Technical efficiency and productivity differentials of dairy farms in three EU countries: the role of CAP subsidies

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Abstract

The impact of EU agricultural support policies on farms' economic performance is an interesting issue for policy makers. The objective of this paper is to investigate technical efficiency and technical efficiency change of specialized German, Dutch and Swedish dairy farms and to compare their relative productivity. Three subsidy-related variables are introduced to reflect the wealth and insurance effect and the coupling effect of Common Agricultural Policy (CAP) subsidies. Our results imply that a higher degree of coupling in farm support negatively affects farm efficiency, and the motivation of farmers to work efficiently is lower when they depend to a higher degree on subsidies as a source of income. Our study indicates that the composition of subsidies has a much smaller effect on efficiency than does the composition of total farm income. Relative productivity scores show that German and Swedish dairy farms have potential for improvement in productivity, compared to the production technology in the Netherlands. In conclusion, it is questionable whether farm income support of CAP since the 1992 CAP reform is suitable to achieve its goal to increase farmers' overall competitiveness by improving their efficiency.

Keywords: *technical efficiency, relative productivity, output distance function, dairy farm, subsidies, CAP*

Introduction

The agricultural income support policy within the European Union **(EU)** Common Agricultural Policy **(CAP)** is complex and involves many policy instruments. In the last two decades, the CAP has gone through three major reforms. In 1992, the MacSharry reform introduced a movement from price support to direct farm payments based on the area farmed and livestock kept, and it also reduced the intervention prices (Folmer et al., 1995, Ingersent et al., 1998). The second reform, Agenda 2000, expanded the shifts towards direct payments. Intervention prices were further reduced, and these cuts were compensated by the introduction of yearly direct payments (Benjamin et al., 1999, EU-Commission, 1999). The 2003 Fischler reform further weakened the link between subsidies and production by introducing the Single Payment Scheme, which was to decouple the direct payments from production (Swinbank and Daugbjerg, 2006). In short, the various CAP reforms have undergone a long process from price support, to the production-related direct subsidies, and eventually to decoupled payments.

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The impact of agricultural support policies on farms' economic performance is an interesting question for policy makers. Economic performance can be studied by efficiency measures such as technical efficiency **(TE)** and productivity (Coelli et al., 2005). Subsidies can increase TE if they provide an incentive to innovate or switch to new technologies (Harris and Trainor, 2005), or decrease TE if higher income from subsidies weakens the motivation in the form of slack or lack of effort (Bergström, 2000). Therefore, how much and in what direction the CAP subsidies affect farm-performance is an empirical question. Several authors studied the effects of participation in EU subsidized credit programs and found a negative effect for German (Brümmer and Loy, 2000) and Greek (Rezitis et al., 2003) farms. Others examined the impacts of CAP direct payments (DP). Iraizoz et al. (2005) found that DPs affected TE negatively for Spanish beef farms, while Hadley (2006) showed that DPs increased TE for dairy and beef producers in England and Wales. The study of Hadley (2006), however, found the opposite impact in other farming sectors. Kleinhanß et al. (2007) reported the distorting effects of direct payments on efficiency. Recently, Zhu and Oude Lansink (2010) found a negative impact of the total CAP subsidies in the crop farms in Germany, the Netherlands, and Sweden.

Actual effects of subsidies on a producer's performance are complex and have led to a large number of studies[3]. First, impact of decoupled income support on a farm's production decisions can be attributed to a wealth effect and an insurance effect. If farmers are risk averse, any measures that reduce risk or increase income will have effects on production (Lopez, 2001). Hennessy (1998) showed that agricultural income support policies directly affect the decisions of producers, that are characterized by decreasing absolute risk aversion, in the presence of uncertainty. In that study, decoupled programs were found to increase expected profit (i.e. wealth effect). Due to the presence of risk and uncertainty in agricultural production, the income-stabilizing effect of income support policy against risk may also affect optimal decisions (i.e. insurance effect). Furthermore, when the income support is explicitly coupled to production, there is a third mechanism (i.e. coupling effect).

Second, subsidies can also indirectly affect production decision through the impact of additional income on off-farm and on-farm labor supply (Newbery and Stiglitz, 1981). That is, income from subsidies changes the time allocated to farming. Findeis (2002) showed that income transfers reduced total working time, due to an increase in affordability of home time. Woldehanna et al. (2000) found that decreased price support in combination with direct income support most likely increased off-farm employment of arable farm households in the Netherlands. El-Osta et al. (2004) found a positive effect of decoupled payments on on-farm labor supply, and thus on production decision. Serra et al. (2005a) showed that the decoupling associated with the 1996 US agricultural policy reform reduced the likelihood of off-farm labor participation. Similarly, Ahearn et al. (2006) found that government payments, whether coupled or decoupled, had a negative effect on off-farm labor participation. Ooms (2007), however, did not find an

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[3] There is also a sizable literature reporting effects of subsidies on farm growth and exit (Pietola et al., 2003; Ahearn et al., 2005; Goodwin and Mishra, 2006; Ooms, 2007). Yet another stream of literature links subsidies to market imperfections and input-output allocation (Moschini and Sckokai, 1994; Oude Lansink and Peerlings, 1996; Bezlepkina et al., 2005; Serra et al., 2005b; Serra et al., 2006).

effect of decoupled payments on the on- and off-farm labor supplies and production. Furthermore, subsidies can affect the firms' long-term performance through an effect on financial variables such as debt, solvability and liquidity. Those financial factors influence investment decisions, thereby affecting farms' production potential in the long run (Hubbard, 1998, Ooms, 2007, Young and Westcott, 2000). These changes in production decision eventually influence their technical efficiency.

Although previous studies have investigated the direct and indirect effects of subsidies, an empirical analysis of the impact of the coupling, and the wealth and insurance components of (CAP) subsidies on efficiency is missing. This paper contributes to the literature by fulfilling the objectives (i) to investigate technical efficiency and technical efficiency change **(TEC)** of specialized German, Dutch and Swedish dairy farms, (ii) to identify the coupling, and the wealth and insurance effect of subsidies and (iii) to determine the relative productivity of dairy farms across countries, which shows the direction of improvement in productivity towards the best production technology. The paper employs a stochastic output distance function and an inefficiency effects model (Battese and Coelli, 1995) to analyze the determinants of efficiency within each country in 1995-2004. We argue that the coupling effect (i.e. impact of coupled subsidies) can be derived from subsidies related to inputs and outputs. The wealth and insurance effect of the CAP payments is derived from a variable representing the share of total subsidies in total income. We compare the performance of the dairy farms in the sample across countries by analyzing their relative productivity. Following the methodology employed by Oude Lansink et al. (2001), we calculate the ratios of predicted output from the 'own country' production technology to the predicted output from the production technologies of 'other countries'. The ratios indicate the potential for improving performance relative to the best available technology across countries. Empirical insights into relative productivity differences between countries might shed some light on the impact of subsidies on the competitiveness because of the potential impacts of subsidies on technical efficiency because of the potential impacts of subsidies on technical efficiency.

The remainder of this paper proceeds as follows. Section 2 presents the theoretical background on the impacts of subsidies and other variables on efficiency and elaborates the output distance function and inefficiency effects model. This is followed by the specification of the empirical model in section 3 and the description of the data in section 4. In section 5, we present and discuss the results. Section 6 concludes.

