Measuring productivity differentials– An application to milk production in Nordic countries

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Abstract **- The aim of this paper is to analyse the regional productivity differentials on dairy farms in Denmark, Finland and Sweden. Several methods have been suggested for analysing productivity differentials in agriculture between groups of farms or countries. Hayami [5] and Hayami and Ruttan [7] suggested the meta-production function approach. This idea has been further developed by Lau and Yotopoulos [9] and Fulginity and Perrin [13]. Battese and Rao [2] suggested the meta-frontier analysis for these comparisons. One of the advantages of meta-frontiers with respect to meta-production functions is that they are able to separate technological differences from the differences in technical efficiency. Battese et al. [5] and O'Donnell et al. [16] have extended this idea and developed both parametric and non-parametric approaches. In this paper, we extend the meta-frontier analysis to the concave nonparametric least squares estimation of the production function suggested by Kuosmanen [18,19]. In addition, we compare the results with the approach where the estimation of meta-frontier can be avoided. The reference can also be the maximum output providing technology that is the one that yields the maximum estimated output, given inputs [21]. In this case the estimation can be based either on average or frontier production functions.**

The farm level data is obtained from the EU's Farm Accountancy Data Network data set for Denmark, Finland and Sweden. They cover 954 dairy farms in 2003.

The results suggest that different method provide slightly different results but in all approaches productivity differentials are considerable in favour of Danish farms. In addition, the Danish technology is not only dominating at the mean but also at most of the data points.

Keywords **- productivity, technical efficiency, meta-frontier**

I. INTRODUCTION

A lot of research has been conducted in the field of international comparison of agricultural productivity. Most of the studies have been based either on the production function analysis, data envelopment analysis or index numbers. Part of the studies has mainly concentrated in partial, for example labour or land, productivities [1] but there are many measuring also TFP (total factor productivity) changes like Coelli and Rao [2] and Alauddin et al. [3] who have applied Malmquist TFP indices, or Ball et al. [4] who applied Fisher TFP indices. The common feature of these studies is that they have used country level data for example from FAO. Very few studies have applied farm level data.

In the production function approach, differences in output (or productivity) across countries (farms) and/or time are explained by differences in the levels of conventional inputs (e.g., land, labour, tractors, livestock, and fertilizer). Hayami [5] and Hayami and Inagi [6] were among the first who conducted cross-country time series analysis on land and labour productivity in agriculture. Several authors have followed their route of research by estimating cross-country production functions and multifactor productivity [e.g., 7,8,9,10]. They have usually employed the so-called meta-production function, which has been seen as an envelopment of country production functions. The purpose of the analysis has been to estimate differences in agricultural productivity among individual countries and especially between developed and developing countries. Internal resource endowments, like land and livestock, modern technical inputs, as machinery and fertilisers, and human capital have been identified as the main sources of productivity variation among countries. In later analyses the role of such aspects like resource constraints or sources of technical change have raised interest. In addition, attempts to measure the influence of the adoption of information and communication technologies or of the research and development expenditure on productivity growth have been made [11].

Once the traditional quantitative inputs of agriculture have been taken into account in the analysis, remaining productivity growth (or change) should be possible to explain by other factors: either by the quality of measured inputs or by some unmeasured inputs, such as publicly provided goods [3]. Alauddin et al. [3] study complemented earlier studies by applying the frontier approach and a total factor productivity measure. In comparison to earlier studies, their data hold greater spatial coverage, their time series is long and their expansive list of explanatory variables includes particularly institutional and environmental variables in the second stage regression. According to their study, the average productivity growth in agriculture has in general been only modest in spite of significant technological improvements. They also concluded that many of the obstacles to agricultural development seem to be endowment based, largely dependent on geography and climate. Thus, we may expect that these effects can be observed when farms located in different production conditions are compared.

Wiebe [12,1] has in his studies focused on identifying the influence of land quality differences on agricultural productivity. He has applied a variant of the quality index earlier used also by Fulginity and Perrin [13] and Craig et al. [11]. Wiebe found out that indicators of the quality of land resource contributed significantly to observed international differences in agricultural labour productivity. Better soils and climate were associated with levels of agricultural output per worker that was 20-30 percent higher in most regions, everything else being equal. Hayami and Ruttan [7] have also stated that resource endowments are the major factor accounting for differences in labour productivity of agriculture between developed countries.

