	y = -0.773 + 0.188t	0.19
Sweden	1.425	-0.804	-7.594	7.116	3.730	-5.972	-4.231	2.818	-0.439	y = -0.123 - 0.070t	0.00
Slovenia	-4.641	2.215	-2.367	8.155	0.474	-4.090	-5.561	7.842	0.253	y = -1.657 + 0.424t	0.04
Slovakia	0.830	-1.048	2.636	4.246	-0.435	0.771	-3.303	-1.009	0.336	y = 2.180 - 0.410t	0.18

Source: own calculation

The question of stability can be analysed using the data provided in Table 12, which presents the Spearman's rank correlations of technical efficiency in the analysed EU member countries. Since the order of farmers in all countries changes dramatically, leapfrogging appears to be a common phenomenon for all member countries. That is, catching up and falling behind processes are important characteristics for cereal producers in all countries. This also holds even if we take into consideration the character of the data. Since we have an unbalanced panel, the values are affected to some extend by the entry and exit of producers to and from the sample.

The highest Spearman's rank correlations were found in Bulgaria, the Czech Republic, Denmark, Finland, Latvia and Netherlands. This suggests that in these countries we may find a group of cereal producers that tend to strengthen their positions.

Table 12 Spearman's rank correlation coefficients of technical efficiency – cereal production

EU member country	Spearman's rank correlation coefficients of technical efficiency							Average
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2010/2011	
Austria	NA	0.1617	0.0000	-0.1799	-0.2630	0.1947	0.0787	-0.0013
Belgium	0.0056	0.0062	-0.1628	-0.0561	-0.0427	-0.0624	0.0735	-0.0341
Bulgaria	NA	NA	NA	0.1756	0.1649	0.2383	0.4188	0.2494
Czech Republic	0.2099	0.3677	0.1302	0.2387	0.3246	0.3597	0.3290	0.2800
Germany	0.1255	0.0657	0.0254	-0.1520	-0.1084	-0.1254	-0.0209	-0.0271
Denmark	0.5251	0.6108	0.4631	0.3345	0.4550	0.3446	0.5262	0.4656
Estonia	0.0231	0.1538	0.0358	-0.1162	-0.0848	0.0286	-0.0763	-0.0051
Spain	-0.2572	0.0318	-0.0021	-0.0622	-0.0363	0.1035	0.3360	0.0162
Finland	0.5674	0.5359	0.4903	0.2436	0.4679	0.5203	0.4518	0.4682
France	0.1601	0.0308	-0.1000	-0.1448	-0.0201	-0.0998	0.0002	-0.0248
United Kingdom	-0.0385	-0.0204	-0.1144	-0.2839	0.1100	-0.1431	-0.0177	-0.0726
Greece	0.2289	0.1171	0.0376	-0.1790	0.1686	0.1711	0.0117	0.0794
Hungary	0.0368	0.1481	-0.0857	-0.2155	-0.1136	-0.0120	-0.0481	-0.0414
Ireland	0.0537	0.0210	-0.0041	-0.1481	0.3000	-0.2162	-0.0192	-0.0018
Italy	0.2466	0.1244	-0.0376	-0.1450	0.0034	-0.0438	0.1739	0.0460
Lithuania	0.3043	0.0259	0.0042	-0.0225	0.0157	0.2062	0.1353	0.0956
Latvia	0.3722	0.2555	0.2236	0.0158	0.4161	0.4777	0.2404	0.2859
Netherlands	0.3371	0.3851	0.2347	0.2841	0.4273	0.4506	0.1507	0.3242
Poland	0.2003	0.1821	0.1975	0.0852	0.0919	0.0639	0.0697	0.1272
Portugal	0.0020	-0.1015	0.1004	-0.0693	0.0604	-0.0841	0.1727	0.0115
Romania	NA	NA	NA	-0.3190	-0.3075	-0.1290	-0.1384	-0.2235
Sweden	0.2716	0.1723	0.0653	-0.1014	-0.2220	0.0646	-0.0362	0.0306
Slovenia	-0.3992	0.0537	-0.1117	-0.2315	-0.0856	0.3519	0.1113	-0.0445
Slovakia	0.1068	0.1702	0.0957	0.1637	0.1396	-0.3125	-0.0236	0.0486

Source: own calculation

4.1.2.2 Milk

Table 13 provides the estimates of parameter *σ, λ* and statistical characteristics of milk producers' technical efficiency. The parameter *λ* is highly significant in almost all EU member states expect for Latvia. That is, inefficiency is not pronounced in milk production for Latvia. In five countries, namely in Austria, Italy, Lithuania, Portugal and Romania, *λ* is smaller than one. This means that the residual variation is caused by the random component rather than by technical efficiency. This suggests that the differences in the efficiency of inputs use are rather small among specialized milk producers in these countries. On the other hand, efficiency differences among milk producers are important reasons for variation in production in the rest of EU countries.

Table 13 Technical efficiency – milk production

EU member country	Sigma	Lambda	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
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
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
Estonia	0.2046***	1.7752***	0.8704	0.0640	0.4275	0.9743	0.7824	0.9379
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
United Kingdom	0.1329***	1.3153***	0.9208	0.0346	0.6142	0.9800	0.8757	0.9561
Greece	LNO	LNO	LNO	LNO	LNO	LNO	LNO	LNO
Hungary	0.2105***	1.7663***	0.8650	0.0653	0.5935	0.9656	0.7706	0.9343
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
Lithuania	0.1796***	0.7746**	0.8984	0.0379	0.7124	0.9673	0.8487	0.9381
Latvia	0.2336***	0.0000	-	-	-	-	-	-
Netherlands	0.1001***	1.0222***	0.9268	0.0367	0.7084	0.9914	0.8780	0.9634
Poland	0.2066***	1.4176***	0.8776	0.0539	0.4274	0.9745	0.8064	0.9333
Portugal	0.1748***	0.8438***	0.8958	0.0394	0.6890	0.9746	0.8453	0.9381
Romania	0.2232***	0.7307***	0.9030	0.0241	0.7558	0.9590	0.8732	0.9292
Sweden	0.1566***	1.7901***	0.8870	0.0585	0.5149	0.9795	0.8104	0.9467
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

The average value of technical efficiency is in the interval 0.79 to 0.93. The lowest average value can be found in Bulgaria and the highest average value was reached in the Netherlands. In these countries we can also find farms with minimal and maximal level of technical efficiency. The minimum value is considerably low (0.27) and indicates problems in input use on a Bulgarian farm. The maximum value is 0.99 and suggests that a Dutch farm operates almost on the country specific production frontier. The overall comparison of technical efficiency among the EU member states will be done using metafrontier analysis.

The difference between the best and the worst farms is considerably large in almost all EU member countries. The difference is in the interval from 0.2 (Romania) to .68 (Bulgaria). Estonia, Spain, France, Poland, Slovenia and Slovakia exceed 0.5.

As in the case of cereals production, the high technical efficiency of the 10 % best farmers is the common feature in all EU countries. The top 10 % producers have a technical efficiency higher than 0.9. This means that the top 10 % producers highly exploit their production possibilities. On the other hand, the level of technical efficiency of the worst 10 % milk producers significantly differs among the countries with the lowest first decile in Bulgaria (0.63) and the highest in the Netherlands (0.88). This result suggests that the worst 10 % milk producers with substantially low technical efficiency, as in the case of Bulgaria or Slovakia, will have problems to keep pace with competitors due to the inefficient inputs use and the sector will face another structural change.

The spread between the 1st and 10th decile is on average 12.9 %. However, this interval is significantly smaller for Romania (5.6 %), Italy (7.1 %), Germany (8.2 %), the Netherlands (8.5 %), Lithuania (8.9 %) and Portugal (9.2 %) and significantly larger in Bulgaria (26.7 %), Slovakia (24.2 %), Finland (18.2 %), Slovenia (17.4 %) and Austria (17.0 %). This suggests that there exist high differences of technical efficiency in milk production among EU member states as well as on the country level. For example, 80 % of pork specialized companies have technical efficiency between 0.63 and 0.90 in Bulgaria and between 0.70 and 0.94 in Slovakia. In Germany, on the other hand, 80 % of farms operate with higher and more similar technical efficiency (0.87 to 0.95).

The development of technical efficiency is provided in Table 14. Overall, we can summarize that the average percentage change is negative for more than half of the countries. Positive average percentage changes were estimated in: Austria, Belgium, Denmark, Estonia, Finland, France, Hungary, Italy, Lithuania and Slovenia. However, positive even very weak trends in technical efficiency were experienced only in Lithuania and Romania. The development of technical efficiency is rather stochastic for most countries. An exception is a more common increase in the years 2006 (14 cases from 22 analysed countries), 2008 (15 cases) and 2011 (15 cases). A strong drop in technical efficiency can be observed in the year 2010 (13 cases). However, the power of decrease was almost two times higher than the power of increase.

The development of technical efficiency was determined by factors specific to each member state. Technological change had positive impact in Austria, Bulgaria, Spain, Finland, the United Kingdom, Italy, Lithuania and Latvia. However, it negatively affected the development of technical efficiency in Belgium, Czech Republic, Germany, Denmark, France, Ireland, Poland, Portugal, Romania, Slovenia and Slovakia. Management and scale effect varied significantly among the countries and contributed mainly to the rather stochastic development of technical efficiency. The significant contribution of management to the technical efficiency development was observed in Bulgaria, Germany, Ireland, Italy, Lithuania, the Netherlands, Portugal, Sweden, Slovenia and Slovakia. Scale effect was pronounced in Bulgaria, Denmark, Estonia, Lithuania, Poland and Slovenia.

