A Metafrontier Analysis of Technical Efficiency of Selected European Agricultures

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I. Introduction

Technical efficiency refers to the situation where it is impossible for a firm to produce, with the given know-how, (1) a larger output from the same inputs or (2) the same output with less of one or more inputs without increasing the amount of other inputs. In practice, the interest is on the relative position in terms of efficiency of a particular firm with respect to others. Therefore, technical efficiency is characterised by the relationship between observed production and some ideal or potential production (Greene, 1993).

Although the beginning of the efficiency work can be traced to the 1950s (Farrell, 1957), there have been a growing interest on its use in benchmarking performance, predominantly as a means of identifying best practice and improving the efficiency of resource use within the agricultural industry (e.g., Defra 2004, SAC 2009).

This paper deals with the estimation of technical efficiency for the agricultural sectors in several European countries and moreover, it aims to compare the efficiency amongst them using a metafrontier analysis. The use of this type of analysis is justified because a frontier, which represents the best available technology within a particular region/country cannot be strictly compared across other regions/countries, unless they operate under the same production set. The metafrontier analysis has been developed in a number of studies (Battese and Rao, 2002; Nkamleu et al., 2006; Chen and Song, 2006; O'Donnell et al., 2008.)

The metafrontier analysis in this paper, which uses data from the Farm Accountancy data Network (FADN), was focused on four farm types: two specialised farming types (i.e., specialist cereals, oilseed and protein crops and specialist dairying) and two more mixed farming sets (i.e., general field cropping and mixed farms), and was applied to a total of 11 countries namely Belgium, Denmark, France, Germany, Hungary, Ireland, Italy, Netherlands, Poland, Spain and the UK. For most of the countries the information was available from 1995 until 2007, excepting Hungary and Poland, for which it was available only since 2004. Also note that not all the farm types were available for all the countries.

The structure of the paper is as follows: it starts presenting an overview of the metafrontier analysis used to compare technical efficiency amongst the European countries. It is followed by the empirical work, which comprises a description of the data used, the estimation and discussion of the results. Finally we present conclusions.

II. Overview of the metafrontier analysis

A metafrontier is a useful concept when the aim of the analysis is to compare the efficiency of different groups (e.g., regions, countries) when there is the suspicion that each group operate under different technologies and therefore their productive frontiers are different. In this brief overview we follow O'Donnell et al (2008).

The starting point of the metafrontier analysis is the idea that there is a space (i.e., a metatechnology set) that encompasses all the possible combinations of outputs (y) and inputs (x). Associated to such set are output and input sets. The output set is defined for any input vector x, as in (1):

$$(1) \qquad P(x) = \{y : (x, y) \in \text{Metatechnology set}\}$$

The boundary of the output set is called the output metafrontier, which is assumed to satisfy the regularity properties in Fare and Primont (1995). The distance ("Metadistance function") with respect to the boundary of the output set provides a characterisation of the output orientated efficiency of any combination of input and output (x, y) is given by (2)

$$(2) \qquad D(x, y) = \inf_\theta \left\{\theta > 0 : \left(y/\theta\right) \in P(x)\right\}$$

An observation (x, y) can be considered technically efficient with respect to the metafrontier if and only if $D(x, y) = 1$ (e.g., a value equal of 0.5 indicates that the output produced is 50 per cent of the metafrontier output given the same vector of inputs).