Theoretical Background

Impact of Subsidies and Other Variables on Inefficiency

Inefficiency models usually include exogenous factors that are related to managerial, environmental, and socio-economic characteristics. The CAP subsidies in the period 1995-2004 is a kind of direct income transfer which is based on historical production. Therefore, there is little possibility for farmers to adjust their production decision solely based on the amount of subsidies they received. As such we treat subsidies as an exogenous variable in the analysis. This study has a specific interest in the impact of subsidies on technical efficiency. According to the European Community's Farm Accounting Data Network (FADN) database, total subsidies consists of six categories: (i) total subsidies on crops including compensatory/area payments, set aside premiums and other crop subsidies, (ii) subsidies on livestock including subsidies on dairying, other cattle, sheep and goats, and other livestock, (iii) other subsidies including environmental subsidies, less favored area subsidies and other rural development payments, (iv) subsidies on intermediate consumption, (v) subsidies on external factors including wages, rent and interests, and (vi) decoupled payments. Since the Single Payment System, which decoupled DPs from production, is used after 2005 (Swinbank and Daugbjerg, 2006), the last category are not reported for the period 1995-2004 used in this study. More details on the volume of subsidies are given in Table 1A of Appendix 1.

The objective of this paper is, among others, to determine the wealth, insurance and coupling effects of subsidies on technical efficiency. However, truly decoupled subsidies (i.e. single farm payments) reflecting the wealth and insurance effect have not been granted in the studied period. We introduce three variables (see Table 1) to reflect the coupling, and the wealth and insurance effect of subsidies. The first and the second subsidy-related variables (i.e. share of livestock subsidies and input-related subsidies in total subsidies) reflect the coupling effect of CAP subsidies. The two variables account for headage livestock payments and arable area payments, which are based on the fixed number of livestock head and fixed area and yields, respectively. It is a generally accepted view, that the area aids and headage payments are largely coupled to production (Beard and Swinbank, 2001). Input-related subsidies have an indirect effect on output through their impact on input use, implying that their degree of coupling will be lower than that of output related subsidies. Note that subsidies on crops are included in the input-related payments, as in the case of specialized dairy farms the production of crops can be treated as input (e.g. feed) for dairying. The third subsidy variable included in the inefficiency model is the share of total subsidies in total farm income. Total subsidies from CAP are considered as a source of non-stochastic income and thus they may influence farmer production decision through the wealth and insurance effect. Furthermore, as the effect of the coupled income support is already controlled by the shares of output-related and input-related payments, the share of total subsidies in total farm income also captures the wealth and insurance effect of other subsidies. Those other subsidies include environmental subsidies, less favored area subsidies, and other rural development payments, which are assumed to be decoupled from production.

Table 1 Explanatory variables (z) in the inefficiency effects model and their definitions

Variable name	Definition
Livestock subsidies	Share of livestock subsidies in total subsidies (%)
Input-related subsidies	Share of the sum of subsidies on crops, intermediate consumption and external factors in total subsidies (%)
Total subsidies	Share of total subsidies in total farm income (%)
Farm size	Farm size in terms of European size units (ESU)
Degree of specialization	Share of milk production in total production (%)
Family labor	Share of family labor in total labor (%)
Rented land	Share of rented land in total utilized land (%)
Long-term debt	Share of long and intermediate run loans in total assets (%)
Short-term debt	Share of short run loans to total assets (%)
Time trend	Time=1 for 1995, time=10 for 2004
Regional dummies	12 dummies for Germany and 2 dummies for Sweden

In the initial analysis, we included the actual levels of subsidies rather than their shares. However, the actual levels of subsidies were correlated with the size variables. Therefore, we propose to use shares rather than actual levels of subsidies in this analysis. However, this solution comes at the cost of a number of homogeneity assumptions, i.e.

- Homogeneity of degree zero of the coupled subsidies components on efficiency. This assumption implies that a 1% increase in all subsidy components does not affect the efficiency through what we call the coupled subsidies effect. In other words, in our approach the coupling effects reach the farmers only through the relative composition.
- Homogeneity of degree zero in total revenues and subsidies. This assumption implies money illusion of farmers in total revenues and subsidies, i.e. a 1% increase in all revenues (through yield and/or price increases) and subsidies does not induce farmers to become more or less efficient. This means that the actual size of subsidies does not provide incentives to farmers but its share in total income does.

Other explanatory variables in the inefficiency model are farm size, specialization, labor use, land use, financial management, and geographical regions[4]. The variable of farm size captures the impact of economies of scale, which has been shown to impact TE both negatively (e.g. Ahmad and Bravo-Ureta, 1996) and positively (e.g. Bravo-Ureta and Rieger, 1991). According to Alvarez and Arias (2003) though, increasing farm size with constant managerial ability can lead to diseconomies of size. The degree of specialization accounts for any advantages related to more knowledge in a single production activity, which could positively affect farm performance (Latruffe et al., 2005). However, a higher degree of specialization may eventually reduce the efficiency of production in case economies of scope are present or due to the fact that more diversified farms are more flexible to adapt to changing market and policy environments (Hadley, 2006). Family labor tests whether it increases (e.g. Hallam and Machado, 1996) or decreases (e.g. Tzouvelekas et al., 2001) farm performance. The share of rented land in total utilized land is used to measure the impact of ownership. Reliance on rented land can improve performance due to the increased financial pressure. However, in case of misaligned incentives between contracting parties, a higher share of rented land can lead to lower TE (Giannakas et al., 2001, Karagiannis et al., 2003).

The shares of long- and short-term debts in total assets account for the impact of financial risk and pressure on farmers. Farms that have relatively high debt ratios may not be able to keep up with technical/technological changes and new legislative environment (Paul et al., 2000). However, debts may have a positive effect on farm performance if they provide an incentive to farmers to produce efficiently (Zhengfei and Oude Lansink, 2006), and if they result in more efficient capital investments (Barnes, 2008).

Differences in TE may be attributed partly to differences in environmental conditions (e.g. climate, soil) to the extent to which these conditions are the same in one specific region. These differences are accounted for by including regional dummies in the inefficiency effects model. The FADN database provides us with 13 regions for

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[4] Factors such as milking system and feeding system may also explain differences in efficiency across farms. However this information is not available so we will not consider these variables in the paper.

Germany, 1 region for the Netherlands and 3 regions for Sweden. Note that the regional dummies do not account for all differences in environmental conditions between farms. The part which is not explained by dummies is reflected by the error term. In addition, the parameter estimates of the explanatory variables in Table 1 may be slightly biased (e.g. Kumbhakar et al., 2008).

Output Distance Function and Inefficiency Effects Model

Assume that the production technology is defined by an output set *Y*(*x*), representing the vector of outputs $y \in R_+^M$ that can be produced by an input vector $x \in R_+^N$. That is $Y(x) = \{y \in R_+^M : x \text{ can produce } y\}$. The output distance function[5] is defined as $D_O(x, y) = \min\{\theta : y/\theta \in Y(x)\}$. $D_O(x, y)$, and is non-decreasing, positively linearly homogenous and convex in *y*, and decreasing in *x* (see Färe and Primont, 1995). The value of the distance function is less than or equal to one for all feasible output vectors. On the outer boundary of the production possibilities set, the value of $D_O(x, y)$ is one. Thus, the output distance function indicates the potential radial expansion of production to the frontier.

The output distance function is by definition linearly homogenous in outputs, which is imposed by dividing all outputs (vector *y*) by one of the outputs (y_m). Homogeneity in outputs implies that $D_0^t(x_i^t, y_i^t / y_{mi}^t; \beta) = D_0^t(x_i^t, y_i^t; \beta) / y_{mi}^t$. Taking the logarithms on both sides, adding a random error term (v_{it}) for the statistical 'noise' and using $u_{it} = -\ln D_0^t(x_i^t, y_i^t; \beta)$, we obtain the normalized output distance function[6] (see Coelli and Perelman, 1999, Fuentes et al., 2001):

$$-\ln y_{mi}^t = \ln D_0^t(x_i^t, y_i^t / y_{mi}^t; \beta) + u_{it} + v_{it} \tag{1}$$

where β is a vector of parameter to be estimated, u_{it} is a non-negative random error term representing the time-varying technical inefficiency and independently distributed $N^+(z_{it}\delta, \sigma_u{}^2)$. The output-oriented technical efficiency for firm *i* at time *t* is defined as

$$TE_{it} = \exp(-u_{it}) = D_0^t(x_i^t, y_i^t; \beta). \tag{2}$$

Different factors can explain the TE differences amongst firms. These factors are exogenous variables, which are neither inputs to the production process nor outputs of the firm, but which nonetheless exert an influence on producer's performance. Our approach assumes that the exogenous factors influence the degree of TE and hence these factors are modeled directly in the inefficiency term. The basic model is based on Kumbhakar et al. (1991) and Battese and Coelli (1995). It is assumed that the $u_{it}'s$ are non-negative random variables reflecting firm-specific and time-specific deviations from the frontier, associated with TE of production. In equation (1), u_{it} is specified as

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[5] An output distance function instead of input distance function in the empirical analysis is used because the possibility for leasing and purchasing milk quota in the countries allows for expansion or contraction of milk output. Furthermore, we argue that there are more severe limitations in the markets of inputs like land, labor and capital. Not surprisingly an abundance of empirical micro economic studies considers these inputs as short-run fixed.