Table 14 Developments of technical efficiency (% change) – milk production

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	NA	0.370	-0.537	-0.287	0.224	0.680	-0.422	-0.001	0.004	y = -0.008 + 0.003t	0.00
Belgium	-0.719	1.087	0.121	-0.339	-0.738	1.705	-1.134	0.101	0.010	y = 0.065 - 0.012t	0.00
Bulgaria	NA	NA	NA	-0.325	0.047	1.362	0.428	-1.901	-0.078	y = 0.754 - 0.277t	0.13
Czech Republic	-0.072	0.928	-0.624	-0.004	-1.592	1.445	0.442	-0.540	-0.002	y = 0.056 - 0.013t	0.00
Germany	0.873	-0.287	0.272	0.337	-2.868	3.239	-0.221	-1.842	-0.062	y = 0.634 - 0.155t	0.04
Denmark	0.039	-0.700	-0.512	0.834	1.107	-1.571	0.404	0.403	0.001	y = -0.276 + 0.061t	0.03
Estonia	0.349	0.745	-1.364	-0.285	-0.344	3.448	-2.652	0.247	0.018	y = 0.196 - 0.040t	0.00
Spain	-1.087	0.195	1.087	0.097	0.599	-0.241	-2.119	1.267	-0.025	y = -0.101 + 0.017t	0.00
Finland	1.508	-1.642	-1.149	0.657	1.381	-0.225	-0.262	-0.238	0.004	y = 0.102 - 0.022t	0.00
France	-0.748	0.852	0.200	1.128	-0.171	-2.160	0.682	0.248	0.004	y = 0.125 - 0.027t	0.00
United Kingdom	-0.149	-0.091	-0.680	1.089	0.558	-0.636	-1.037	0.831	-0.014	y = -0.107 + 0.021t	0.00
Greece	-	-	-	-	-	-	-	-	-	-	-
Hungary	0.307	0.612	1.677	-3.493	2.095	0.030	-1.545	0.455	0.017	y = 0.505 - 0.108t	0.02
Ireland	0.065	0.167	-0.718	-0.903	0.847	0.735	-1.287	0.678	-0.052	y = -0.220 - 0.037t	0.01
Italy	0.404	-0.138	-0.310	-0.093	0.152	0.369	0.179	-0.329	0.029	y = 0.097 - 0.015t	0.02
Lithuania	0.209	-0.304	-2.758	1.123	1.660	-0.566	0.308	1.470	0.143	y = -0.875 + 0.226t	0.15
Latvia	-	-	-	-	-	-	-	-	-	-	-
Netherlands	-0.167	0.081	0.059	0.816	-0.835	-0.108	-0.162	0.308	-0.001	y = 0.001 - 0.001t	0.00
Poland	-0.672	-0.045	0.301	1.160	0.233	-1.899	0.479	0.139	-0.038	y = -0.079 + 0.009t	0.00
Portugal	0.955	-0.062	0.912	-1.296	0.047	1.078	-0.908	-0.938	-0.026	y = 0.811 - 0.186t	0.23
Romania	NA	NA	NA	-0.656	0.357	-0.185	0.040	0.058	-0.077	y = -0.410 + 0.111t	0.22
Sweden	0.313	1.269	-1.017	-0.848	0.421	1.419	-2.793	1.113	-0.015	y = 0.313 - 0.073t	0.02
Slovenia	-1.569	0.928	-1.731	-0.037	0.798	0.786	-0.344	1.258	0.011	y = -1.158 - 0.260t	0.31
Slovakia	-2.294	3.061	-1.262	6.457	-2.844	-7.331	1.443	1.827	-0.118	y = 0.244 - 0.080t	0.00

Source: own calculation

Table 15 presents the Spearman's rank correlations of technical efficiency. The high and stable values of Spearman's rank correlations are pronounced only in Austria, Czech Republic, Finland, Latvia, the Netherlands and to some extend Portugal. That is, the order of milk producers is quite stable and leapfrogging does not appear to be a particularly common phenomenon in these countries. This suggests that structural change occurs in such a way that the most successful companies strengthen their position. Companies with poor performance are not able to catch up with the developments of the sector leaders, and therefore fall more and more behind. However, this is not the case in the rest of EU member states, in which leapfrogging cannot be avoided.

Table 15 Spearman's rank correlation coefficients of technical efficiency – milk production

EU member country	Spearman's rank correlation coefficients of technical efficiency						
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2010/2011
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
United Kingdom	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

4.1.2.3 Pork

Table 16 presents the estimates of parameter σ, λ and the statistical characteristics of technical efficiency of pork producers. The parameter λ is significant only in 12 member states, namely in Belgium, the Czech Republic, Germany, Denmark, Spain, France, Hungary, Italy, the Netherlands, Poland, Sweden and Slovakia. However, in the Czech Republic, Germany and Poland the differences in the efficiency of inputs use are rather small among pork specialized companies (λ is smaller than one). The variability of residuals is caused by random components. That is, the technical efficiency differences among pork producers do not contribute so much to the variation in production in these countries. However, this is not the case of Belgium, Denmark, Spain, France, Hungary, Italy, Netherlands, Sweden and Slovakia. In these countries the efficiency differences among producers are pronounced

Table 16 Technical efficiency – pork production

EU member country	Sigma	Lambda	Statistical characteristics of technical efficiency					
			Mean	Std.Dev	Min.	Max	1st Decile	10th Decile
Austria	0.1231	0.0001	-	-	-	-	-	-
Belgium	0.1151***	2.2179***	0.9219	0.0422	0.6904	0.9837	0.8652	0.9653
Bulgaria	0.0210***	19011.1	-	-	-	-	-	-
Czech Republic	0.1391***	0.7069***	0.9256	0.0286	0.7178	0.9769	0.8909	0.9534
Germany	0.1603***	0.8551***	0.9182	0.0254	0.6587	0.9796	0.8878	0.9452
Denmark	0.1318***	1.7065***	0.8998	0.0476	0.6633	0.9815	0.8363	0.9546
Estonia	0.2316***	171802	-	-	-	-	-	-
Spain	0.3678***	1.6305***	0.7973	0.0894	0.2896	0.9495	0.6810	0.8878
Finland	0.2345***	50481.1	-	-	-	-	-	-
France	0.1416***	3.3420***	0.9019	0.0603	0.5307	0.9875	0.8199	0.9625
United Kingdom	0.1571***	2661930	-	-	-	-	-	-
Greece	0.3777	535047	-	-	-	-	-	-
Hungary	0.2721***	2.5928***	0.8251	0.0930	0.4516	0.9617	0.6949	0.9248
Ireland	LNO	LNO	-	-	-	-	-	-
Italy	0.3209***	1.7476***	0.8259	0.0847	0.3492	0.9777	0.7145	0.9112
Lithuania	0.2955***	2084680	-	-	-	-	-	-
Latvia	0.2121	0.0212	-	-	-	-	-	-
Netherlands	0.1478***	2.5950***	0.8918	0.0591	0.5506	0.9804	0.8088	0.9553
Poland	0.1831***	0.6372***	0.9255	0.0179	0.7345	0.9788	0.9032	0.9449
Portugal	0.3890***	5043790	-	-	-	-	-	-
Romania	0.1745	0.1234	-	-	-	-	-	-
Sweden	0.2444***	3.1592***	0.8407	0.0934	0.3102	0.9737	0.7222	0.9376
Slovenia	0.3094***	36927.4	-	-	-	-	-	-
Slovakia	0.2508***	1.2620**	0.8389	0.0672	0.5344	0.9587	0.7465	0.9072

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

We did not obtain interpretable results for 12 EU member states. Either the residual variation was dominated by a random component (λ approaches zero) or vice versa. The low number of observations was the common reason for these results. Since we estimated the multiple output distance function only for specialized producers, i.e. with share of pork production on total animal production higher than 50 %, we were left with a low number of observations for some countries.

The average value of technical efficiency of pork specialized farms is in the interval between 0.80 and 0.93. Spain is the country with the lowest average value of technical efficiency. The highest average value was estimated for the Czech Republic. Whereas the minimum values differ significantly among the countries (interval 0.29 to 0.74), the interval of maximum values is considerably close (0.95-0.99). This means that highly efficient producers operate close to the frontier in all EU member states. On the other hand, the large differences among the best and worst producers can be identified. These differences are in the interval from 0.24 (Poland) to 0.66 (Sweden).

The differences in technical efficiency can be also found in the top 10 % producers. These top producers have a technical efficiency higher than 0.88. On the other hand, the first decile (the worst 10 % producers) has a higher variation among the countries from 0.69 in Hungary to 0.90 in Poland.