Similarly technology sets, output sets (with their corresponding group frontiers for the boundary of the set) and distances can be defined for each one of the specific k groups considered in the analysis. Their representations are given by (3) and (4):

$$(3) \qquad P^k(x) = \left\{y : (x, y) \in \text{Technology set}^k\right\}$$

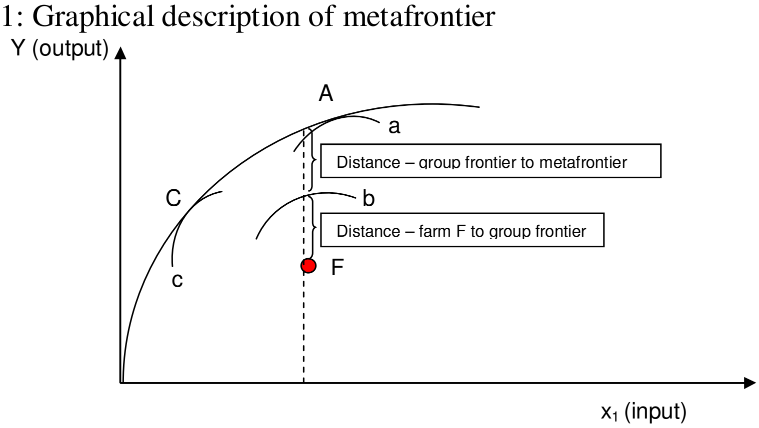
$$(4) \qquad D^k(x, y) = \inf_\theta \left\{\theta > 0 : \left(y/\theta\right) \in P^k(x)\right\}$$

A value $D^k(x, y) = 0.5$ indicates that the output produced is 50 per cent of the frontier of the k group given the same vector of inputs. Note that since the metafrontier encompasses the group frontiers then the $D^k(x, y) \leq D(x, y)$. A way to characterise the relationship between a specific group frontier and the metafrontier is to consider the output orientated metatechnology ratio (MTR^k) for an (x,y) and which represents how close the group k frontier is to the metafrontier. The MTR^k is given by (5):

$$(5) \qquad MTR^k(x, y) = \frac{D(x, y)}{D^k(x, y)}$$

Graphically, the metafrontier and the frontiers can be represented by Figure 1 below, where the efficiency of all firms within the regions farms can be measured relative to their own frontier (a, b, c) or with respect to the metafrontier (C,A).

Figure 1: Graphical description of metafrontier



Source: Battese *et al.* (2004).

III. Estimation procedure

The estimation procedure comprises three stages: First, group frontiers are estimated using the well-known stochastic production frontiers procedure (Coelli et al., 1998). If the exponent of the frontier production function is linear in the parameter vector β^k, then the model and the efficiency distance can be written as in (6) and (7):

$$(6) \qquad y = f\left(x;\beta^k\right)e^{V_i^k - U_i^k} \equiv e^{x'\beta^k + V_i^k - U_i^k}$$

$$(7) \qquad D^k(x,y) = e^{-U_i^k}$$

The second step consists of the computation of the metafrontier (i.e., find the parameters of the metafrontier function), which can be done by solving an optimisation problem that minimises the absolute deviations between the metafrontier and the group frontiers for all the observations constraint by the fact that the output at the metafrontier is always greater or equal than the output from the groups. Since the coefficient vectors of the group frontiers are fixed and if the function are log linear in the parameters (as in the case of the translog function used in this paper), the optimisation problem becomes the linear programming problem (8) (O'Donnell et al. 2008, p. 241) where $\bar{x}$ is the vector mean of values over the observations.

$$(8) \qquad \begin{array}{l} \min\limits_{\beta} \ \bar{x}'\beta \\ \text{s.t } x'\beta \geq x'\beta^k \end{array}$$

The metatechnology ratio (MTR) can then be estimated by using the coefficient β from (8) in (9):

$$(9) \qquad MTR(x,y) = MTR_i^k = \frac{e^{x_i'\beta^k}}{e^{x_i'\beta}}$$

Finally the third stage consists of the estimation of the distance of each member (say firm or farm) of each group with respect to the metafrontier, which is given by (10)

$$(10) \qquad D(x,y) = D^k(x,y) \cdot MTR(x,y)$$

This procedure was applied to EU farms to compare agricultural efficiency by farm type amongst countries. As mentioned the production function used for the analyses was the Translog function and it considered five inputs: materials, energy, labour, land and capital. The inefficiency term was assumed to follow a half normal distribution. For each of the studied farms type a likelihood ratio test was applied to analyse whether the frontiers were the same for all the countries (i.e., they operate under the same technology). This hypothesis was rejected in all the cases. In terms of the software used for the estimations, the analysis was undertaken using SHAZAM version 10 and the base code provided by Battese et al. (2004).[1]

[1] Due to limitations in the number of pages only the efficiency results are presented. The econometric results are available from the authors upon request.