Earlier mentioned studies have employed production functions, which were estimated using country level data of agriculture. When only cross sectional country data are available we have to make a critical assumption that technical possibilities of farmers in different countries/regions can be described by the same production function. This is, however, unlikely although the functional forms were flexible. In practice, resource and capital endowments may differ even between farmers. In our case we have access to farm level data from various production conditions. Therefore, we start from the assumption that the technologies may differ between countries/regions. When we define a joint production frontier technology for all farms, deviations from the frontier could be called as technical inefficiencies. However, in this case we should not interpret the term only as managerial inefficiency but as a relative productivity difference that can be related to resource endowments, embodied capital or human (managerial) resources.

The globalisation and free trade of agricultural products are enormous challenges for the northern countries and especially for their most northern regions, where natural conditions are hard and production costs are high (poor absolute competitiveness). Therefore, it is of interest to study whether we can observe a technology gap among the Nordic countries and/or their sub-regions. Battese and Rao [14] and Battese et al. [15] have shown that it is possible to decompose technical inefficiency with respect to joint meta-frontier into the product of technical inefficiency in the specific group (representing the knowledge and the environment of the country or region) and the gap between meta-frontier and the group frontier (meta-technology ratio; O'Donnell et al. [16]). Previously mentioned authors have suggested either stochastic and parametric or non-stochastic and non-parametric determination of technology frontiers. Figure 1 illustrates the (smooth) concave enveloping meta-frontier with respect to country specific frontiers. The advantage of the meta-frontier approach is that it is possible to separate the technical efficiency difference between countries from the technology difference between groups.

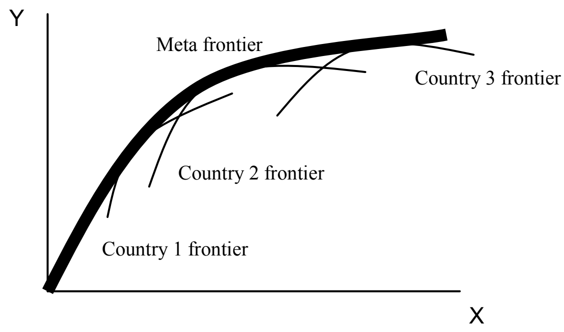

Figure 1. Concave envelopment of country frontiers.

Another question is whether we should impose the concave envelopment on the meta-frontier. This is not necessarily a valid assumption when we apply the analysis on a limited number of groups. This is illustrated by Figure 2 which presents a piecewise concave envelopment of the frontier. There is not a joint concave envelopment of the frontier but only a piecewise concave envelopment which is determined by one of the countries in turn. Some of the comparison methods applied in this study do not necessitate a concave meta-frontier assumption. We suggest a farm-wise comparison of productivities without the estimation of a common meta-frontier but applying the original country specific production functions in order to estimate the respective maximum output levels for each country.

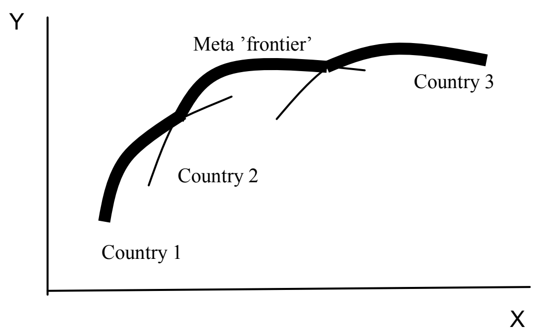

Figure 2. Piecewise concave envelopment of the data.

Absolute or relative differences in agricultural productivity between countries or regions are an important starting point for the analysis how productivity could be improved. Our aim is to estimate regional (country) productivity differences starting from regional production functions and frontiers. We aim at comparing several methods – parametric and non-parametric, stochastic and non-stochastic, frontier and average production functions – in the estimation of productivity differentials between countries. The results indicate that different approaches provide somewhat different productivity differentials but the Finnish technology is always the least productive when the Danish technology is the most productive.