[6] Endogeneity of a normalized output distance function is a theoretical concern in the literature. As Brümmer et al. (2002) argued, the normalized output distance function does not suffer the problem of endogeneity. Besides, a large body of the literature employed this approach for the empirical studies.

$$u_{it} = z_{it}\delta + w_{it}\,, \tag{3}$$

where z_{it} is a vector of firm-specific time-varying J variables (called explanatory variables or exogenous factors) exogenous to the production process, and δ is an unknown vector of J parameters to be estimated. The error term $w_{it} \sim N(0,\ \sigma_w^2)$ is truncated from below by the variable truncation point $-z_{it}\delta$. The frontier model (1) with inefficiency effects model (3) allows for a simultaneous estimation of the impact of different factors that determine TE. Therefore, technical efficiency corresponding to the production frontier and inefficiency effects is defined as

$$TE_{it} = \exp(-u_{it}) = \exp\{-z_{it}\delta - w_{it}\}\,. \tag{4}$$

Technical efficiency change rate is defined as: $TEC = -\frac{\partial u_t}{\partial t}$. Taking the derivative of the definition of technical efficiency (i.e. $TE_{it} = \exp\{-u_{it}\}$) with respect to *t*, it is not difficult to obtain a general form of TEC:

$$TEC = -\frac{\partial u_t}{\partial t} = \frac{\partial TE_{it}}{\partial t}\frac{1}{TE_{it}}\,. \tag{5}$$

Empirical Model

Technical Efficiency and Technical Efficiency Change

This study employs a Translog specification of the output distance function. The Translog provides an attractive framework for estimating stochastic frontier models, allowing for a more flexible functional form representation of the technology than the Cobb-Douglas (Greene, 1980).

For the vector of outputs $\mathrm{y} \in \mathrm{R}_+^{\mathrm{M}}$, each output is indexed by *m* or *n*, *m* or *n*=1, 2, …, *M*. For the vector of inputs $\mathrm{x} \in \mathrm{R}_+^{\mathrm{N}}$, each input is indexed by *j* or *k*, *j* or *k*=1, 2, …, *N*. The vector of exogenous variables is $z \in R^J$ and each variable is indexed by *p*, *p*=1, 2, …, *J*. After multiplying by -1 in both sides of (1), we obtain the following specification for the *i*-th firm at time *t*:

$$\begin{aligned}\ln y_{1i}^t = {} & \beta_0 + \sum_{k=1}^{N}\beta_k \ln x_{ki}^t + \frac{1}{2}\sum_{k=1}^{N}\sum_{j=1}^{N}\beta_{kj}\ln x_{ki}^t \ln x_{ji}^t \\ & + \sum_{m=2}^{M}\beta_m \ln\frac{y_{mi}^t}{y_{1i}^t} + \frac{1}{2}\sum_{m=2}^{M}\sum_{n=2}^{M}\beta_{mn}\ln\frac{y_{mi}^t}{y_{1i}^t}\ln\frac{y_{ni}^t}{y_{1i}^t} + \sum_{k=1}^{N}\sum_{m=2}^{M}\beta_{km}\ln x_{ki}^t \ln\frac{y_{mi}^t}{y_{1i}^t} \\ & + \beta_t t + \frac{1}{2}\beta_{tt}t^2 + \sum_{k=1}^{N}\beta_{kt}\ln x_{ki}^t t + \sum_{m=2}^{M}\beta_{mt}\ln\frac{y_{mi}^t}{y_{1i}^t} t + v_{it} - u_{it}\,,\end{aligned} \tag{6}$$

where u_{it} is defined by:

$$u_{it} = z_{it}\delta + w_{it} = \delta_0 + \sum_{p=1}^{J}\delta_p z_{pit} + w_{it}\,. \tag{7}$$

The distributions of the error terms in (6) and (7) have the assumptions: $v_{it} \sim iid\, N(0,\sigma_v^2)$, $u_{it} \sim N^+(z_{it}\delta,{\sigma_u}^2)$ and $w_{it} \sim N(0,\ \sigma_{\mathrm{w}}^2)$. Using $\varepsilon_{it} = v_{it} - u_{it}$ in (6), technical efficiency is estimated as

$$TE_{it} = E[\exp(-u_{it})|\varepsilon_{it}]\,. \tag{8}$$

The marginal effect of each exogenous variable (z_p) on technical efficiency can be calculated from:

$$\partial TE_{it} / \partial z_{pit} = \partial E[\exp(-u_{it}) | \varepsilon_{it}] / \partial z_{p_{it}} = TE_{it} \Psi \delta_p , \tag{9}$$

where $\Psi = \sigma_w{}^{-1}[\sigma_w + \frac{\phi(\rho)}{1-\Phi(\rho)} - \frac{\phi(\sigma_w + \rho)}{1-\Phi(\sigma_w + \rho)}]$ and $\rho = \sigma_w{}^{-1}[\delta_0 + \sum_{p=1}^{J} \delta_p z_{pit}]$ (Kumbhakar and Lovell, 2000, p270)[7].

Totally differentiation (8) with respect to *t* gives:

$$\frac{\partial TE_{it}}{\partial t} = \frac{\partial TE_{it}}{\partial z_{1it}} \frac{\partial z_{1it}}{\partial t} + \frac{\partial TE_{it}}{\partial z_{2it}} \frac{\partial z_{2it}}{\partial t} + ... + \frac{\partial TE_{it}}{\partial z_{Jit}} \frac{\partial z_{Jit}}{\partial t} + \frac{\partial TE_{it}}{\partial w_{it}} \frac{\partial w_{it}}{\partial t} \tag{10}$$

For an empirical study, we use a discrete time (*t*=1, 2… T). With *t*-1 as the base year, the rate of technical efficiency change (5) can be written as:

$$TEC = \frac{TE_{it} - TE_{it-1}}{TE_{it-1}} = \frac{\Delta TE_{it}}{TE_{it-1}} . \tag{11}$$

Using (10) and (11), we obtain::

$$TEC = ZC_1 + ZC_2 + ... + ZC_J + WC , \tag{12}$$

where $ZC_1 = \frac{1}{TE_{it-1}} \frac{\partial TE_{it}}{\partial z_{1it}} (z_{1it} - z_{1it-1})$, …, $ZC_J = \frac{1}{TE_{it-1}} \frac{\partial TE_{it}}{\partial z_{Jit}} (z_{Jit} - z_{Jit-1})$, and $WC = \frac{1}{TE_{it-1}} \frac{\partial TE_{it}}{\partial w_{it}} (w_{it} - w_{it-1})$. Clearly, technical inefficiency or technical efficiency is explained by a set of specified exogenous variables (vector *z*) and the error term *w* captures the influences of the other unspecified factors in the stochastic frontier model. Therefore, technical efficiency change can be decomposed into the contributions of explanatory variables (ZC_1,…, ZC_J) and unspecified factors (*WC*) (Zhu and Oude Lansink, 2010).