IV. Used data

The Farm Account Data Network of the EU represents a central data archive for Member States to lodge national accounts within a prescribed format. All member states are required to submit data under rigorous quality assurance protocols. The financial data are converted into a common currency (€). Data currently covers approximately 80,000 holdings across the European Union 27 member states.

The variables used in the estimation were 'output', which was the value of main output less subsidies; 'materials', which comprises all variable costs aside from energy used on the farm enterprises. For cropping farms these include cost of fertilizers, seeds, crop protection and other costs, for livestock these include cost of feed, veterinary and medicine as well as other costs; 'energy', which is the total cost of energy consumed on the farm, comprising fuel and oil, and electricity; 'land', which was equal to total area used for agricultural production; 'labour', equal to total hours of labour paid and unpaid in hours and 'capital', which included the flow of services, taking running and maintenance costs, depreciation and interest of capital stock. All the nominal variables were deflated using price indices base year 2000 from Eurostat.

V. Discussion of the results

Specialist cereals, oilseed and protein crops (COP) farms

The analysis of this farm type was based on a subsample of 8 countries: UK (7,199 observations); France (15,375); Denmark (4,303); Spain (15,821); Germany (8,731); Italy (24,138); Poland (3,177); Hungary (3,144). The mean technical efficiency per year from the stochastic production frontier estimations are presented in Figure 1. It should be noted that these results are relative to their own technical frontier and do not indicate rankings of efficiency at this stage.

Figure 1. Mean technical efficiency, selected FADN countries, specialist cereals, oilseed and protein crops (COP) farms

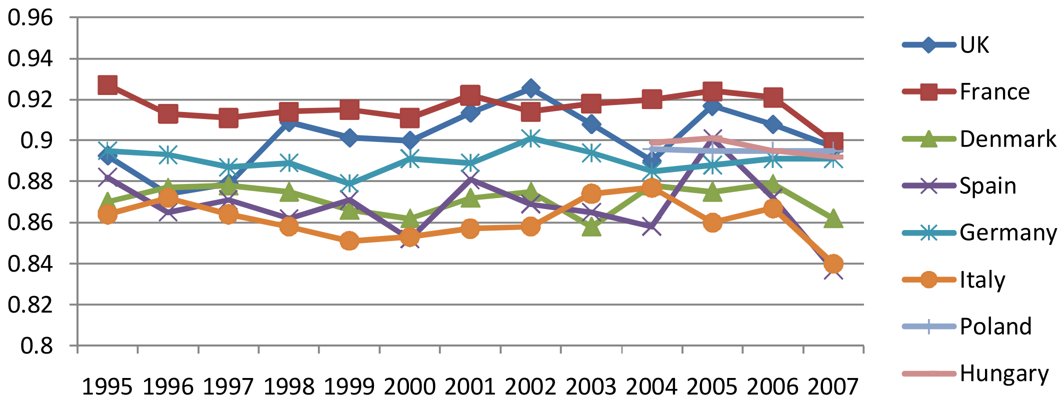


Table 1 shows the various mean technical efficiencies for each country and the linear technical change coefficient from the production function estimation (i.e., Translog), which indicates movement of the frontier over the 1995 to 2007 period. All countries tend to register fairly high mean levels of technical efficiency. However, all countries have had a regression (on average) of the frontier, the largest seeming to be Poland. Notable also is the lack of significance of technical change for Germany and Hungary, which reflects neutral technical change over this period.