The paper is organized as follows. At first we present the methods and estimation approaches applied in the study. This section is followed by a detailed description of Danish, Finnish and Swedish farm data. The empirical results are presented thereafter. The last section concludes.

II. ESTIMATION OF FRONTIERS

Several methods are available for defining the frontier or production function in order to estimate productivity differences. We may apply parametric or non-parametric methods for estimating production function and production frontiers. In this study, we compare the results of these approaches.

We start from estimating country specific stochastic frontier production functions in order to estimate technical inefficiencies for farms within the country. We apply the log-linear (Cobb-Douglas or translog) model and the method of maximum likelihood as Battese and Rao [14] and Battese et al. [15]. More formally the function is $\ln y_i = TL(\beta; \mathbf{x}_i) + v_i - u_i$, where y is the output, **x** if the vector of inputs, β s are regression coefficients, v is a stochastic error term N$(0, \sigma_v^2)$ and u is one-sided error term N^+ $(0, \sigma_u^2)$ capturing inefficiency. The technical inefficiency with respect to the country frontier (CTE) can be solved as TE =exp(-u_i). As Battese et al. [15] have pointed out, a separately estimated joint stochastic frontier production function does not necessarily envelope regional or country frontiers. Therefore, they suggested that the meta-frontier could be determined by a mathematical programming model. In the case of log-linear production function the model can simply be expressed as

$$\begin{aligned} &\min_{\beta} \bar{x}'\beta \\ &s.t.\ x_i'\beta \geq x_i'\hat{\beta}_k \end{aligned} \quad (1)$$

Thus, the model searches for the regression coefficients β, which minimize the value of the objective function at the sample mean, subject to inequality constraints confirming that the meta-frontier output estimate is at least as large as the country k frontier output estimate. The output estimates of the meta-frontier can be compared with the output estimates of the country frontier which shows the technology ratio (MTR) between country- and meta-frontier estimates.

Data envelopment analysis (DEA) can also be applied in these comparisons [16,17]. The virtue of the DEA is that no specific functional form has to be assumed. On the other hand, the conventional DEA does not make any difference between stochastic noise and inefficiency but all deviations from the frontier are interpreted as inefficiencies. The DEA is fairly easy to apply also in the meta-frontier approach: we have to solve separate models for each country in order to specify the country-specific inefficiency (CTE) and one for the joint data set for solving the meta-frontier inefficiency (MTE). Meta-technology ratio, the relative productivity of technologies can be obtained by the ratio between MTE and CTE.

Data envelopment analysis is a non-parametric but non-stochastic method. In this study we applied also the stochastic non-parametric estimation method, which has been developed by Kuosmanen [18,19]. It is called StoNED (stochastic non-parametric envelopment of data). This model applies a two stage method, which is applied to each country separately. At first a piecewise linear production function is estimated. Concave nonparametric least squares (CNLS) can be written as a quadratic programming problem:

$$\begin{aligned} &\min_{\alpha,\beta,\hat{\varepsilon}} \sum_{i=1}^{n} \hat{\varepsilon}_i^2 \\ &s.t. \\ &y_i = \alpha_i + \boldsymbol{\beta}_i'\mathbf{x}_i + \hat{\varepsilon}_i \ \ \forall i = 1,...,n \\ &y_h \leq \alpha_i + \boldsymbol{\beta}_i'\mathbf{x}_h + \hat{\varepsilon}_h \ \ \forall h, i = 1,...,n \\ &\boldsymbol{\beta}_i' \geq 0 \ \ \forall i = 1,...,n \end{aligned} \quad (2)$$

CNLS allows for the intercept and the slope coefficients to vary from one firm to another. Thus, there are n different slope vectors $\boldsymbol{\beta}_i'$, i=1,..,n. This resembles a random parameters model (RPM) except that the CNLS estimates n tangent hyper-planes to one unspecified production function whereas the RPM estimates n different production functions of the a priori specified functional form. α_i ja $\boldsymbol{\beta}_i'$ are farm specific constants and slopes. The second constraint of the quadratic programming problem imposes concavity and the third constraint monotonicity. Inefficiencies are solved in the second stage by the method of moments, which allows us to divide the error variance in (x) into the variance of the one-sided error term (technical inefficiency) and the variance of the stochastic error term (noise). Here we utilize the second and third central moments (see [20]). When the variances are known, we can apply the conditional estimator to determine farm level inefficiency [21].