Relative Productivity

The output distance function (6) and inefficiency effects model (7) are estimated for the Netherlands, Sweden and Germany, respectively. For comparing the differences in performance across the three countries, one possibility is to use a pooled model on TE as discussed by Brümmer et al. (2002). However, in this paper we propose to use a relative productivity measurement because assuming a common frontier for three countries is not appropriate considering the different production technologies. The relative productivity measure is conceptually similar to the inter-firm catch-up approach presented by Oude Lansink et al. (2001). It measures the relative performance of a

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[7] Alternatively, we can obtain $\frac{\partial TE_{it}}{\partial z_{it}}$ using the marginal effect of exogenous variables on the technical inefficiency $\frac{\partial E(u_{it})}{\partial z_{it}}$ (see equation 9 of Wang, 2002). Using $TE_{it} = E[\exp(-u_{it}) | \varepsilon_{it}] \cong \exp[-E(u_{it})]$ for small u_{it}, we obtain $\frac{\partial TE_{it}}{\partial z_{it}} = \exp[-E(u_{it})] \cdot (-\frac{\partial E(u_{it})}{\partial z_{it}}) = -TE_{it} \frac{\partial E(u_{it})}{\partial z_{it}}$.

country within the industry as the ratio of output evaluated at country's own production technology to the output evaluated at the production technology of the 'best performing country'. Relative productivity indicates not only the differences in technologies across countries (i.e. potential for technical change) that stem from the different adoption rates of innovations across countries in a specific sector, but also the potential differences in input quality across countries (e.g. managerial capability, education, experience). Furthermore, relative productivity differences can be due to differences in composition of vintages of capital (Oude Lansink et al., 2000).

The estimates of the output distance function can be used to make a comparison of the relative productivity of dairy farms in these countries. The output distance function (6) can be written as

$$\ln y_{1it} = f(x_{it}, y_{it}/y_{1it}, \beta) + \ln D_o , \tag{13}$$

or,

$$\ln(\frac{y_{1it}}{D_o}) = f(x_{it}, y_{it}/y_{1it}, \beta) . \tag{14}$$

Note that smaller values of D_o indicate closer proximities to the frontier and a higher value of $\ln(y_{1it}/D_o)$. The deterministic part of the output distance function, i.e. $f(x_{it}, y_{it}/y_{1it}, \beta)$, provides a measure of the production potential in each country. In the analysis of the relative productivity, the output for each country (e.g. $\ln y_1$) can be predicted using its own technology and the technologies of other countries. If the output under its own technology is higher than the outputs from technologies in other countries, this specific country is more productive than its counterparts.

Data and Descriptive Statistics

Data for specialized dairy farms over the period 1995-2004 are obtained from the FADN under the principal type of farming: specialist dairying *PTF41*. The FADN database contains mainly input expenditures and output revenues. The available FADN data did not allow us to distinguish conventional from organic farms, so both farm types are represented. It should be noted though that conventional and organic dairy farms may have different production frontiers (see e.g. Gardebroek et al. 2010), and this is not accounted for in our study. Price indexes of agricultural products with year 2000 as the base year are obtained from EUROSTAT and are used to calculate Tornqvist price indexes for the aggregate inputs and outputs. Next, we compute implicit input and output quantities as the ratios of values to the price indexes.

According to the FADN database, farm total output consists of three categories: crops and crop products, livestock and livestock products and other outputs. Since we focus on dairy farms, we separate milk from the livestock and livestock products. Table 2A of Appendix 1 shows the composition of outputs for specialized dairy farms. It shows that the dairy output (milk & products) amounts to at least 65% of the total outputs. Therefore, we aggregate the remaining part (crops & crop products, other livestock products and other output) as 'other products', and finally distinguish two outputs (milk and other products) for the total outputs. Regarding the inputs, we distinguish one variable input, which includes crop-specific costs such as fertilizers, livestock-specific inputs such as feed, veterinary fees and milk tests etc., and three factor inputs (capital, labor and land). In FADN, livestock heads are included in the category of capital. This classification is in line with other applications in the literature (e.g. Brümmer et al., 2002). Descriptive statistics of variables in the output distance function are shown in Table 2, whereas more detailed yearly summary statistics of the model variables are available upon request.

Table 2 Descriptive statistics of model variables in output distance function

	Mean	Std. Dev.	Minimum	Maximum
Germany[a]				
Milk (€)	90,888	58,662	13,252	413,046
Other products (€)	32,810	19,991	4,347	136,177
Variable inputs (€)	73,470	43,791	6,868	438,746
Capital stock (100 €)	2,825	4,385	337	458,499
Labor (hrs)	4,036	1,950	2,186	31,910
Land (ha)	58	37	8	364
Netherlands[b]				
Milk (€)	159,668	87,422	11,563	525,867
Other products (€)	42,355	39,276	3,776	311,657
Variable inputs (€)	102,330	52,922	16,698	467,700
Capital stock (100 €)	4,168	2,441	425	31,308
Labor (hrs)	4,362	1,656	756	13,149
Land (ha)	42	23	6	214
Sweden[c]				
Milk (€)	97,128	106,332	184	1407,383
Other products (€)	36,363	45,217	150	501,265
Variable inputs (€)	91,446	95,277	3,876	1431,048
Capital stock (100 €)	3,238	2,916	176	33,010
Labor (hrs)	4,468	2,398	500	36,756
Land (ha)	84	84	4	1,119

[a] *Based on 2845 farms and 12458 observations in 1995-2004*

[b] *Based on 696 farms and 3223 observations in 1995-2004*

[c] *Based on 597 farms and 3341 observations in 1995-2004*

Empirical Results

Technical Efficiency Differentials

As a standard empirical application of Battese and Coelli (1995) model, we use the maximum likelihood method to estimate the model. Parameter estimates of output distance function and inefficiency effects model for each country are shown in Appendix 2. The scores for TE and TEC are shown in Table 3. Mean TE in the period of 1995-2004 is 61% in Germany, 55% in the Netherlands, and 79% in Sweden. The annual scores show an increasing trend for the Netherlands, while average TE is decreased in Sweden. These trends are also indicated by the average TEC results (positive for the Netherlands and negative for Sweden). German dairy farms exhibit an increasing TE in 1995-2000, then a decreasing in 2000-2001, thereafter stabilized in 2001-2003 and a decrease in 2003-2004. The average TEC in 1995-2004 in German dairy farm is very small.

Table 3 Technical efficiency (TE) and technical efficiency change (TEC) of dairy farms

	Germany		Netherlands		Sweden	
Year	TE	TEC	TE	TEC	TE	TEC
1995	0.583	-	0.472	-	0.827	-
1996	0.575	-0.008	0.472	0.013	0.838	-0.011
1997	0.601	0.041	0.510	0.058	0.798	-0.056
1998	0.608	0.010	0.534	0.048	0.800	-0.001
1999	0.636	0.022	0.578	0.080	0.771	-0.029
2000	0.654	0.017	0.557	-0.042	0.792	0.022
2001	0.619	-0.030	0.590	0.062	0.767	-0.032
2002	0.621	0.015	0.597	0.007	0.764	0.002
2003	0.622	-0.005	0.627	0.042	0.782	0.032
2004	0.612	-0.009	0.614	-0.008	0.759	-0.036
Average	0.614	0.004	0.553	0.027	0.788	-0.011