A metafrontier was then constructed using the parameter estimates and data constructed for each of the 8 countries. The mean technical efficiency, metatechnology ratios and subsequent metafrontier scores are presented in Table 2.

Table 1. Mean Technical Efficiency and Technical Change of selected FADN Countries, Specialist cereals, oilseed and protein crops (COP) farms.

	Mean Technical Efficiency	**Linear TC**
UK	0.900	-0.07***
France	0.916	-0.07***
Denmark	0.871	-0.03***
Spain	0.868	-0.08***
Germany	0.891	-0.004
Italy	0.862	-0.04***
Poland	0.896	-0.34**
Hungary	0.897	-0.07

(*=P<0.05, **=P<0.01, ***=P<0.001)

Table 2. Mean technical efficiencies, metatechnology ratios and metafrontier estimates for 8 EU FADN countries, specialist cereals, oilseed and protein crops (COP) farms

	Mean Technical Efficiency	**Mean**	**Mean**
UK	0.900	0.773	0.696
France	0.916	0.550	0.504
Denmark	0.872	0.571	0.498
Spain	0.868	0.753	0.654
Germany	0.891	0.680	0.606
Italy	0.862	0.761	0.656
Poland	0.896	0.900	0.806
Hungary	0.897	0.724	0.649

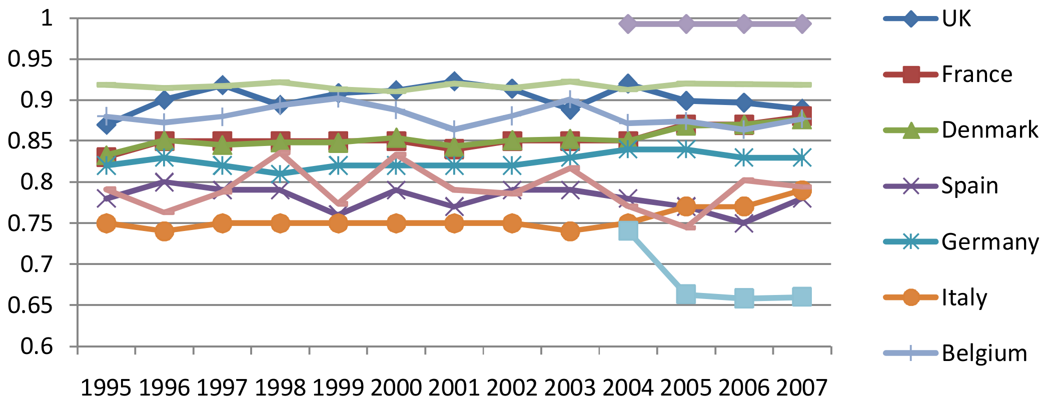
Table 2 shows that mean metatechnology ratios range from 0.55, for France, up to 0.90, for Poland. Notably the UK, along with Germany and Italy, do not have a maximum MTR value of 1, indicating that they do not have farms which touch the metafrontier. Poland is clearly closer to the metafrontier than other countries. The high TE and MTR scores lead to high mean metafrontier scores and Poland is the clear leader in cereals when compared to an EU technology. Conversely, Denmark and France, which both had high levels of mean technical efficiency relative to their own frontiers, are clearly lagging behind the other countries when compared across a metafrontier. The UK seems to be the leader of the mid-efficiency group, composed of the remaining countries. The metafrontier scores vary between 0.61 and 0.69 in this group.

General field cropping farms

The work for the 'general field cropping' farms was based on a sample of 11 countries (UK, 4,798 observations); France (7,013); Denmark (2,601); Spain (12,928); Germany (8,335); Italy (24,339); Belgium (1,190); Ireland (255); Netherlands (2,919);

Poland (4,419); and Hungary (677). The mean technical efficiency scores by country are presented in Figure 2.