StoNED is thus applied in estimating the country specific efficiencies (CTE). This information is also used in determining the expected value for inefficiency in each country. This expected inefficiency is then used to shift the estimates of the production function upwards in order to define the production frontier for each country. Meta-technology ratio is solved by applying DEA on the joint data, where the original output is replaced by the inefficiency corrected (by country) output estimate. In this case the DEA efficiency score shows directly the meta-technology ratio (MTR), i.e., the relative productivity difference between the meta- and country-frontier.

In the meta-frontier analysis, the output efficiency of each farm can be defined either as a deviation from the country-frontier or from the joint meta-frontier. When the meta-frontier envelopes all regional production frontiers, the output efficiency can be decomposed into two components (MTE meta-frontier efficiency and CTE country-frontier efficiency) and the ratio of these two can be called as meta-technology ratio (also earlier called as technology gap) MTR. Their dependency on each other can be expressed as follows:

$$MTE = CTE * MTR \text{ or } MTR = MTE / CTE. \quad (3)$$

In addition, the results based on the above presented approaches are compared to the approach, where the output estimates are calculated directly by at first estimating average or frontier production functions, and then using each farm's inputs as input values for each country-specific production function in turn. This follows that in this case we get for each farm three alternative output estimates, which can then be compared when searching for the technology providing the highest output. In this comparison it is needless to solve any meta-frontier function but only output estimates on each technology have to be solved.

III. DATA

The empirical data are from farm accountancy data network of the EU. The FADN data set covers individual dairy farms from three Nordic countries - Denmark, Finland and Sweden – in 2003. The three countries are of interest since Denmark is very export oriented and competitive in European standards whereas Finland represents the opposite position. Sweden stands there in between as the conditions for agricultural production in southern parts of Sweden are quite comparable with those in Denmark whereas the northern part of Sweden resembles Finland by its natural conditions.

In the analysis, we apply five inputs (labour, fertilizer, purchased feed, materials and capital) and one aggregate output. Labour is measured in hours. Other inputs are measured in monetary terms. Capital includes the cost of machinery and buildings. In the specialized dairy farms there is also a very close link between the number of cows and milk output, which leads us to exclude the cow number from inputs. Output captures only sales return (milk and other outputs) at market prices. Subsidies, direct payments excluding investment aids and price support on milk, are excluded[1].

Monetary values of inputs and outputs are converted to euros applying the exchange rates of national currencies for Denmark and Sweden. We use the same rates as in the FADN. Farm specific prices are not available[2]. Thus, we cannot apply for example the cost function approach when there is not enough variation in prices. We could apply either production or distance functions. Our sample farms are specialized in milk. Therefore, we chose the production function approach.

Finnish farms are on average the smallest and Danish farms the largest (Table 1). In the data set the average size of dairy farms in Finland is 21 cows, when the average in Sweden is 36 and in Denmark 84. The total input consumption is the largest in Denmark but the average labour input per farm is approximately at the same level in all three countries. This difference can be partially explained by more extensive use of contract work and differences in farming (labour saving) technology. The differences also suggest that there is a need for country or region specific production functions.

Table 1. Descriptive statistics per farm.

		Denmark	Finland	Sweden
		Mean	Mean	Mean
Output (€)	Mean	310134	83443	133430
	Std	161966	45964	133389
Purchased feed (€)	Mean	77346	18039	32627
	Std	48282	13336	38401
Fertilizer (€)	Mean	5400	5053	4363
	Std	3561	3656	4974
Labour (h)	Mean	4543	5095	4461
	Std	1630	1723	2251
Variable cost (€)	Mean	96333	32539	43250
	Std	48662	17560	37909
Capital cost (€)	Mean	57988	23508	35061
	Std	33462	18200	37352

There are also significant differences per cow although milk yields per cow are approximately at the same level in all three countries. All cost categories per cow are the smallest in Denmark except the cost of purchased feed. The animal density and thus also manure spreading per hectare are high in Denmark compared to Finland and especially to Sweden. This implies that the use of purchased fertilizers per hectare

[1] The land is not included as an inputs because it highly correlates with other inputs.