Table 17 Developments of technical efficiency (% change) – pork production

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	-	-	-	-	-	-	-	-	-	-	-
Belgium	0.190	0.357	0.711	2.801	-6.364	0.108	-0.994	-0.692	-0.485	y = 0.795 - 0.285t	0.07
Bulgaria	-	-	-	-	-	-	-	-	-	-	-
Czech Republic	-0.068	0.233	-0.601	0.269	0.898	-0.707	0.171	-0.218	-0.003	y = 0.053 - 0.012t	0.00
Germany	1.043	0.064	-0.254	-4.673	-1.013	0.505	-4.873	-6.510	-1.964	y = 1.873 - 0.853t	0.51
Denmark	0.227	0.236	-2.095	-0.030	0.476	-4.364	-2.472	0.957	-0.883	y = -0.094 - 0.175t	0.05
Estonia	-	-	-	-	-	-	-	-	-	-	-
Spain	1.498	-2.560	2.848	-1.098	-4.688	1.327	2.748	-0.399	-0.040	y = -0.314 + 0.061t	0.00
Finland	-	-	-	-	-	-	-	-	-	-	-
France	-1.442	0.666	2.105	-4.072	-2.886	0.532	1.374	0.607	-0.389	y = -1.158 + 0.171t	0.04
United Kingdom	-	-	-	-	-	-	-	-	-	-	-
Greece	-	-	-	-	-	-	-	-	-	-	-
Hungary	-0.052	1.588	0.273	-11.092	6.499	1.284	-4.120	-3.716	-1.167	y = 0.631 - 0.400t	0.04
Ireland	-	-	-	-	-	-	-	-	-	-	-
Italy	0.872	-0.156	0.497	1.894	-5.982	-2.087	2.729	-4.639	-0.859	y = 1.272 - 0.474t	0.14
Lithuania	-	-	-	-	-	-	-	-	-	-	-
Latvia	-	-	-	-	-	-	-	-	-	-	-
Netherlands	1.762	0.689	0.839	-4.872	-3.106	0.208	-1.248	1.461	-0.534	y = 0.105 - 0.142t	0.02
Poland	-0.260	0.646	0.249	-0.163	-0.179	-0.778	0.043	-0.820	-0.158	y = 0.380 - 0.119t	0.36
Portugal	-	-	-	-	-	-	-	-	-	-	-
Romania	-	-	-	-	-	-	-	-	-	-	-
Sweden	-0.268	1.120	-2.499	3.637	-1.847	-2.111	1.709	0.393	0.017	y = -0.157 + 0.039t	0.00
Slovenia	-	-	-	-	-	-	-	-	-	-	-
Slovakia	-1.733	-3.601	-1.965	3.784	3.391	1.225	-0.174	1.803	0.341	y = -2.394 + 0.608t	0.31

Source: own calculation

The spread between 1st and 10th decile is on average 14.0 %. However, this interval is significantly smaller for Poland (4.2 %), Germany (5.7 %), the Czech Republic (6.3 %), and significantly higher in Hungary (23.0 %), Sweden (21.5 %), and Spain (20.9 %). This means that 80 % of Hungarian farms operate with a technical efficiency between 0.70 and 0.93. On the other hand, 80 % of Polish farms have a technical efficiency between 0.90 and 0.95. This demonstrates the significant variability among countries as well as low technical efficiency differences in Poland, Germany and the Czech Republic.

Table 17 provides the development of technical efficiency. As in the case of milk production, the average percentage change is negative in almost all analysed countries. Sweden and Slovakia are exceptions. However, the significant positive trend was estimated only for

Slovakia. The development of technical efficiency is rather stochastic for most countries. However, some common patterns can be observed. Pork producers experienced a decrease in the years 2007 (7 cases from 12 analysed countries), 2008 (8 cases) and 2011 (7 cases). In addition, there was an increase in 2009 (7 cases). Since the decrease was much stronger, the majority of countries experienced a sharp drop in technical efficiency between 2006 and 2011. This can be a consequence of pork production crises in the EU.

The development of technical efficiency was driven by factors specific for each member state. Technological change had a positive impact especially in Spain and Italy. It negatively affected the development of technical efficiency in the Czech Republic, Germany, Denmark and Poland. Management and scale effect varied significantly among the countries and contributed mainly to the rather stochastic development of technical efficiency. Management had a positive trend in Spain, Netherlands, Poland and Sweden. The significant scale effect was found in Germany, Denmark, the Netherlands, Poland and Sweden. The scale and management component positively influenced technical efficiency especially at the beginning of the analysed time period.

Table 18 Spearman's rank correlation coefficients of technical efficiency – pork production

EU member country	Spearman's rank correlation coefficients of technical efficiency						
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2010/2011
Austria	-	-	-	-	-	-	-
Belgium	-0.3006	-0.1411	-0.0634	-0.0667	-0.0573	-0.2019	0.2243
Bulgaria	-	-	-	-	-	-	-
Czech Republic	0.5510	0.5656	0.4258	0.2731	0.4362	0.2867	0.3080
Germany	0.1732	0.1052	0.0516	0.0184	0.0556	0.0546	0.1871
Denmark	0.3464	0.3754	0.0154	0.4150	0.1304	-0.0887	-0.3727
Estonia	-	-	-	-	-	-	-
Spain	0.1846	-0.2711	0.0368	0.0747	0.3376	0.0596	0.1500
Finland	-	-	-	-	-	-	-
France	0.1949	-0.2201	0.0283	0.1354	-0.0233	0.0163	-0.1169
United Kingdom	-	-	-	-	-	-	-
Greece	-	-	-	-	-	-	-
Hungary	-0.4236	-0.2191	-0.2134	0.1559	-0.6264	0.0681	-0.6000
Ireland	-	-	-	-	-	-	-
Italy	0.2795	0.1007	0.1400	-0.0286	0.0118	-0.0934	-0.2167
Lithuania	-	-	-	-	-	-	-
Latvia	-	-	-	-	-	-	-
Netherlands	0.5519	0.2388	-0.5879	-0.1179	0.1765	-0.1703	0.2466
Poland	-0.1765	-0.0161	-0.0470	-0.0951	-0.1405	-0.1392	-0.1403
Portugal	-	-	-	-	-	-	-
Romania	-	-	-	-	-	-	-
Sweden	0.2001	0.1059	-0.0352	-0.0147	-0.1027	0.0433	-0.0237
Slovenia	-	-	-	-	-	-	-
Slovakia	0.3429	0.3256	-0.0679	0.8095	-0.8000	-0.5000	-0.9000

Source: own calculation

The Spearman's rank correlations of technical efficiency in the analysed EU member countries are presented in Table 18. The most stable positive value can be observed in the Czech Republic. In other countries, the order of milk producers varied significantly in the analysed period. This suggests that as far as technical efficiency is concerned leapfrogging appears to be a common phenomenon also in pork production in EU member countries.

4.1.3 TFP

This chapter provides the discussion on TFP developments and its components for cereal, milk and pork production. The productivity comparisons among the EU member countries will be carried out using metafrontier analysis in chapter 4.2.

4.1.3.1 Cereals

Table 19 TFP development (% change) – cereal production

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	NA	-0.699	-4.472	0.126	-0.578	-0.284	0.071	7.812	0.282	y = -4.605 + 1.222t	0.51
Belgium	-0.837	-3.952	-1.804	-1.804	0.425	3.451	4.735	11.979	1.524	y = -6.573 + 1.799t	0.75
Bulgaria	NA	NA	NA	-12.779	-6.258	-2.624	7.823	14.365	0.106	y = -20.405 + 6.837t	0.98
Czech Republic	-2.883	-2.584	-2.411	-1.676	-0.664	2.541	4.073	5.227	0.203	y = -5.471 + 1.261t	0.90
Germany	-7.912	-8.160	-5.749	-1.379	2.686	6.500	5.887	7.244	-0.110	y = -11.743 + 2.585t	0.93
Denmark	-9.541	-7.254	-0.682	4.131	-2.899	0.074	11.349	8.066	0.405	y = -10.925 + 2.518t	0.74
Estonia	6.771	10.840	-1.266	9.677	-4.801	-0.221	-11.006	-12.241	-0.281	y = 13.308 - 3.029t	0.69
Spain	6.825	-15.859	7.277	12.881	2.680	-7.873	-3.579	-0.177	0.272	y = 2.590 - 0.515t	0.02
Finland	-14.283	-6.682	-2.841	10.560	2.192	-2.377	5.154	-1.228	-1.188	y = -8.880 + 1.709t	0.31
France	-6.024	-2.130	-0.494	0.479	-1.300	-0.660	6.316	4.459	0.081	y = -5.991 + 1.342t	0.74
United Kingdom	-9.865	-4.897	1.140	6.673	1.326	0.693	7.943	1.146	0.520	y = -6.690 + 1.602t	0.47
Greece	1.174	0.967	1.064	2.437	0.024	-4.002	-3.940	3.327	0.131	y = 1.582 - 0.322t	0.08
Hungary	7.503	0.126	-3.356	-9.858	1.065	-2.543	-0.478	9.723	0.273	y = -1.114 + 0.308t	0.02
Ireland	1.263	-6.008	-0.576	-1.450	-9.182	-7.459	9.571	18.685	0.606	y = -8.580 + 2.041t	0.28
Italy	-12.441	-12.840	-4.713	5.957	2.745	2.656	13.406	12.138	0.864	y = -16.396 + 3.835t	0.87
Lithuania	2.516	0.976	-18.267	8.822	7.364	0.473	2.112	-2.358	0.205	y = -1.205 + 0.313t	0.01
Latvia	-0.438	7.160	-2.608	3.483	1.983	5.539	-3.936	-8.992	0.274	y = 5.225 - 1.100t	0.25
Netherlands	-14.435	-5.427	-4.754	-2.221	3.138	8.029	10.350	4.451	-0.109	y = -13.759 + 3.033t	0.83
Poland	10.841	3.797	-0.269	-2.722	-5.211	-4.394	0.752	0.344	0.392	y = 5.940 - 1.233t	0.34
Portugal	-29.651	-2.814	1.203	-3.739	14.954	8.056	0.512	-4.995	-2.059	y = -14.299 + 2.720t	0.26
Romania	NA	NA	NA	-13.688	-3.063	-2.155	-1.503	7.384	-2.605	y = -15.716 + 4.370t	0.85
Sweden	-0.597	1.894	-5.093	12.864	5.503	-8.953	-3.909	-3.461	-0.219	y = 3.424 - 0.810t	0.08
Slovenia	-6.539	-6.063	-8.323	7.684	1.376	-2.593	5.033	38.304	3.610	y = -16.761 + 4.527t	0.54
Slovakia	-6.065	-6.165	-2.346	2.325	6.013	1.016	3.970	7.118	0.733	y = -7.663 + 1.866t	0.79

Source: own calculation

Table 19 presents the percentage change of TFP with respect to the sample average for each EU member state. We can observe a positive trend in TFP in the majority of EU member countries. Only Estonia and Sweden are exceptions. Moreover, the positive trend is not strong in some countries (Finland, Lithuania) and some countries experienced a rather stochastic development (Spain, Greece, Hungary, Portugal, Latvia). The rather strong positive trend in TFP was pronounced in Austria, Belgium, Bulgaria, the Czech Republic, Denmark, France, the United Kingdom, Italy, the Netherlands, Slovenia and Slovakia. These countries except for the Netherlands also experienced an average positive TFP change over the period 2004 - 2011. On the other hand, a negative average change in TFP was estimated for Germany, Estonia, Finland, the Netherlands, Portugal, Romania and Sweden.