Figure 2. Mean technical efficiency scores by country for general field cropping farms



Mean technical efficiencies are presented in Table 3. These range from 0.68, Hungary, up to 0.99, for Poland. The UK has performance of 0.90, taken at the mean for its efficiency relative to its own frontier. However, the UK, along with the Netherlands and Poland have negative technical change coefficients, indicating that the frontier has regressed over time for the general cropping sectors within these countries. In the case of the UK, the frontier fell annually by 0.7 per cent over the period.

Table 3. Mean Technical Efficiency and Technical Change of selected FADN Countries, general field cropping farms

	Mean Technical Efficiency	**Linear TC**
UK	0.902	-0.007
France	0.853	0.005
Denmark	0.853	0.014
Spain	0.780	0.029***
Germany	0.825	0.038***
Italy	0.755	0.025***
Belgium	0.881	0.007
Ireland	0.792	0.026
Netherlands	0.917	-0.003
Poland	0.992	-0.004
Hungary	0.680	0.603**

(*=P<0.05, **=P<0.01, ***=P<0.001)

A metafrontier was constructed using the parameter estimates and data constructed for each of the 11 countries. Results for metatechnology ratios and metafrontier estimates are presented in Table 4.

Whereas most farms generate high mean technical efficiencies, metatechnology ratios tend to vary between 0.52 for Hungary, up to 0.80 for France. The countries with farms on the metafrontier were France, Denmark, Spain, Belgium and Ireland. Notably the UK, along with the remaining countries did not have farms on the frontier, reflecting the poor performance recorded in the UK level analysis for this sector. The maximum MTR recorded for 1 farm was 0.79 for the UK.

Table 4. Mean technical efficiencies, metatechnology ratios and metafrontier estimates for 11 EU FADN countries, general field cropping farms

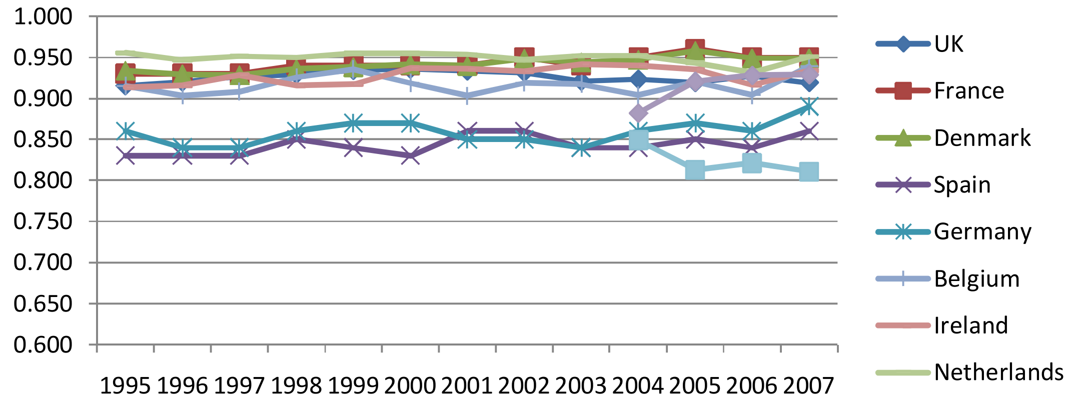
	Mean Technical Efficiency	Mean MTR	Mean MF
UK	0.902	0.686	0.619
France	0.853	0.797	0.680
Denmark	0.853	0.775	0.661
Spain	0.780	0.708	0.552
Germany	0.825	0.788	0.650
Italy	0.755	0.669	0.505
Belgium	0.881	0.663	0.584
Ireland	0.792	0.683	0.541
Netherlands	0.917	0.767	0.704
Poland	0.992	0.692	0.686
Hungary	0.680	0.513	0.349

Most of the metafrontiers tend to range across the 0.5 to 0.6 categories. The highest performing country, relative to the metafrontier, is the Netherlands which records a value of 0.70. The lowest performer, by a wide margin, seems to be Hungary which began with low levels of technical efficiency relative to its own technological frontier and has been strongly penalised when compared with the technology available to all of the 11 member states' technology.