[2] Input and output prices have not been adjusted by the possible differences in absolute price levels. In the input side this is not even possible since sufficient price and quantity data are not available. If the price levels differ, the price differences end up to differences in quantities in the monetary proxies of inputs and outputs. If the difference in price levels of inputs and outputs are equal, it does not affect the productivity differential when constant returns to scale prevails. If this is not the case, the differences in price levels affect the productivity differential.

is at a low level in Denmark compared to Sweden and especially Finland.

IV. RESULTS AND DISCUSSION

Tables 2 – 4 present average meta- and country-frontier efficiencies (MTE and CTE), and meta-technology ratios (MTR), which are determined using different methods. MTE shows the technical efficiency of the farms with respect to the joint meta-frontier, which is determined in relation to the whole data sample. This efficiency differs from CTE, which describes technical efficiency of farms with respect to their own regional (e.g., country) frontier. MTR shows the ratio of these figures, i.e., how large is the difference between the frontiers. It indicates the relative productivity difference between technologies when possible efficiency differences between countries have been taken into account.

Table 2 summarizes technical MTE and CTE efficiencies based on the StoNED -method. More precisely, country-specific efficiencies have been estimated by StoNED, but the joint meta-frontier has been estimated applying DEA on the data where outputs are by country specific efficiencies corrected StoNED output estimates. This comparison indicates that the MTE is clearly lowest on Finnish farms (0.61), but the CTE is close to the Danish level. However, the level is slightly lover (0.90). Thus, in comparison to the joint meta-frontier it should be possible increase output by more than 30 %, in order to reach the frontier. When compared to the country frontier, the average inefficiency is only 10 %. In Sweden, the average efficiency with respect to the Swedish country frontier is lower than in Finland and Denmark (0.86), but the difference between MTE and CTE is smaller. Therefore, according to the StoNED –model, productivity of Swedish farms is closer to the level of Danish farms. MTR of Finnish farms is considerably lower than on Danish and Swedish farms.

Table 2 Technical efficiency with respect to the meta-frontier (MTE) and country frontier (CTE), and the meta-technology ratio (MTR) according to StoNED –estimation.

	MTE	CTE	MTR
Denmark	0.845	0.922	0.916
Finland	0.609	0.900	0.677
Sweden	0.716	0.861	0.832

Also in the case when DEA –approach is used in the estimation of country and meta-frontiers, the efficiency scores are very similar (Table 3). Since the stochasticity is not accounted for in the country specific frontier estimations, the average values of CTEs are lower in the DEA-approach than in the StoNED -approach. MTE scores are also clearly lower in Denmark. The average Finnish and Swedish MTE scores obtain smaller values. The changes in MTE- and CTE-scores follow that the relative productivity (MTR) of Finnish farms with respect to Swedish and Danish farms is somewhat higher than on the basis of the StoNED -model. The order of the countries is the same in both models, but in the DEA approach MTR of Swedish farms is close to the Danish level.

Table 3 Technical efficiency with respect to the meta-frontier (MTE) and country frontier (CTE), and the meta-technology ratio (MTR) according to the DEA-approach (variable returns to scale).

	MTE	CTE	MTR
Denmark	0.810	0.839	0.965
Finland	0.668	0.820	0.815
Sweden	0.748	0.797	0.939

Also according to the Cobb-Douglas –model (Table 4) relative productivity of Finnish farms (MTR) is the lowest, but the difference in average technical efficiency with respect to Denmark is small as in the previous models. In Sweden the average country specific efficiency is clearly lower than in Denmark and Finland. When the joint meta-frontier is determined by the LP model (2), MTE efficiency scores of Finland and Sweden become almost equal. Since the country specific efficiency of Swedish farms is lower than that of Finland, the MTR-ratio is also in this case higher for Sweden but clearly lower than for Danish dairy farms.