Table 20 Spearman's rank correlation coefficients of TFP – cereal production

EU member country	Spearman's rank correlation coefficients of TFP						
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2011/2010
Austria	NA	0.9266	0.9057	0.8483	0.8291	0.9263	0.9288
Belgium	0.8022	0.8586	0.8035	0.9082	0.8407	0.8927	0.9500
Bulgaria	NA	NA	NA	0.6939	0.6912	0.7160	0.7668
Czech Republic	0.9103	0.9349	0.8711	0.9010	0.9184	0.9407	0.9403
Germany	0.9114	0.8945	0.8267	0.7670	0.8893	0.8860	0.8245
Denmark	0.8673	0.8806	0.8734	0.7783	0.8399	0.8682	0.8762
Estonia	0.6167	0.6379	0.6581	0.7084	0.6976	0.7491	0.7882
Spain	0.7056	0.7183	0.8324	0.7809	0.7341	0.7348	0.8353
Finland	0.8484	0.8573	0.8291	0.7639	0.8522	0.8762	0.8419
France	0.9250	0.9170	0.9043	0.8742	0.8810	0.8906	0.9226
United Kingdom	0.9177	0.9228	0.9209	0.8461	0.8643	0.8023	0.8712
Greece	0.9293	0.8767	0.8647	0.8744	0.9398	0.9228	0.8620
Hungary	0.6680	0.7353	0.6191	0.5633	0.6565	0.7098	0.7194
Ireland	0.8826	0.8793	0.8885	0.8116	0.8062	0.6955	0.8029
Italy	0.8435	0.8277	0.8534	0.7165	0.7178	0.7240	0.8012
Lithuania	0.8108	0.4757	0.4240	0.4823	0.4481	0.6323	0.5505
Latvia	0.6298	0.4832	0.2955	0.3997	0.5108	0.4852	0.4638
Netherlands	0.8355	0.8781	0.8468	0.8894	0.9007	0.9212	0.8038
Poland	0.7399	0.7823	0.8048	0.7850	0.7957	0.8387	0.8457
Portugal	0.3261	0.5078	0.4961	0.4197	0.5900	0.4651	0.7738
Romania	NA	NA	NA	0.9242	0.8933	0.9371	0.9237
Sweden	0.8269	0.8225	0.7833	0.8141	0.6816	0.7284	0.8103
Slovenia	0.4325	0.7050	0.4519	0.3830	0.4955	0.6647	0.4817
Slovakia	0.3875	0.5287	0.5304	0.6593	0.4931	0.4080	0.6050

Source: own calculation

Technical change was the important factor that contributed predominantly positively to TFP development. Thus, adoption of innovations seems to be a significant source of growth in many EU countries. The contribution of technical efficiency to the TFP development was rather stochastic as we observed in the previous chapter. On average, almost half the countries experienced the positive impact of technical efficiency on TFP development while for the other half it was negative. The contributions of management and scale components were specific for each country and we cannot observe any common patterns. This suggests that, despite some common factors, the EU member countries are characterized by idiosyncratic developments in TFP.

As opposed to Spearman's rank correlation calculated for technical efficiency, Spearman's rank correlation for TFP suggests that the order of cereal 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.

4.1.3.2 Milk

The development of total factor productivity in milk production is provided in Table 21. The table presents the percentage change of TFP with respect to the sample average for each

Table 21 TFP development – milk production

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	NA	-54.325	11.472	-11.302	6.634	9.586	0.754	87.348	7.167	y = -53.472 + 15.16t	0.61
Belgium	-0.607	1.404	1.282	-1.270	-1.169	2.236	-1.830	0.228	0.034	y = 0.429 - 0.088t	0.02
Bulgaria	NA	NA	NA	0.278	-4.150	0.032	3.360	0.389	-0.018	y = -2.338 + 0.773t	0.21
Czech Republic	-6.624	-4.147	-4.425	-1.260	-0.612	4.896	5.829	7.868	0.191	y = -9.448 + 2.142t	0.95
Germany	-3.560	-3.854	-1.547	-0.359	-2.137	5.834	4.290	3.936	0.326	y = -5.758 + 1.352t	0.76
Denmark	-10.906	-7.914	0.118	3.453	4.610	2.233	4.606	4.269	0.059	y =- 9.387 + 2.099t	0.71
Estonia	-1.872	-0.527	-2.158	0.070	0.301	3.989	-0.847	1.528	0.061	y = -2.129 + 0.487t	0.36
Spain	1.894	2.910	1.156	0.621	0.772	-0.220	-3.304	-2.060	0.221	y = 3.581 - 0.747t	0.80
Finland	-6.547	-5.678	-2.834	1.777	4.333	2.227	2.951	3.117	-0.082	y = -6.967 + 1.530t	0.77
France	-1.943	-1.160	-1.990	-0.543	-0.880	-1.531	3.170	5.215	0.042	y = -3.857 + 0.867t	0.63
United Kingdom	1.058	-0.553	-1.728	-0.288	-0.673	-1.574	0.237	4.703	0.148	y = -1.435 + 0.352t	0.18
Greece	-	-	-	-	-	-	-	-	-	-	-
Hungary	4.069	0.190	1.391	-5.526	0.375	0.284	-2.062	2.555	0.160	y = 1.192 - 0.230t	0.04
Ireland	5.139	-1.978	-2.495	-1.607	-8.490	-10.458	7.793	17.607	0.689	y = -4.956 + 1.254t	0.11
Italy	-9.041	-6.283	-2.899	1.145	2.886	4.281	6.283	6.096	0.308	y = -9.981 + 2.287t	0.94
Lithuania	2.191	1.746	-1.241	0.308	0.056	-0.870	-0.902	-0.108	0.147	y = 1.673 - 0.339t	0.44
Latvia	-1.041	0.849	0.437	0.607	1.573	1.508	-0.281	-2.542	0.139	y = 0.780 - 0.143t	0.06
Netherlands	0.381	-0.145	-1.465	-0.188	-1.763	-0.618	0.871	3.327	0.050	y = -1.379 + 0.318t	0.24
Poland	7.780	3.906	1.260	-0.619	-2.246	-6.441	-2.303	0.097	0.179	y = 6.048 - 1.304t	0.55
Portugal	-5.562	-4.406	-1.643	-0.960	0.681	5.266	5.637	3.908	0.365	y = -7.074 + 1.653t	0.90
Romania	NA	NA	NA	4.886	0.313	-3.761	-1.885	4.489	0.808	y = 1.706 - 0.299t	0.02
Sweden	-0.012	1.492	-2.190	-1.947	0.675	1.459	-1.614	2.754	0.077	y = -0.855 + 0.207t	0.08
Slovenia	-7.582	-5.495	-8.987	-0.544	0.381	4.168	7.046	14.452	0.430	y = -13.356 + 3.064t	0.89
Slovakia	-9.825	-1.586	-4.363	4.798	1.593	-2.658	8.718	9.369	0.756	y = -9.304 + 2.236t	0.68

Source: own calculation

EU member country, except for Greece. The positive change of TFP can be observed in the majority of EU member states. The slight negative average change was estimated only in Bulgaria and in Finland. However, the trend functions show a positive and strong trend in Finland. In addition, the strong positive trend of TFP can be observed in Austria, the Czech Republic, Germany, Denmark, Finland, France, Italy, Portugal, Slovenia and Slovakia. On the other hand, the development of TFP is characterized by a strong negative trend in Spain and Poland. Finally, a rather stochastic development of TFP is observed in: Belgium, Hungary, Latvia, Romania and Sweden.

Technical change contributed positively to TFP development in the majority of the analysed countries. Similarly to the case of cereal production, we can conclude, that adoption of innovations is a significant source of growth in the milk production sector in at least 70% of EU member states. Technical efficiency contribution to TFP development was predominantly negative, as seen in the previous chapter (Table 14). The contribution of management and scale components were specific to each country. However, the impact of these components was not as strong as the impact of technical change in the majority of EU countries. Finally,

Table 22 Spearman's rank correlation coefficients of TFP – milk production

EU member country	Spearman's rank correlation coefficients of TFP						
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2010/2011
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
United Kingdom	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

we can again conclude that, despite some common factors, a rather idiosyncratic development of TFP in milk production in EU member countries can be observed.

Table 22 provides Spearsman´s rank correlations of TFP. Based on the high values of this coefficient, we can conclude that the order of milk specialized companies is stable over time. Similar to cereal production, the most successful milk producers strengthen their position and the weak producers are not able to catch up with the development of the sector leaders and fall behind.

4.1.3.3 Pork

The development of total factor productivity of pork producers in 22 EU member states is shown in Table 23. The percentage change of TFP cannot be computed for Greece and Ireland due to the low number of observations.