The estimates of technical inefficiency effects model (see Appendix 2) show that both the output-related and the input-related subsidies have negative impacts on TE in Germany and the Netherlands, but no significant impact in Sweden. The marginal effects of exogenous variables on TE (Table 4) show that an increase of one percent point in the share of livestock subsidies in total subsidies causes 0.07% and 0.04% decreases in TE, while an increase of one percent point in the share of input-related subsidies in total subsidies leads to 0.06% and 0.02% decreases in TE for Germany and the Netherlands, respectively. These results suggest that a higher degree of coupling in the farm support negatively affects farm efficiency. Marginal effects of the share of total subsides in total farm income are significantly negative in each of the three countries. An increase of one percent point in the share of total subsidies in total farm income leads to a 1.12%, 0.87% and 0.89% decrease in TE in Germany, the Netherlands and Sweden, respectively. These findings show that the motivation of farmers to work efficiently is lower when they depend to a higher degree on subsidies as a source of income. This suggests that the wealth and insurance effect of subsidies tends to make farmers less efficient. These results for the effects of subsidies on technical efficiency are in line with those of Iraizoz et al. (2005) for Spanish beef production, Kleinhanß et al. (2007) for German and Spanish livestock farms, and Zhu and Oude Lansink (2010) for German, Dutch and Swedish crop farms. According to these findings, it is questionable whether farm income support of CAP since the 1992 reform is suitable to achieve its goal to increase farmers' competitiveness by improving their efficiency. Additionally, our findings (Table 4) imply that the composition of subsidies (i.e. the share of coupled subsidies in total subsidies) has a much smaller effect on efficiency than does the composition of total farm income (i.e. the share of total subsidies in total income). This result is especially of importance in the light of the 2003 CAP reform, which decoupled farm income support from production such that the future CAP payments were supposed to not influence production decisions. However, those decoupled payments have a wealth and insurance effect on production (Sckokai and Moro, 2006), which may also impact technical efficiency. In a recent study, for example, Serra et al. (2008) has shown that increasing decoupled payments led to lower TE for Kansas farmers. Future research is certainly warranted on the impact of decoupled CAP payments on efficiency after the 2003 CAP reform.

Table 4 Marginal effects of exogenous variables on TE

	Germany	Netherlands	Sweden
Livestock subsidies	-0.0007	-0.0004	-0.0000
Input-related subsidies	-0.0006	-0.0002	-0.0000
Total subsidies	-0.0112	-0.0087	-0.0089
Farm size	0.0025	0.0016	0.0014
Degree of specialization	0.0040	0.0046	0.0014
Family labor	-0.0004	0.0003	-0.0003
Rented land	0.0002	-0.0001	0.0004
Long-term debt	-0.0001	0.0003	-0.0001
Short-term debt	-0.0003	-0.0018	-0.0002
Time trend	-0.0012	0.0181	-0.0016

Table 4 also shows that marginal effects of the other exogenous variables have a similar pattern for German and Swedish dairy farms. In German and Swedish farms, larger size, higher degree of specialization, lower share of family labor, more rented land, and lower degree of indebtedness increased efficiency. However, different results are obtained with respect to three exogenous factors (i.e. the share of family labor, the share of rented land and the share of long-term debts) for Dutch dairy farms. First, a higher share of family labor is found to increase TE in the Netherlands. This finding is in line with that of Hallam and Machado (1996) for Portuguese dairy farms, who found that farms relying on family labor were more efficient than those relying on hired labor. Second, a higher share of rented land in total land, which is a proxy for ownership, decreases TE. This effect may imply negative influence of agency costs between land owners and farmers in the Netherlands (Giannakas et al., 2001, Karagiannis et al., 2003). Third, a higher share of long-term debts in total assets increases TE for Dutch farms. The positive effect may be caused by investments into more efficient assets (Barnes, 2008) or may be attributed to the disciplinary role of debts (Zhengfei and Oude Lansink, 2006). Furthermore, technical efficiency is decreased over time exogenously (i.e. time trend has negative impact on TE) in Sweden and Germany. In Sweden, this may be attributed to the accession to the EU which entailed the introduction of dairy quota. In Germany, this may be a result of the unification which has initially caused a deterioration of the performance of particularly the eastern German farms.

Technical efficiency changes differently over time in the three countries. The mean annual TEC (Table 3) between 1995 and 2004 is 0.4%, 2.7% and -1.1% respectively for Germany, the Netherlands and Sweden. That is, technical efficiency of dairy farms in Germany and the Netherlands on average improves, whereas it decreases in Sweden.

The contributions of the specified exogenous variables and the other unspecified factors to technical efficiency change are presented in Table 5. In general, it can be concluded that changes in TE over the period 1995-2004 are largely explained by the variables specified in the inefficiency model for each country. Unspecified factors only slightly contribute to TEC in the Netherlands and Sweden.

Table 5 Contributions of specified variables and unspecified factors to TEC

	Germany	Netherlands	Sweden
Livestock subsidies	-0.004	-0.005	0
Input-related subsidies	0.001	0	0
Total subsidies	-0.008	-0.007	-0.011
Farm size	0.014	0.005	0.006
Degree of specialization	0.003	0.004	-0.005
Family labor	0	0	0
Rented land	0	0	0
Long-term debt	0	-0.001	0
Short-term debt	0	0	0
Time trend	-0.002	0.035	-0.004
Total specified variables	0.004	0.032	-0.014
Unspecified factors	0	-0.005	0.003
TEC	0.004	0.027	-0.011

Examining the contribution of the subsidy-related variables to TEC gives a more complete overview on the influence of CAP subsidies on the farmers' performance between 1995 and 2004. First, both the volume and the share of the output-related livestock subsidies have increased remarkably in each country (Table 1A of Appendix 1). Therefore, the increase in livestock subsidies causes a negative change in TE in Germany and the Netherlands, where these subsidies have significantly negative marginal impact on efficiency. Second, the volume of the input-related subsidies and its share in total subsidies are growing throughout the period in each country, except for 2004. There is, on average, a minor positive effect of this share on TEC in Germany, but no change in the Netherlands. In Sweden, the marginal effect of the share of input-related subsidies in total subsidies is not significant; therefore, the changes in those payments over the studied period do not affect the farmers' performance significantly. Third, the amount of total subsidies as well as their share in total farm income is increasing in each country. Given its significantly negative marginal impact on TE, this higher reliance on CAP payments has a negative contribution to the technical efficiency change in the countries. In short, what we can see is that in the three studied EU countries the farmers' total income becomes more dependent on subsidies under the CAP reform in the period 1995-2004. These changes in farm support, however, have significantly worsened the farmers' performance, thereby further reinforcing the doubt on the suitability of CAP payments for improving overall competitiveness.

Regarding the effects of the other specified variables on TEC over time, similar results for farm size is found. That is, an increase in the mean farm size improves the performance (i.e. increased TEC) as its marginal effect is positive for each country. The impact of changes in the degree of specialization is positive in Germany and the Netherlands, where farmers become more specialized in dairy production between 1995 and 2004. In Sweden, however, the trend in specialization is the opposite, which worsens the efficiency of the Swedish farmers over time. Furthermore, in the Netherlands, the remarkably decreasing share of long-term loans in total assets has a negative impact on technical efficiency change. This result may imply the adverse effect of lower investments for Dutch farmers, given that the marginal effect of long-term loans is significantly positive for the Netherlands.

Relative Productivity

The TE analyses above are based on single-country models and can only be used for measuring the scope for improvement in technical efficiency relative to the best performed farm within each country. For cross-country comparison, we use the relative productivity. In Table 6 we present the average relative productivity scores. To compute the relative productivity scores, we first insert the inputs used in one country in the production frontier of each of the three countries. The value obtained in this way is divided by the value of the frontier output obtained from the own technology (the production frontier). Table 6 reports average values of these ratios for the period 1995-2004; while more detailed, annual results are presented in Appendix 3. In contrast to the TE results, the three countries rank oppositely in terms of the relative productivity. That is, on average for a given set of total inputs the Dutch production technology results in the highest output, followed by the German and Swedish technologies. More specifically, the productivity of German dairy farms would be, on average, 6.1% higher if these farms would use the production technology of the Dutch dairy farms. Output of German dairy farms, however, would decrease by 11% by adopting the Swedish production technology. Regarding the Dutch farms, the output using their own technology is on average higher than using the alternative technologies available in the other countries (Germany and Sweden). In Sweden, dairy farms are relatively less productive than their counterparts in both Germany and the Netherlands. Swedish productivity could be improved by 13.3% or 20.4%, when using the German or the Dutch production technology, respectively.