Dairy farm

The sample for the efficiency analysis of dairy farms comprised UK (13080); France (13161); Denmark (5,525); Spain (15,327); Germany (21,997); Belgium (3,431); Ireland (5,381); Netherlands (4,924); Poland (4,755); Hungary (365)[2], giving robust estimates. The mean technical efficiencies of the EU dairy farms, relative to their own frontier, are presented in Figure 3.

Figure 3. Mean technical efficiency scores for dairy farms



[2] Italy is also included in the FADN sample but failed to provide robust estimates of technical efficiency.

Most countries tend to register fairly high and constant levels of mean technical efficiencies throughout the study period. Mean technical efficiencies for the whole period tend to be in the 0.9 to 0.95 range, with only Hungary showing a lower level of mean technical efficiency. Notably for all countries, aside from Poland, the frontier has been moving positively forward, as evidence by the technical change coefficient. The overall mean technical efficiency per country is presented in Table 5

Table 5. Mean Technical Efficiency and Technical Change of selected FADN Countries, dairy farms

	Mean Technical Efficiency	**Linear TC**
UK	0.926	0.018***
France	0.942	0.014***
Denmark	0.942	0.036***
Spain	0.843	0.028***
Germany	0.858	0.055***
Belgium	0.916	0.054***
Ireland	0.928	0.022***
Netherlands	0.949	0.012***
Poland	0.915	-0.333***
Hungary	0.823	0.474**

(*=P<0.05, **=P<0.01, ***=P<0.001)

A metafrontier was constructed using the parameter estimates and data constructed for each of the 10 countries. Results are presented for the metatechnology ratios and the metafrontier scores, compared with their mean technical efficiency scores in Table 6.

Table 6. Mean technical efficiencies, metatechnology ratios and metafrontier estimates for 10 EU FADN countries, dairy farms

	Mean TE	**Mean MTR**	**Mean MF**
UK	0.926	0.883	0.817
France	0.942	0.657	0.619
Denmark	0.942	0.625	0.589
Spain	0.843	0.732	0.617
Germany	0.858	0.769	0.660
Belgium	0.916	0.599	0.549
Ireland	0.928	0.513	0.476
Netherlands	0.949	0.603	0.572
Poland	0.915	0.925	0.846
Hungary	0.823	0.654	0.539

Metatechnology ratios are high for several countries, notably Poland and the UK. The lowest MTR of 0.51 was found in Ireland, followed by Belgium. These two latter countries seem to have quite high technical efficiency scores relative to their own technology but then seem to suffer quite severely when compared against an EU wide technology. Thus these countries emerge with low metafrontier scores. Conversely, the UK seems to produce high technical efficiency scores and is also closer, at the mean, to its metatechnology ratio, as is Poland. These two countries therefore emerge as relatively technically efficient with respect the 10 EU states compared here. The UK, along with France, Spain, Germany, Poland and Hungary, all farms on the metafrontier.

Mixed Farms

The sample for the efficiency analysis of mixed farms comprised 11 countries: UK (5,339 observations); France (10,888); Denmark (2,601); Spain (4,825); Germany (17,251); Italy (14,136); Belgium (2,058); Ireland (794); Netherlands (517); Poland (10,163); and Hungary (921). The mean annual technical efficiencies is presented in Figure 4.

Table 7 shows the mean technical efficiencies for these countries along with the linear technical change coefficient. Most countries have high mean levels of technical efficiency relative to their own frontier. These range from 0.70 for Hungary to 0.91 for Belgium. There is a relatively even distribution between negative and positive change to the linear technical change coefficient. The UK, along with France, Ireland, Netherlands and Poland, has experienced a decline in the frontier over the period. For the UK the frontier regressed by an average of 2.6 per cent per annum. The remaining countries had a positive growth in the frontier.