Table 23 TFP development – pork production

EU member country	2004	2005	2006	2007	2008	2009	2010	2011	Average change	Trend function	R2
Austria	NA	2.47	-2.55	-9.18	-5.61	-4.33	2.27	3.61	-1.90	y = -4.462 + 0.640t	0.08
Belgium	-1.98	2.98	2.43	2.95	-7.72	-0.42	-4.34	-5.05	-1.39	y = 2.752 - 0.921t	0.31
Bulgaria	NA	NA	NA	-33.68	364.63	-23.70	-53.12	-11.23	48.58	y = 160.440 - 37.286t	0.11
Czech Republic	2.98	-1.14	-3.54	-1.67	-3.48	1.39	2.75	6.23	0.44	y = -2.514 + 0.657t	0.22
Germany	-16.87	-7.71	-6.28	-25.59	-11.36	13.26	-6.39	-9.45	-8.80	y = -15.839 + 1.564t	0.12
Denmark	-16.13	-11.13	-1.33	-6.14	0.85	14.55	10.37	11.47	0.32	y = -18.721 + 4.230t	0.86
Estonia	2.01	-2.00	17.04	-12.98	2.84	26.24	-29.71	-36.48	-4.13	y = 15.400 - 4.340t	0.24
Spain	1.29	-1.10	4.45	6.88	2.06	3.17	-5.67	-7.45	0.46	y = 5.421 - 1.104t	0.30
Finland	-16.41	-27.40	21.24	4.29	32.93	35.97	51.64	88.31	23.82	y = -40.523 + 14.298t	0.88
France	-3.27	-2.08	0.50	-1.16	3.31	2.60	2.27	0.78	0.37	y = -2.891 + 0.724t	0.57
United Kingdom	-13.98	1.28	3.64	-1.59	-4.81	5.92	0.04	-7.89	-2.17	y = -4.321 + 0.477t	0.03
Greece	-	-	-	-	-	-	-	-	-	-	-
Hungary	-0.77	-1.47	0.08	-10.95	7.62	3.42	-4.29	-1.64	-1.00	y = -1.450 + 0.100t	0.00
Ireland	-	-	-	-	-	-	-	-	-	-	-
Italy	-2.55	-2.87	0.83	7.87	5.28	8.90	17.44	-6.51	3.55	y = -1.562 + 1.136t	0.13
Lithuania	-12.23	-12.51	-10.79	-6.42	11.28	-3.39	39.47	106.80	14.03	y = -46.672 + 13.489t	0.64
Latvia	-6.07	2.63	2.70	-3.66	0.66	2.11	6.75	9.56	1.83	y = -5.266 + 1.578t	0.58
Netherlands	0.49	-5.54	1.34	-8.91	-4.34	3.56	5.20	10.70	0.31	y = -6.991 + 1.623t	0.39
Poland	10.41	4.75	-4.63	-8.62	-7.62	-2.38	-5.92	-2.45	-2.06	y = 5.210 - 1.615t	0.37
Portugal	2.98	-1.14	-3.54	-1.67	-3.48	1.39	2.75	6.23	0.44	y = -2.514 + 0.657t	0.22
Romania	NA	NA	NA	-12.30	-12.14	-3.73	-0.26	13.31	-3.02	y = -21.951 + 6.309t	0.90
Sweden	1.27	4.78	-0.19	5.38	-3.18	-4.39	-0.22	-5.16	-0.22	y = 4.669 - 1.085t	0.45
Slovenia	-3.38	-1.11	-8.95	-9.31	-6.82	1.87	13.62	15.23	0.14	y = -12.649 + 2.843t	0.53
Slovakia	-5.55	-5.59	-3.05	4.14	6.70	14.20	18.06	12.44	5.17	y = -10.821 + 3.553t	0.88

Source: own calculation

We can observe the positive average change of TFP in 13 countries. However, the significant positive trend is pronounced only in eight countries, namely Denmark, Finland, France, Lithuania, Latvia, Romania, Slovenia and Slovakia.

The negative average change was estimated in Austria, Belgium, Germany, Estonia, the United Kingdom, Hungary, Poland, Romania and Sweden. However, a rather stochastic than deterministic development of TFP can be observed in these countries.

The development of TFP was affected in each member country by different factors. Technical change contributed positively to TFP development in the majority of the analysed countries, especially in recent years. The conclusion that the adoption of innovations is a significant source of growth is confirmed also in the pork sector. Technical efficiency contribution to the TFP development was mostly negative. The management component had a rather stochastic impact on TFP development and on average the impact was more negative than positive. The contribution of scale components was also specific for each country. Thus, idiosyncratic development is also pronounced for pork production.

Table 24 Spearman's rank correlation coefficients of TFP – pork production

EU member country	Spearman's rank correlation coefficients of TFP						
	2005/2004	2006/2005	2007/2006	2008/2007	2009/2008	2010/2009	2010/2011
Austria	NA	0.9913	0.9903	0.9720	0.9544	0.9872	0.9970
Belgium	0.8060	0.8747	0.6605	0.6891	0.8738	0.8771	0.8099
Bulgaria	NA	NA	NA	0.4000	0.8000	0.5000	0.6000
Czech Republic	0.8980	0.8696	0.8841	0.8951	0.8567	0.9164	0.9495
Germany	0.8052	0.9307	0.8929	0.8964	0.9581	0.9499	0.8853
Denmark	0.7192	0.8029	0.7846	0.9008	0.7436	0.9365	0.7182
Estonia	1.0000	0.9261	1.0000	1.0000	1.0000	0.8000	0.8571
Spain	0.9012	0.8420	0.8405	0.7645	0.8544	0.8404	0.5877
Finland	-	-	-	-	-	-	-
France	0.8271	0.6805	0.6266	0.6896	0.7241	0.7695	0.6748
United Kingdom	0.9536	0.8810	0.9505	0.8182	0.8909	0.9244	0.9714
Greece	-	-	-	-	-	-	-
Hungary	0.0974	0.1555	0.2144	0.5176	0.1121	0.3363	-0.0303
Ireland	-	-	-	-	-	-	-
Italy	0.9014	0.8208	0.8477	0.7500	0.9176	0.7033	0.8167
Lithuania	0.7631	0.7250	0.8115	0.7915	0.9023	0.7762	0.9371
Latvia	0.8689	0.8453	0.9207	0.9009	0.9255	0.9909	0.9755
Netherlands	0.8376	0.7222	0.6264	0.8071	0.7706	0.7606	0.8602
Poland	0.9761	0.9847	0.9851	0.9796	0.9799	0.9805	0.9772
Portugal	1.0000	0.7008	0.9333	1.0000	0.8000	0.8286	0.8000
Romania	NA	NA	NA	0.9853	0.9828	0.9838	0.9891
Sweden	0.7419	0.7218	0.6509	0.7236	0.6363	0.7687	0.7466
Slovenia	0.9048	0.9273	0.8833	0.9727	0.8956	0.9762	0.7619
Slovakia	0.5692	0.7335	0.8536	0.9524	0.4000	1.0000	1.0000

Source: own calculation

Table 24 provides the Spearsman´s rank correlations of TFP. As in the case of cereal and milk production, high values of coefficients can be observed. This suggests that leapfrogging is not a common phenomenon in EU member countries as far as productivity growth in pork production is concerned. We can conclude that the sector development is r characterized by the strengthening position of the most successful pork producers, whereas the weak producers fall more and more behind.

4.2 Metafrontier analysis

This chapter provides the results of metafrontier analysis. We focus on the country and regional comparison of technical efficiency and total factor productivity in cereal, milk and pork production. Thus, we provide an overview which regions perform better in terms of technical efficiency and productivity and which regions are falling behind.

4.2.1 Cereals

Table 25 provides parameter estimate of stochastic metafrontier multiple output distance function for cereal production in 24 EU member states (Cyprus, Luxemburg and Malta are missing). As was expected, the first order parameters standardly discussed in production function estimate as well as the parameters on unobservable fixed management are highly significant, even with 1 % significance level. This also holds for majority of second order parameters.

As far as theoretical consistency of the estimate is concerned we can conclude that monotonicity requirements as well as requirements on convexity in outputs and quasi convexity in inputs are met, 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 and parameters of inputs can be interpreted as elasticities of production on the sample mean (as in the case of country estimates of multiple output distance function). That is, the share of other plant production is 7 % and the share of animal production is 52 % for the analysed sample. Cereal production dominates the plant production, however, more than half of the output is created by animal production. This holds on the sample mean. As was expected the highest elasticities of production are for material inputs and land. On the other hand, the lowest elasticity was estimated for capital. These estimates correspond to the values estimated for individual countries (see chapter 4.1).

Table 25 Parameter estimates – cereal metafrontier

Means for random parameters				Coefficient on unobservable fixed management			
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
Const.	-0.1763	0.0015	0.0000	**Alpha_m**	-0.3633	0.0006	0.0000
Time	-0.0036	0.0002	0.0000	**Time**	-0.0009	0.0003	0.0004
X1	-0.0751	0.0011	0.0000	**X1**	-0.0168	0.0010	0.0000
X2	-0.2274	0.0011	0.0000	**X2**	-0.0415	0.0009	0.0000
X3	-0.0352	0.0009	0.0000	**X3**	-0.0200	0.0007	0.0000
X4	-0.1259	0.0010	0.0000	**X4**	0.0404	0.0008	0.0000
X5	-0.5157	0.0010	0.0000	**X5**	0.0418	0.0008	0.0000
				Alpha_mm	-0.0493	0.0007	0.0000
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
TT	-0.0039	0.0002	0.0000	**X13**	0.0038	0.0013	0.0034
Y2	0.0743	0.0008	0.0000	**X14**	0.0037	0.0015	0.0156
Y3	0.5212	0.0005	0.0000	**X15**	0.0441	0.0014	0.0000
Y2T	0.0033	0.0003	0.0000	**X23**	-0.0133	0.0010	0.0000
Y3T	0.0035	0.0002	0.0000	**X24**	-0.0059	0.0011	0.0000
Y22	0.0274	0.0011	0.0000	**X25**	0.0264	0.0013	0.0000
Y33	0.1281	0.0003	0.0000	**X34**	0.0221	0.0009	0.0000
Y23	-0.0213	0.0005	0.0000	**X35**	0.0054	0.0011	0.0000
X1T	0.0036	0.0004	0.0000	**X45**	0.0011	0.0012	0.3752
X2T	0.0103	0.0004	0.0000	**Y2X1**	0.0114	0.0013	0.0000
X3T	-0.0071	0.0003	0.0000	**Y2X2**	-0.0288	0.0010	0.0000
X4T	-0.0015	0.0004	0.0000	**Y2X3**	-0.0007	0.0009	0.4109
X5T	-0.0078	0.0004	0.0000	**Y2X4**	0.0000	0.0010	0.9661
X11	-0.0045	0.0022	0.0398	**Y2X5**	0.0196	0.0011	0.0000
X22	0.0500	0.0017	0.0000	**Y3X1**	-0.0266	0.0007	0.0000
X33	-0.0239	0.0007	0.0000	**Y3X2**	0.0414	0.0006	0.0000
X44	-0.0355	0.0010	0.0000	**Y3X3**	0.0145	0.0006	0.0000
X55	-0.0917	0.0018	0.0000	**Y3X4**	0.0155	0.0005	0.0000
X12	-0.0469	0.0017	0.0000	**Y3X5**	-0.0300	0.0008	0.0000
Sigma	0.1641	0.0007	0.0000				
Lambda	0.9925	0.0173	0.0000				

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

Since the sum of production elasticities is -0.979 slightly decreasing returns to scale were estimated for the EU member countries. Since the sum is closed to one the impact of scale efficiency on a productivity change will not be large on the EU average. However, the impact might be large for individual countries since the returns to scale differ significantly among the countries.