Table 6 Mean values of the relative productivity ratios

	German technology	Dutch technology	Swedish technology
German farms	1.000	1.061	0.890
Dutch farms	0.956	1.000	0.850
Swedish farms	1.133	1.204	1.000

The findings for productivity differentials are of importance given that productivity, together with technical efficiency, is a determinant of overall competitiveness

(O'Mahoney and van Ark, 2003, Poppe et al., 2007, Porter, 1990). Therefore, the analysis of farm efficiency and the comparison of production technologies across countries provide insights to the competitiveness of farms and their potential for improving productivity and resource use (Abdulai and Tietje, 2007). In addition to the fact that there is an opportunity in each country to improve competitiveness by increasing technical efficiency, the relative productivity scores unveil further potential for improvement in German and Swedish dairy farms. Relative to Dutch farms, farmers operating in those two countries employ a less productive technology, despite the fact that mean TE scores are higher in those countries than in the Netherlands.

Conclusions

In this paper, we have investigated technical efficiency and technical efficiency change of specialized German, Dutch and Swedish dairy farms between 1995 and 2004. We have introduced three subsidy-related variables to reflect the wealth and insurance effect and the coupling effect of CAP subsidies. Furthermore, we have compared the performance of the dairy farms in the sample across countries by analyzing their relative productivity.

Our results show the greatest average TE for Swedish farms, followed by German and Dutch farms. Average TEC results indicate an increasing trend in the Netherlands and Germany and decreasing trend in Sweden. In German and Swedish dairy farms, larger size, higher degree of specialization, lower share of family labor, more rented land, and lower degree of indebtedness increase TE. However, three exogenous factors including the share of family labor in total labor, the share of rented land in total land and the share of long-term debts in total assets have an opposite effect in the Netherlands compared to that in Germany and Sweden. In contrast to the technical efficiency results, the three countries rank oppositely in terms of relative productivity. That is, on average for a given set of total inputs the Dutch production technology results in the highest output, followed by the German and Swedish technologies. Relative productivity scores show that German and Swedish dairy farms have potential for improvement in productivity, compared to the production technology in the Netherlands.

Regarding the effects of CAP subsidies, various observations can be made. First, both output-related and input-related subsidies have negative impacts on TE in Germany and the Netherlands, but no significant impacts in Sweden. Second, a higher share of total subsides in total farm income has a negative effect on TE in each country. Third, in each country the farmers' total income become more dependent on subsidies; these changes in farm support have significantly worsened the farmers' performance. Our results imply that a higher degree of coupling in farm support negatively affects farm efficiency. The motivation of farmers to work efficiently is lower when they depend to a higher degree on subsidies as a source of income. Moreover, our results indicate that the composition of subsidies has a much smaller effect on efficiency than does the composition of total farm income. This latter finding is especially of importance in the light of the 2003 CAP reform, which has decreased the share of coupled subsidies but left the share of subsidies in total income unaffected. In summary, farm income support of CAP since the 1992 CAP reform may have decreased farmers' overall competitiveness by decreasing their technical efficiency.

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Appendix 1 – Data

Table 1A Mean livestock subsidies, input-related subsidies and total subsidies of dairy farms (EUR)

		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Mean
Germany	Livestock subsidies	1,181	2,218	1,270	1,094	902	1,785	2,592	3,363	3,537	7,371	2,662
	Input-related subsidies	6,923	7,653	8,501	8,791	7,053	7,190	6,910	9,220	10,205	9,952	8,322
	Total subsidies	13,695	14,728	14,329	14,249	12,194	13,159	14,211	18,095	19,159	22,504	15,877
Netherlands	Livestock subsidies	442	521	995	450	327	990	1,709	2,595	2,741	8,824	1,925
	Input-related subsidies	1,556	1,650	1,644	2,068	2,286	2,317	2,912	3,381	3,581	3,443	2,461
	Total subsidies	3,394	3,130	3,011	2,970	3,191	4,001	6,489	7,752	8,240	13,791	5,520
Sweden	Livestock subsidies	0	2,401	7,529	6,515	7,158	2,083	3,006	3,424	3,210	9,594	4,622
	Input-related subsidies	2,888	5,044	4,620	5,420	5,580	13,830	11,078	11,269	11,122	9,095	8,309
	Total subsidies	10,046	10,159	19,742	20,146	21,547	26,753	28,449	29,707	28,204	29,363	23,090

Source: FADN

Table 2A Composition of outputs in each country (%)

Year	Crops & crop products	Livestock and Livestock products		Other output	Total
		Milk & products	Other livestock products		
Germany					
1995	7	67	21	5	100
1996	8	68	19	5	100
1997	7	69	19	5	100
1998	7	70	17	6	100
1999	5	72	18	6	100
2000	5	75	15	5	100
2001	5	76	14	5	100
2002	6	73	15	5	100
2003	7	73	15	6	100
2004	6	71	16	6	100
Average	6	71	17	5	100
Netherlands					
1995	1	75	21	3	100
1996	1	76	20	3	100
1997	1	76	19	3	100
1998	1	79	16	4	100
1999	2	79	15	4	100
2000	1	80	15	4	100
2001	3	82	11	4	100
2002	2	82	11	5	100
2003	2	82	11	5	100
2004	2	81	12	5	100
Average	2	79	15	4	100
Sweden					
1995	4	77	15	4	100
1996	11	72	11	5	100
1997	8	77	12	4	100
1998	7	75	13	5	100
1999	7	76	11	5	100
2000	9	74	12	5	100
2001	9	74	11	6	100
2002	9	73	11	6	100
2003	19	65	10	6	100
2004	19	65	9	7	100
Average	11	73	11	5	100

Source: FADN

Note: crops and crop products include cereals, protein crops, energy crops, potatoes, sugar beets, industrial crops, vegetables and flowers, fruit, wine and grapes, olive & olive oil, forage area, other crop output. Livestock and livestock products include cows' milk & products, beef and veal, pig meat, sheep and goats, poultry meat, eggs, other livestock & products. Other output includes leased land, agistment, forestry products, contract work, hiring out of equipment, receipts of tourisms etc.