Figure 4. Mean annual technical efficiency for mixed enterprises

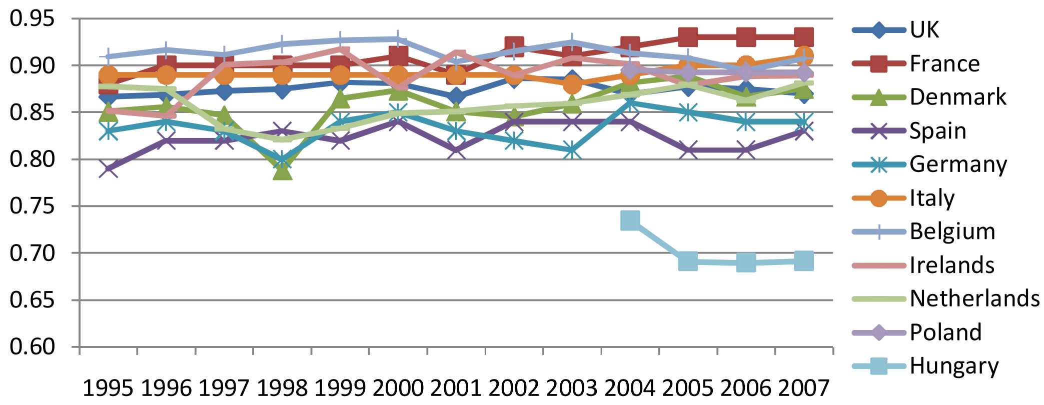


Table 7. Mean Technical Efficiency and Technical Change of selected FADN Countries, mixed farms

	Mean Technical Efficiency	Linear TC
UK	0.875	-0.0260***
France	0.909	-0.0137***
Denmark	0.858	0.0204
Spain	0.823	0.0333***
Germany	0.834	0.0276***
Italy	0.892	0.0321***
Belgium	0.914	0.0051
Ireland	0.890	-0.0248
Netherlands	0.857	-0.0092
Poland	0.893	-0.0555
Hungary	0.702	0.0296*

(*=P<0.05, **=P<0.01, ***=P<0.001)

A metafrontier was constructed using the parameter estimates and data constructed for each of the 11 countries. Results are presented in Table 8. Metatechnology ratios tend to vary from between 0.55, for Italy and Spain, to 0.84, for the Netherlands. The countries Spain, Germany, Italy and Belgium did not have farms on the metafrontier, with maximum MTR values of below 1. The remainder, including the UK, had at least one farm operating on the metafrontier.

Table 8. Mean technical efficiencies, metatechnology ratios and metafrontier estimates for 11 EU FADN countries, mixed farms

	Mean TE	**Mean MTR**	**Mean MF**
UK	0.875	0.728	0.637
France	0.909	0.707	0.643
Denmark	0.858	0.685	0.588
Spain	0.823	0.546	0.449
Germany	0.834	0.795	0.663
Italy	0.892	0.547	0.488
Belgium	0.914	0.604	0.552
Ireland	0.890	0.628	0.559
Netherlands	0.857	0.843	0.722
Poland	0.893	0.793	0.708
Hungary	0.702	0.767	0.538

Consequently, whilst the technical efficiencies of the FADN countries, measured against their own frontiers are relatively high for mixed farms, it seems that when compared to a metafrontier most countries are penalised with low scores. These seem to have a high dispersion across the countries, with Spain and Italy generating the lowest scores, compared to 0.72 for the Netherlands. For the UK technical efficiencies against their own frontier are reasonably high, similarly technological gap ratios are in the highest performing country ranges. Consequently, UK performance, relative to a European frontier is reasonable. Most countries, including the UK have farms which reach the metafrontier, aside from Spain, Germany, Italy and Belgium.