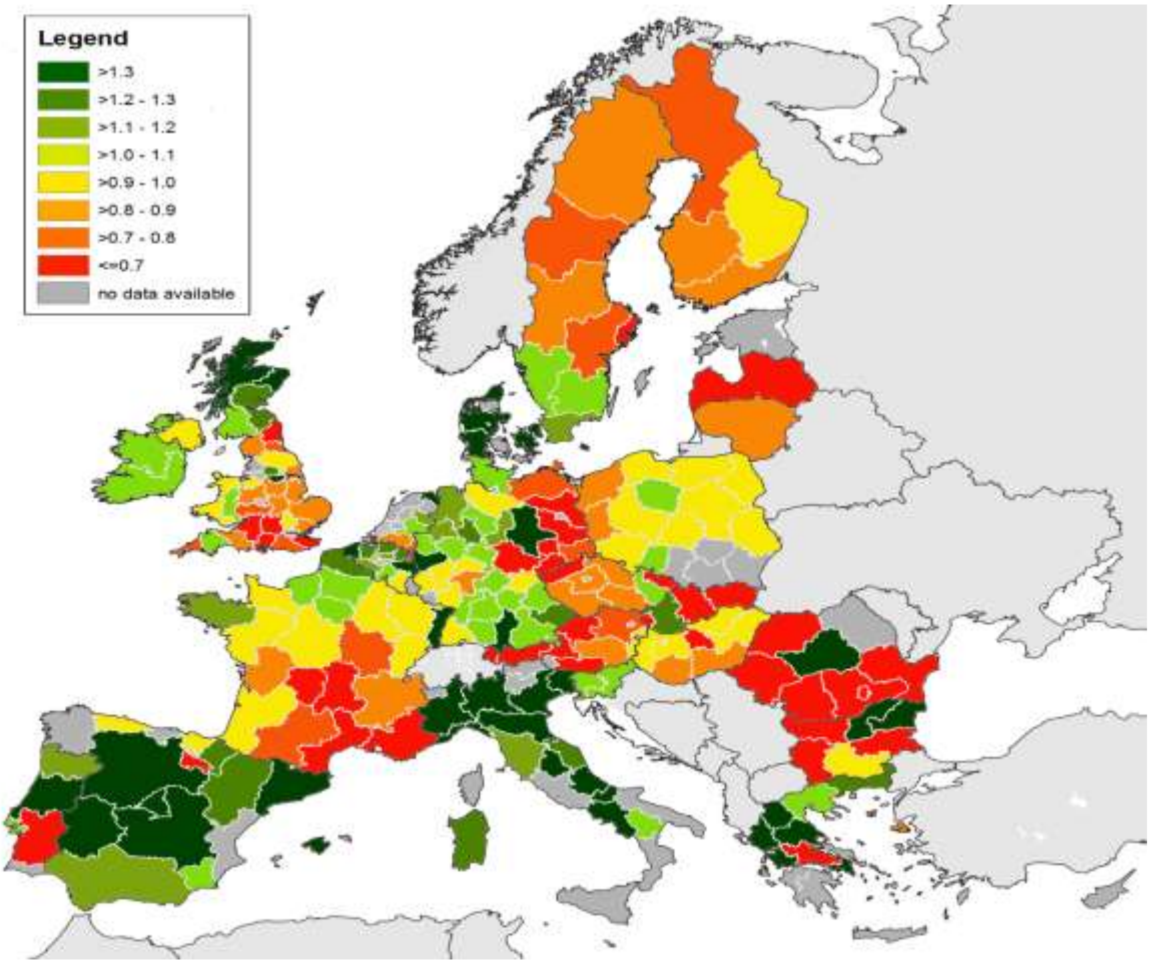
The parameters on unobservable management are highly significant which suggests that the chosen specification well approximates the estimated relationship and that heterogeneity among firms is an important characteristic of farmers with cereal specialisation in EU member countries. The unobservable management contributes positively to the production and the impact accelerates over time. The increase in management has a positive impact on production elasticities of material inputs and negative on other inputs. The impact of technological change on technical efficiency is not pronounced (the coefficient is almost zero).

Technological change has a significant positive contribution ($\beta_T < 0$) to the production and the impact of technical change is accelerating over time ($\beta_{TT} < 0$). Moreover, the biased technological change is pronounced. The technological change is labour and land saving and capital and material using. This direction of the technological change correspond to our expectations. The adoption of innovations lead to the situation where labour become scarcer and capital more abundant.

Parameter λ is highly significant and about one. That is the variation in u_{it} is almost equal to the variation in the random component v_{it}. The estimates indicate that efficiency differences among cereal producers are important reasons for variation in production. However, the estimate did not reveal significant differences among countries not even among regions. The results show that cereal producers in EU member countries highly exploit their production possibilities (evaluated on the sample mean). The averages of technical efficiency calculated on regional level (NUTSII) are in the interval 0.89 and 0.92.

On the contrary to the technical efficiency estimate TFP differences among countries as well as among regions are significantly pronounced. Figure 2 depicts the differences in TFP on the regional level. The lowest Törnqvist-Theil indexes (TTI), value lower than 0.7 (red colour in the Figure), were estimated for regions in the United Kingdom, south France, east Germany, the north Czech Republic, west Austria, central and east Slovakia, Latvia and most of regions in Bulgaria and Rumania. The most productive regions can be especially found in Spain, Italy, Germany and Denmark. We can conclude that catching up and falling behind processes are highly pronounced in cereal production among EU regions. This conclusion is in line with findings in chapter 4.1.

Figure 2: Regional differences in TFP – cereal production



Source: own calculation

4.2.2 Milk

Table 26 provides the parameter estimate of stochastic metafrontier model for milk production. First we will again discuss the parameter estimate. As in the case of cereal production, the first order as well as the second order parameters are highly significant, even with 1 % significance level. Moreover, monotonicity and convexity (convexity in outputs and quasi convexity in inputs) requirements are met.

Table 26 Parameter estimates – milk metafrontier

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				

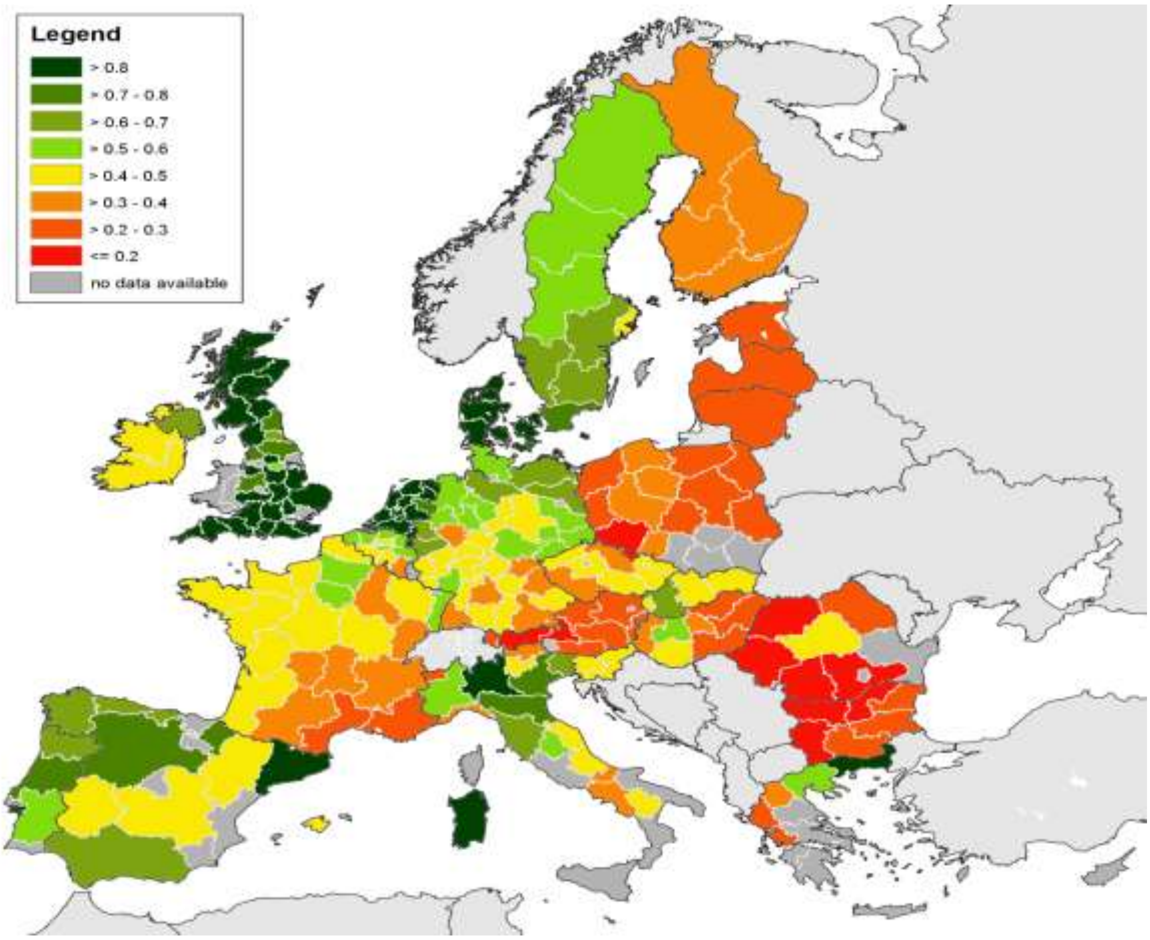
Note: ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively
Source: own calculation

Milk specialisation is highly pronounced among the producers. On average, the share of other animal production is 7.3 % and the share of plant production is about 21.7 %. The highest production elasticity is for material inputs and the lowest for capital. However, more intensive capital technology can be found as compared to the cereal production. The capital elasticity is about two times higher, 6.6 %.