Appendix 2 – Parameter Estimates

Germany

Number of observations: 12458 Log likelihood: 7284.	Coefficient	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Ln (*milk*)						
Ln (*variable inputs*)	0.91585	0.11023	8.31	0	0.69980	1.13190
Ln (*capital*)	0.49771	0.08661	5.75	0	0.32795	0.66746
Ln (*labour*)	0.41502	0.13208	3.14	0.002	0.15615	0.67390
Ln (*land*)	0.56515	0.10648	5.31	0	0.35645	0.77385
Ln (*other products/milk*)	0.09494	0.05803	1.64	0.102	-0.01878	0.20867
Time	0.06415	0.01534	4.18	0	0.03409	0.09421
Ln (*variable inputs*)**2	0.01576	0.00819	1.92	0.054	-0.00030	0.03182
Ln (*variable inputs*)*Ln (*capital*)	0.00385	0.01078	0.36	0.721	-0.01728	0.02498
Ln (*variable inputs*)*Ln (labour)	-0.07312	0.01391	-5.26	0	-0.10039	-0.04585
Ln (*variable inputs*)* Ln (*land*)	-0.03464	0.01266	-2.74	0.006	-0.05945	-0.00984
Ln (*variable inputs*)* Ln (*other products/milk*)	-0.05750	0.00641	-8.96	0	-0.07007	-0.04493
Ln (*capital*)**2	-0.01813	0.00439	-4.13	0	-0.02673	-0.00954
Ln (*capital*)* Ln (*labour*)	0.00164	0.01169	0.14	0.888	-0.02127	0.02455
Ln (*capital*)* Ln (*land*)	-0.01280	0.01089	-1.18	0.24	-0.03415	0.00854
Ln (*capital*)* Ln (*other products/milk*)	0.00778	0.00549	1.42	0.156	-0.00298	0.01853
Ln (*labour*)**2	0.00228	0.00904	0.25	0.801	-0.01544	0.02000
Ln (*labour*)* Ln (*land*)	0.01434	0.01381	1.04	0.299	-0.01273	0.04140
Ln (*labour*)* Ln (*other products/milk*)	-0.01350	0.00660	-2.05	0.041	-0.02643	-0.00057
Ln (*land*)**2	-0.02567	0.00807	-3.18	0.001	-0.04148	-0.00985
Ln (land)* Ln (*other products/milk*)	0.02441	0.00595	4.1	0	0.01275	0.03607
Ln (*other products/milk*)**2	-0.05114	0.00335	-15.25	0	-0.05771	-0.04456
Time* Ln (variable inputs)	0.00330	0.00151	2.18	0.029	0.00034	0.00627
Time* Ln (*capital*)	-0.00624	0.00128	-4.87	0	-0.00875	-0.00373
Time* Ln (*labour*)	-0.00130	0.00159	-0.82	0.413	-0.00443	0.00182
Time*Ln (*land*)	-0.00678	0.00137	-4.93	0	-0.00947	-0.00408
Time* Ln (*other products/milk*)	-0.00042	0.00074	-0.57	0.57	-0.00188	0.00103
Time_square	0.00105	0.00024	4.3	0	0.00057	0.00152
Constant	-3.35796	0.59043	-5.69	0	-4.51517	-2.20074
u						
Share of livestock subsidies	0.00124	0.00009	13.92	0	0.00106	0.00141
Share of input-related subsidies	0.00103	0.00006	16.1	0	0.00090	0.00116
Share total subsidies in total income	0.01945	0.00029	67.5	0	0.01888	0.02001
Farm size	-0.00431	0.00012	-35.65	0	-0.00455	-0.00408
Specialization degree	-0.00694	0.00066	-10.55	0	-0.00823	-0.00565
Family labour	0.00075	0.00011	6.85	0	0.00053	0.00096
Rented land	-0.00041	0.00006	-7.24	0	-0.00053	-0.00030
Long-term debt	0.00013	0.00009	1.43	0.152	-0.00005	0.00030
Short-term debt	0.00043	0.00012	3.67	0	0.00020	0.00066
time	0.00205	0.00422	0.49	0.628	-0.00622	0.01031
Niedersachsen	0.06634	0.00497	13.36	0	0.05661	0.07607
Nordrhein-Westfalen	0.01916	0.00574	3.34	0.001	0.00791	0.03040
Hessen	0.07805	0.00611	12.77	0	0.06608	0.09003
Rheinland-Pfalz	0.02109	0.00642	3.28	0.001	0.00850	0.03368
Baden-Württemberg	0.00809	0.00659	1.23	0.219	-0.00482	0.02101
Bayern	-0.03754	0.00604	-6.21	0	-0.04938	-0.02569
Saarland	0.01827	0.01188	1.54	0.124	-0.00501	0.04155
Brandenburg	0.04153	0.01464	2.84	0.005	0.01284	0.07022
Mecklenburg-Vorpommen	0.01218	0.01240	0.98	0.326	-0.01211	0.03648
Sachsen	0.06540	0.00797	8.21	0	0.04978	0.08102
Sachsen-Anhalt	0.02387	0.01344	1.78	0.076	-0.00248	0.05022
Thüringen	0.02563	0.01126	2.28	0.023	0.00355	0.04771
Constant	0.91289	0.07098	12.86	0	0.77378	1.05200
σ^2	0.0191	0.0003			0.0186	0.0196
γ	0.5661	0.0581			0.4507	0.6747
σ_u^2	0.0108	0.0011			0.0086	0.0130
σ_v^2	0.0083	0.0011			0.0061	0.0104

Netherlands

Number of observations: 3223 Log likelihood: 2155	Coefficient	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Ln (*milk*)						
Ln (*variable inputs*)	1.71782	0.19013	9.04	0	1.34518	2.09046
Ln (*capital*)	0.66615	0.16720	3.98	0	0.33844	0.99386
Ln (*labour*)	0.64838	0.24675	2.63	0.009	0.16476	1.13200
Ln (*land*)	0.38907	0.18714	2.08	0.038	0.02228	0.75585
Ln (*other products/milk*)	-0.33126	0.07921	-4.18	0	-0.48652	-0.17601
Time	-0.03057	0.02540	-1.2	0.229	-0.08036	0.01921
Ln (*variable inputs*)**2	0.02925	0.01762	1.66	0.097	-0.00528	0.06378
Ln (*variable inputs*)*Ln (*capital*)	-0.06263	0.02549	-2.46	0.014	-0.11259	-0.01267
Ln (*variable inputs*)*Ln (l*abour*)	-0.07669	0.02998	-2.56	0.011	-0.13545	-0.01793
Ln (*variable inputs*)* Ln (*land*)	-0.14692	0.02305	-6.37	0	-0.19211	-0.10174
Ln (*variable inputs*)* Ln (*other products/milk*)	-0.00150	0.01053	-0.14	0.887	-0.02214	0.01915
Ln (*capital*)**2	-0.00911	0.01233	-0.74	0.46	-0.03329	0.01506
Ln (*capital*)* Ln (*labour*)	-0.01406	0.02545	-0.55	0.581	-0.06394	0.03581
Ln (*capital*)* Ln (*land*)	0.04731	0.02229	2.12	0.034	0.00363	0.09099
Ln (*capital*)* Ln (*other products/milk*)	-0.00865	0.00986	-0.88	0.38	-0.02797	0.01066
Ln (*labour*)**2	-0.01521	0.01817	-0.84	0.403	-0.05082	0.02041
Ln (*labour*)* Ln (*land*)	0.09495	0.02679	3.54	0	0.04245	0.14746
Ln (*labour*)* Ln (*other products/milk*)	0.02387	0.01178	2.03	0.043	0.00078	0.04696
Ln (*land*)**2	-0.07426	0.01428	-5.2	0	-0.10225	-0.04628
Ln (land)* Ln (*other products/milk*)	0.00336	0.00962	0.35	0.727	-0.01550	0.02221
Ln (*other products/milk*)**2	-0.03920	0.00419	-9.35	0	-0.04742	-0.03099
Time* Ln (variable inputs)	0.00278	0.00300	0.92	0.355	-0.00311	0.00866
Time* Ln (*capital*)	-0.00002	0.00286	-0.01	0.995	-0.00562	0.00558
Time* Ln (*labour*)	-0.00277	0.00333	-0.83	0.406	-0.00931	0.00376
Time*Ln (*land*)	0.00811	0.00266	3.05	0.002	0.00289	0.01332
Time* Ln (*other products/milk*)	0.00225	0.00119	1.88	0.06	-0.00009	0.00459
Time_square	0.00121	0.00037	3.27	0.001	0.00048	0.00194
Constant	-6.78290	1.02622	-6.61	0	-8.79425	-4.77156
u						
Share of livestock subsidies	0.00073	0.00010	7.57	0	0.00054	0.00091
Share of input-related subsidies	0.00034	0.00009	3.87	0	0.00017	0.00051
Share total subsidies in total income	0.01643	0.00100	16.51	0	0.01448	0.01838
Farm size	-0.00307	0.00012	-26.34	0	-0.00330	-0.00284
Specialization degree	-0.00877	0.00071	-12.41	0	-0.01016	-0.00739
Family labour	-0.00048	0.00023	-2.05	0.04	-0.00093	-0.00002
Rented land	0.00026	0.00008	3.23	0.001	0.00010	0.00042
Long-term debt	-0.00060	0.00014	-4.28	0	-0.00087	-0.00032
Short-term debt	0.00334	0.00066	5.07	0	0.00205	0.00463
time	-0.03419	0.00697	-4.9	0	-0.04786	-0.02053
Constant	1.85499	0.09091	20.4	0	1.67681	2.03317
σ^2	0.0158	0.0004			0.0151	0.0166
γ	0.4307	0.1482			0.1880	0.7120
σ_u^2	0.0068	0.0024			0.0022	0.0115
σ_v^2	0.0090	0.0023			0.0045	0.0136