VI. Conclusions

The purpose of this paper has been to compare technical efficiencies by selected farms types across a number of countries within the EU using data from the Farm Account Network data were used. Four farm types were chosen for the analysis, namely two which are relatively specialised, e.g. dairying and cereals, and two which are more mixed in nature, e.g. general cropping and mixed.

Generally, most countries benefit from high technical efficiencies relative to their own frontiers and this is true of the specialised activities for cereals and dairying where, across the EU countries technical efficiencies average over 0.90. Thus, at the mean there are a number of farms operating relatively close to the technical efficiency frontier. However, when compared against a metafrontier, which represents the EU technology set, all countries suffer in terms of their technical efficiency scores.

Whilst the metafrontier methodology provides a useful framework for the comparison of efficiency amongst different countries/regions, it is important to highlight that data limitations might weaken the results, and therefore, some caution is required when interpreting the results. The fact that the measures of inputs and outputs are based on nominal figures (i.e., actual quantities are not observed) deflated by average price indices per country may introduce problems of comparison between countries. This might particularly true for countries which are not Euro based, e.g. especially Poland and Hungary, where in addition to issues on relative prices one has to add the movements on their exchange rates. Also this may explain the large growth in the frontier over the short period of their inclusion within the EU FADN data set.

VII. References

Battese, G.E. and Coelli, T.J. (1995). A model for technical efficiency effects in a stochastic production for panel data. Empirical Economics, 20, 325-332.

Battese G.E. and Rao, D.S.P. (2002). Technology potential, efficiency and a stochastic metafrontier function. International Journal of Business Economics 1, 1–7

Battese GE, Rao DSP, O'Donnell CJ (2004). A metafrontier production function for estimation of technical efficiencies and technology potentials for firms operating under different technologies. Journal of Productivity Analysis, 21, 91–103

Chen, Z and Song, S. (2006). Efficiency and Technology Gap in China's Agriculture: A Regional META-Frontier Analysis. University of Nevada Economics Working Paper Series Working Paper No. 06-005

Coelli, T.J., Rao, D.S.P., and Battese, G.E. (1998). An Introduction to Efficiency and Productivity Analysis, Kluwer Academic Publishers, Boston.

Defra (2004). Farm Business Benchmarking on-line. Website: http://www.defra.gov.uk/foodfarm/farmmanage/advice/documents/benchmark-online.pdf,

Fare, R. and Primont, D. (1995). Multi-output production and duality: theory and applications. Kluwer, Boston.

Fare, R., Grosskopf, S, Lovell, C.A.K. and Pasurka, C. (1989). Multilateral Productivity Comparisons when Some Outputs are Undesirable: A Non-Parametric Approach. Review of Economics and Statistics 71 (1), 90-98.

Farrell, M.J. (1957) The measurement of productive efficiency, Journal of the Royal Statistical Society, A120, 253-81.

Greene, W. H. (1993). "Frontier Production Functions", EC-93-20. Stern School of Business, New York University.

Hadley, D. (2006) Efficiency and Productivity at the Farm Level in England and Wales 1982 to 2002, Report to Defra, London.

Moreira, V.H. and Bravo-Ureta, B.E. (2010). Technical efficiency and metatechnology ratios for dairy farms in three southern cone countries: a stochastic meta-frontier model. Journal of Productivity Analysis 33, 33-45

Nkamleu, G.B., Nyemeck, J. and Sanogo,D. (2006). Metafrontier Analysis of Technology Gap and Productivity Difference in African Agriculture. Journal of Agriculture and Food Economics 1, 111-120.

O'Donnell CJ, Griffiths WE (2006) Estimating state-contingent production frontiers. American Journal of Agricultural Economics 88, 1, 249–266
O'Donnell, C.J., Rao, D.S.P., Battese, G.E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empirical Economics , 34, 231–255
SAC (2009). Farm Management Handbook, SAC, Edinburgh.

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