The sum of production elasticities is 0.889. That is the decreasing returns to scale were estimated for the EU member countries. The estimate revealed that the scale efficiency will have a significant impact on productivity change, evaluated on the sample mean. However, this also holds for individual EU member countries.

Since all parameters on unobservable management are highly significant chosen specification well approximates the estimated relationship and the heterogeneity among firms is an important characteristic of milk producers in EU member countries. The unobservable management contributes positively to the production and the impact is accelerating. As in the case of cereal production, the increase in management has a positive impact on production elasticities of material inputs and negative on labour, land and capital. The impact of technological change on technical efficiency is negative with increasing management.

Figure 3: Regional differences in technical efficiency – milk production



Source: own calculation

Technological change has a significant positive contribution to the production and it slightly accelerates over time. Moreover, the biased technological change was revealed by the estimate. The technological change is labour, land and other material saving and capital and specific material using. These findings again correspond to our expectations about the adoption of innovations. That is, labour become scarcer and capital more abundant.

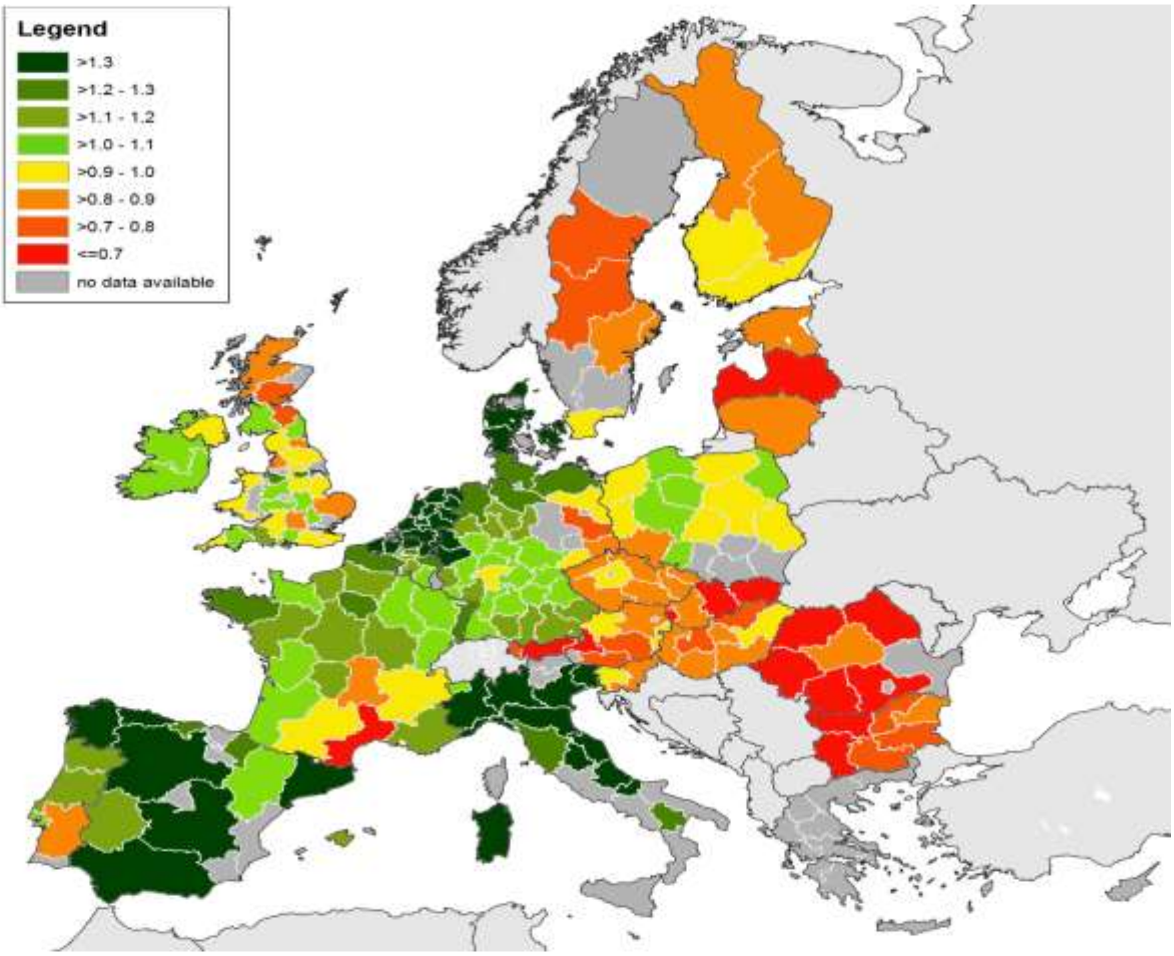
Parameter λ is highly significant and about 1.23. That is the variation in u_{it} is more pronounced than the variation in the random component v_{it}. The estimates indicate that efficiency differences among cereal producers are important reasons for variation in production. Moreover, we also found significant regional differences in technical efficiency of milk producers.

Figure 3 depicts regional comparison of technical efficiency. The comparison is done in the way that the technical efficiency of individual producers are related to the best producer. Thus, on the regional level we can observe how the region is closed to the best practice.

The results suggest that regions that highly exploit their production possibilities can be found in Denmark, the Netherlands, north Germany, north Italy, the United Kingdom, Sweden, Portugal and some regions in Spain. On the contrary, the regions with bad production practise can be especially found in the new member states, Austria and south France. These findings correspond to our expectations.

Figure 4 depicts the regional differences in TFP. The lowest Törnqvist-Theil indexes (TTI), value lower than 0.7 (red colour in the Figure), were estimated for regions situated especially in new member states (Latvia, Slovakia, Romania and Bulgaria). The most productive regions can be found in Spain, Italy, the Netherlands and Denmark. We can again conclude that catching up and falling behind processes are highly pronounced in milk production among EU regions.

Figure 4: Regional differences in TFP – milk production



Source: own calculation

4.2.3 Pork

Table 27 provides the parameter estimate of stochastic metafrontier model for pork production and 12 EU countries (Austria, Belgium, Denmark, Germany, Spain, France, Italy, the Netherlands, Poland, Portugal, Romania and Sweden). As in the case of cereal and milk production, majority of the first order as well as the second order parameters are highly significant, even with 1 % significance level. Moreover, monotonicity and convexity (convexity in outputs and quasi convexity in inputs) requirements are met.

Table 27 Parameter estimates – pork metafrontier

Means for random parameters				Coefficient on unobservable fixed management			
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
Const.	-0.1139	0.0045	0.0000	**Alpha_m**	-0.0247	0.0018	0.0000
Time	-0.0174	0.0011	0.0000	**Time**	0.0001	0.0009	0.9498
X1	-0.0897	0.0044	0.0000	**X1**	0.0030	0.0031	0.3267
X2	-0.1269	0.0039	0.0000	**X2**	0.0198	0.0025	0.0000
X3	-0.0619	0.0035	0.0000	**X3**	-0.0297	0.0025	0.0000
X4	-0.4647	0.0031	0.0000	**X4**	0.1411	0.0023	0.0000
X5	-0.3342	0.0044	0.0000	**X5**	-0.0968	0.0031	0.0000
				Alpha_mm	-0.2412	0.0025	0.0000
Variable	**Coef.**	**SE**	**P [|z|>Z*]**	**Variable**	**Coef.**	**SE**	**P [|z|>Z*]**
TT	-0.0041	0.0012	0.0007	**X13**	-0.0097	0.0058	0.0959
Y2	0.0989	0.0014	0.0000	**X14**	0.0322	0.0061	0.0000
Y3	0.2781	0.0024	0.0000	**X15**	0.0185	0.0077	0.0169
Y2T	-0.0007	0.0007	0.3229	**X23**	0.0233	0.0041	0.0000
Y3T	-0.0013	0.0010	0.2131	**X24**	-0.0064	0.0046	0.1690
Y22	0.0580	0.0010	0.0000	**X25**	0.0125	0.0060	0.0380
Y33	0.1213	0.0017	0.0000	**X34**	-0.0289	0.0036	0.0000
Y23	-0.0019	0.0011	0.0774	**X35**	0.0268	0.0046	0.0000
X1T	0.0241	0.0021	0.0000	**X45**	0.1559	0.0042	0.0000
X2T	-0.0046	0.0016	0.0036	**Y2X1**	-0.0060	0.0028	0.0307
X3T	-0.0043	0.0014	0.0018	**Y2X2**	-0.0133	0.0022	0.0000
X4T	0.0065	0.0015	0.0000	**Y2X3**	0.0069	0.0022	0.0014
X5T	-0.0196	0.0019	0.0000	**Y2X4**	0.0282	0.0018	0.0000
X11	0.0542	0.0114	0.0000	**Y2X5**	-0.0015	0.0030	0.6109
X22	0.0219	0.0064	0.0007	**Y3X1**	0.0865	0.0044	0.0000
X33	-0.0316	0.0032	0.0000	**Y3X2**	-0.0514	0.0030	0.0000
X44	-0.1503	0.0039	0.0000	**Y3X3**	-0.0233	0.0028	0.0000
X55	-0.1776	0.0078	0.0000	**Y3X4**	0.0055	0.0025	0.0286
X12	-0.0842	0.0070	0.0000	**Y3X5**	0.0031	0.0038	0.4188
Sigma	0.2338	0.0025	0.0000				
Lambda	1.9968	0.0668	0.0000				