Table 4 Technical efficiency with respect to the meta-frontier (MTE) and country frontier (CTE), and the meta-technology ratio (MTR). Deterministic LP model for the determination of the meta-frontier (production functions of Cobb-Douglas –type).

	MTE	CTE	MTR
Denmark	0.767	0.894	0.858
Finland	0.625	0.880	0.710
Sweden	0.622	0.806	0.772

The first three columns in Table 5 gather the meta-technology ratios, which have been expressed as relative ratios, keeping Denmark as the benchmark. These ratios can be used to show, how large output the Finnish (or Swedish) farms have on average obtained in comparison to the Danish farms with their Finnish (or Swedish) input levels, taking country specific efficiency differences into account. When the relative productivity has been determined applying different methods, the Finnish farms have achieved 72 – 84 % of the Danish output level. Producticity of Swedish farms also lagged behind the Danish farms in 2003. They achieved on average 85 – 97 % of the output level of Danish technology with their inputs, depending on the method. Thus, the average relative output level of the

Swedish farms was clearly higher than that of Finnish farms.

Technology ratio is very similar also when comparisons are made directly between different technologies, given inputs, either using average or frontier production functions (the last two columns in Table 5). The only difference between these two is that on the basis of the frontier production function the Finnish farms seem to get closer to the Danish productivity level than on the basis of the average production function.

Danish technology dominates the technology of other countries, i.e., its productivity is higher that productivity of the Finnish and Swedish technology, as Table 6 shows. When Danish farms' inputs are used, in more than 98 % of cases the Danish average production function produces larger output than Finnish and Swedish technologies. When Finnish observations are used, the share is close to 96 %, and for Swedish farms it is less than 88 %. Danish technology clearly dominates the technologies of other countries. When the output estimates are determined on the basis of the frontier production functions, the Danish technology still dominates but not as strongly as in the case of average production functions, as the last three columns in Table 6 indicate.

Table 5 Relative productivity according to different methods (Denmark as a benchmark).

	Concave meta-frontier			Production function	
	CD	DEA	StoNED	aver.PF	frontPF
Denmark	1.000	1.000	1.000	1.000	1.000
Finland	0.828	0.844	0.721	0.815	0.861
Sweden	0.900	0.972	0.848	0.944	0.946

Table 6 The share of each technology of the largest output estimate producing technologies for the input use of each farm by country (average and frontier Cobb-Douglas production function).

	Average production function			Frontier production function		
	Largest output estimate, % of farms			Largest output estimate, % of farms		
	Danish technology	Finnish technology	Swedish technology	Danish technology	Finnish technology	Swedish technology
Input use of Danish farms	98.08 %	0.27 %	1.65 %	86.26 %	2.75 %	10.99 %
Input use of Finnish farms	95.72 %	3.95 %	0.33 %	78.95 %	12.83 %	8.22 %
Input use of Swedish farms	87.58 %	6.54 %	5.88 %	62.75 %	23.86 %	13.40 %

V. CONCLUSIONS

In this study the concept of meta-technology ratio was utilized in the determination of productivity differentials between Finnish, Swedish and Danish dairy farms. Several different methods were applied in the analysis of the FADN data from 2003. According to the analysis, different methods provide to some extent different results, but according to all methods Finnish production technology of dairy farms is on average the least productive. Finnish dairy farms are able to produce 75 – 85 % of the output level, given inputs, achievable by Danish technology. However, the average technical efficiency of Finnish farms relative to the Finnish technology is close to the Danish farms' technical efficiency with respect to their own Danish technology. Thus, the Finnish farms utilise the country-specific technology approximately as well as the Danish farms. The average inefficiency of Swedish farms is the highest.

As several authors have claimed, the productivity differences between regions and farms are affected by resource endowments and constraints, the adoption of modern technology, public research and development expenditure, and human capital. Some like Alauddin et al. [3] have concluded that most of the obstacles to agricultural development are endowment based, largely dependent on geography and climate. This is also likely to be an important contributor to the observed differences when the farms of the same size are compared between Nordic countries.

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