Sweden

Number of observations: 3341

Log likelihood: 1291	Coefficient	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Ln (*milk*)						
Ln (*variable inputs*)	0.63462	0.18297	3.47	0.001	0.27601	0.99324
Ln (*capital*)	-0.27054	0.15872	-1.7	0.088	-0.58162	0.04053
Ln (*labour*)	0.78805	0.21295	3.7	0	0.37067	1.20544
Ln (*land*)	0.21124	0.14031	1.51	0.132	-0.06376	0.48623
Ln (*other products/milk*)	-0.38599	0.09675	-3.99	0	-0.57561	-0.19636
Time	0.05461	0.02877	1.9	0.058	-0.00177	0.11099
Ln (*variable inputs*)**2	0.02639	0.01725	1.53	0.126	-0.00742	0.06021
Ln (*variable inputs*)*Ln (*capital*)	-0.07605	0.02344	-3.24	0.001	-0.12199	-0.03010
Ln (*variable inputs*)*Ln (l*abour*)	0.05984	0.02760	2.17	0.03	0.00574	0.11394
Ln (*variable inputs*)* Ln (*land*)	-0.02760	0.01778	-1.55	0.121	-0.06244	0.00725
Ln (*variable inputs*)* Ln (*other products/milk*)	-0.00981	0.01201	-0.82	0.414	-0.03334	0.01372
Ln (*capital*)**2	0.08031	0.01371	5.86	0	0.05343	0.10718
Ln (*capital*)* Ln (*labour*)	-0.03521	0.02359	-1.49	0.136	-0.08144	0.01102
Ln (*capital*)* Ln (*land*)	-0.03532	0.01701	-2.08	0.038	-0.06865	-0.00198
Ln (*capital*)* Ln (*other products/milk*)	-0.01478	0.00984	-1.5	0.133	-0.03406	0.00450
Ln (*labour*)**2	-0.06228	0.01621	-3.84	0	-0.09406	-0.03051
Ln (*labour*)* Ln (*land*)	0.07617	0.02178	3.5	0	0.03348	0.11886
Ln (*labour*)* Ln (*other products/milk*)	0.01273	0.01408	0.9	0.366	-0.01487	0.04033
Ln (*land*)**2	-0.03720	0.00731	-5.09	0	-0.05153	-0.02287
Ln (land)* Ln (*other products/milk*)	0.03012	0.00821	3.67	0	0.01402	0.04621
Ln (*other products/milk*)**2	-0.06580	0.00300	-21.94	0	-0.07168	-0.05992
Time* Ln (variable inputs)	-0.01408	0.00405	-3.48	0.001	-0.02201	-0.00615
Time* Ln (*capital*)	0.00890	0.00293	3.03	0.002	0.00314	0.01465
Time* Ln (*labour*)	-0.00922	0.00386	-2.39	0.017	-0.01678	-0.00166
Time*Ln (*land*)	0.01222	0.00296	4.14	0	0.00643	0.01801
Time* Ln (*other products/milk*)	-0.00747	0.00182	-4.11	0	-0.01103	-0.00391
Time_square	0.00082	0.00052	1.58	0.114	-0.00020	0.00184
Constant	-1.91418	0.85869	-2.23	0.026	-3.59717	-0.23118
u						
Share of livestock subsidies	0.00003	0.00029	0.09	0.931	-0.00054	0.00059
Share of input-related subsidies	0.00004	0.00027	0.13	0.894	-0.00049	0.00057
Share total subsidies in total income	0.02063	0.00081	25.37	0	0.01904	0.02223
Farm size	-0.00319	0.00044	-7.3	0	-0.00405	-0.00233
Specialization degree	-0.00332	0.00105	-3.17	0.002	-0.00537	-0.00127
Family labour	0.00069	0.00054	1.29	0.196	-0.00036	0.00174
Rented land	-0.00086	0.00017	-5	0	-0.00120	-0.00052
Long-term debt	0.00032	0.00031	1.04	0.298	-0.00029	0.00094
Short-term debt	0.00057	0.00068	0.83	0.408	-0.00078	0.00191
time	0.00365	0.00499	0.73	0.464	-0.00612	0.01342
Slattbygdslan	0.14260	0.01920	7.43	0	0.10496	0.18024
Skogs-och mellanbbygdslan	0.07563	0.01768	4.28	0	0.04098	0.11027
Constant	0.14097	0.10600	1.33	0.184	-0.06680	0.34873
σ^2	0.0410	0.0020			0.0373	0.0451
γ	0.7048	0.0255			0.6525	0.7522
σ_u^2	0.0289	0.0022			0.0246	0.0331
σ_v^2	0.0121	0.0009			0.0104	0.0138

Appendix 3 – Estimation of relative productivity

Germany

	German technology	Dutch technology	Swedish technology
Predicted output (logarithm)			
1995	7.082	7.306	6.189
1996	7.062	7.309	6.212
1997	7.004	7.278	6.158
1998	6.896	7.394	6.190
1999	6.814	7.429	6.188
2000	6.868	7.428	6.256
2001	6.802	7.437	6.245
2002	6.739	7.500	6.297
2003	6.757	7.562	6.363
2004	6.679	7.574	6.342
Average	6.860	7.414	6.241
Ratios of predicted output using other technology to predicted output using own technology			
1995	1.000	1.018	0.859
1996	1.000	1.020	0.864
1997	1.000	1.026	0.864
1998	1.000	1.061	0.884
1999	1.000	1.074	0.890
2000	1.000	1.066	0.893
2001	1.000	1.077	0.900
2002	1.000	1.091	0.912
2003	1.000	1.099	0.921
2004	1.000	1.111	0.927
Average	1.000	1.061	0.890

Netherlands

	German technology	Dutch technology	Swedish technology
Predicted output (logarithm)			
1995	7.334	7.416	6.373
1996	7.285	7.336	6.274
1997	7.238	7.324	6.252
1998	7.097	7.53	6.342
1999	7.097	7.495	6.329
2000	7.073	7.405	6.281
2001	7.082	7.487	6.372
2002	7.039	7.613	6.428
2003	7.057	7.601	6.483
2004	7.011	7.575	6.482
Average	7.135	7.471	6.357
Ratios of predicted output using other technology to predicted output using own technology			
1995	0.990	1.000	0.858
1996	0.994	1.000	0.854
1997	0.989	1.000	0.852
1998	0.943	1.000	0.841
1999	0.947	1.000	0.843
2000	0.956	1.000	0.847
2001	0.947	1.000	0.851
2002	0.926	1.000	0.844
2003	0.930	1.000	0.853
2004	0.927	1.000	0.856
Average	0.956	1.000	0.850

Sweden

	German technology	Dutch technology	Swedish technology
Predicted output (logarithm)			
1995	6.989	6.915	5.701
1996	7.100	7.205	6.088
1997	7.090	7.165	6.066
1998	7.009	7.215	6.096
1999	6.965	7.248	6.137
2000	6.923	7.346	6.207
2001	6.875	7.318	6.187
2002	6.770	7.398	6.165
2003	6.727	7.673	6.258
2004	6.680	7.665	6.231
Average	6.907	7.333	6.132
Ratios of predicted output using other technology to predicted output using own technology			
1995	1.231	1.218	1.000
1996	1.172	1.191	1.000
1997	1.174	1.187	1.000
1998	1.155	1.19	1.000
1999	1.142	1.188	1.000
2000	1.121	1.192	1.000
2001	1.117	1.191	1.000
2002	1.104	1.21	1.000
2003	1.081	1.236	1.000
2004	1.079	1.244	1.000
Average	1.133	1.204	1.000