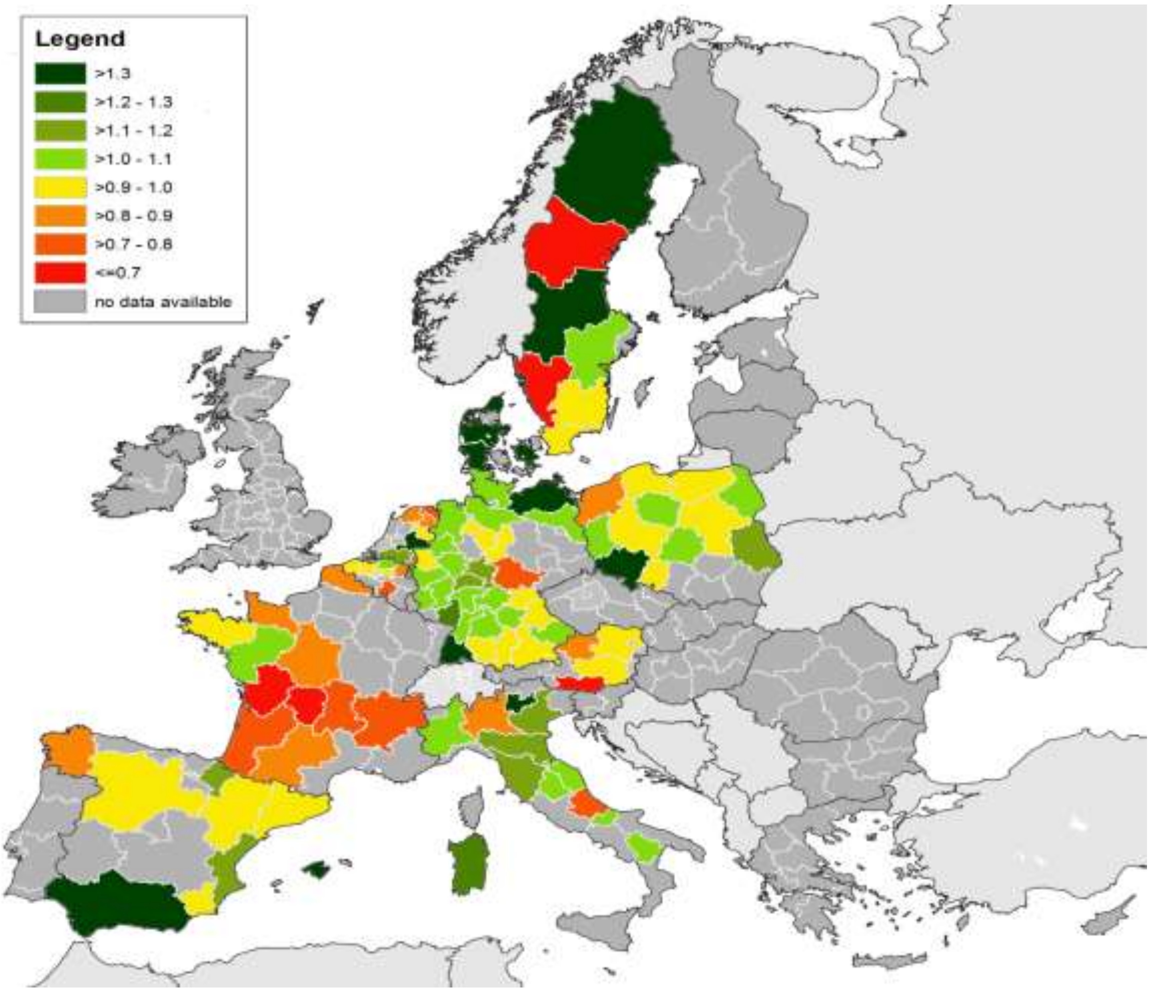
Note: ***, **, * denotes significance at the 1%, 5%, and 10% level, respectively
Source: own calculation

Pork specialisation is highly pronounced among in the analysed sample. On average, the share of other animal production is about 10 % and the share of plant production is about 27.8 %. The highest production elasticity is for material inputs and the lowest for capital. However, more intensive capital technology can be found as compared to the cereal production. The capital elasticity is almost the same as in the case of milk production, 6.2 %.

Economy of scale are pronounced. The estimate revealed increasing returns to scale. The sum of production elasticities is -1.08. Thus, the impact of scale efficiency on a productivity change will be considerably large, evaluated on the sample mean. This also holds for analysed countries.

The parameters on unobservable management are highly significant except of time and labour. That is, the results are in favour of chosen model specification and heterogeneity among the pork producers is significantly pronounced. The unobservable management contributes positively to the production and the impact is strongly accelerating with increasing management. The increase in management has a positive impact on production elasticities of land and specific material inputs and negative on capital and other material inputs. The impact of technological change on technical efficiency is not significant with increasing management.

Figure 5: Regional differences in TFP – pork production



Source: own calculation

Technological change has a significant positive contribution to the production and it accelerates over time. Moreover, the biased technological change was revealed by the estimate. The technological change is labour and specific material saving and land, capital and other material using. These findings again correspond to our expectations about the adoption of innovations. That is, labour become scarcer and capital more abundant.

Parameter λ is highly significant and about two. That is the variation in u_{it} is more pronounced than variation in the random component v_{it}. The estimates indicate that efficiency differences among pork producers are important reasons for variation in production. Moreover, we found significant differences among regions. The results show that pork producers in majority of cases the producers highly exploit their production possibilities. The averages of technical efficiency calculated on regional level (NUTSII) are in the interval 0.85 and 0.95. However, there regions with considerably low technical efficiency. This especially holds for some regions in France and Slovakia with technical efficiency lower than 0.75.

Figure 5 depicts the differences in TFP on the regional level. The lowest Törnqvist-Theil indexes (TTI), value lower than 0.7 (red colour in the Figure), were estimated for two regions in Sweden, France and one region in Austria and Italy. The most productive regions can be especially found in Denmark. Majority of region in Germany and Italy have TTI higher than one. On the contrary, regions in France have TTI lower than one and these regions seem to fall more and more behind as far as productivity growth is concerned. Thus, we can conclude that catching up and falling behind processes are highly pronounced also in the case of pork production among EU regions.

5 Conclusions

The stochastic frontier analysis of cereal, milk and pork producers revealed significant differences in technology among the countries. Moreover, there is an indication of economies of scale for majority of countries in cereal as well as milk and pork production.

Technological change had a significant positive contribution to the production possibilities in majority of countries. The biased technical change is pronounced also for almost all countries. However, the direction of biased technical change differs among the countries and no common patterns can be identified.

Moreover, the estimate revealed that efficiency differences among producers are important reasons for variation in the production. However, the variation of the average technical efficiency is not large for all EU member countries even if huge differences between the best and the worst farmers exist. High technical efficiency of the 10 % best farmers is the common feature for all countries. The developments of technical efficiency are rather stochastic in many EU member countries and this also holds for factors determining technical efficiency development. Thus, rather idiosyncratic developments of technical efficiency was observed. Leapfrogging in TE appears to be a common phenomenon for all member countries in cereal production. This holds for majority of countries in milk and pork production as well.

On the other hand, leapfrogging can be denied as far as TFP development in cereal as well as milk and pork production is considered. Structural change seems to occur in 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 supposed to fall more and more behind. We can observe a positive trend in TFP in majority of EU member countries. Moreover, technical change was identified as the important factor that contributed predominantly positively to TFP development. This holds for cereal as well as milk and pork production. Moreover, despite the positive TFP development in many countries we did not observed catching up process from between the regions. The metafrontier analysis showed that despite a period of almost 10 years after accession the productivity differences in the agricultural among as well as within countries are quite substantial.

Since adoption of innovation is the most important factor determining TFP growth the policy makers should focus the attention to support the spread of innovations and know-how in the way to support the productivity growth in less productive regions and thus to decreases the differences among the regions in terms of productivity.

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Project information

Title: International comparisons of product supply chains in the agri-food sectors: determinants of their competitiveness and performance on EU and international markets (COMPETE)

Funding: Collaborative research project (small or medium-scale focused research project), FP-7-KBBE.2012.1.4-09, total EU contribution is 2,422,725 €

Duration: 01/10/2013-30/09/2015 (36 months)

Objective: The objective of the COMPETE project is to gain a more comprehensive view on the different elements which contribute to the competitiveness of the European agri-food supply chain in order to provide better targeted and evidence based policies on the EU as well as on the domestic level. The project investigates selected determinants of competitiveness like policy interventions and the business environment, productivity in agriculture and food processing, the functioning of domestic and international markets, the choice of governance structures, and innovative activities in food processing. The research results will enable a congruent, coherent and consistent set of policy recommendations aiming at improving competitiveness of European product supply chain.

Coordinator: IAMO, Germany, Prof. Heinrich Hockmann

Consortium: 16 Partners from 10 European countries. COMPETE brings together academics, trade bodies, NGOs, agricultural co-operative, industry representative advisory services. In addition, the project is supported by the group of societal actors, incorporating farmer, food processing and consumer associations, providing in-depth knowledge on the agri-food sector and speeding up the achievement of the project goals.

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COMPETE
International comparison of product supply chains in the agro-food sector

This project is funded by the European Union

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