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A metafrontier approach to measuring technical efficiencies across the UK dairy sector

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Abstract

A regional approach is applied to measure technical efficiencies on dairy farms which employs the deterministic metafrontier approach. We construct six super regions for the UK, i.e. Eastern, Western, Northern England, Wales, Scotland and Northern Ireland. Data are collected through three different administrative systems, all be it under the same FADN guidance. We find for dairy farming comparative indicators of performance in all three data sets. The stochastic frontier approach is applied to construct 6 regional frontiers and a pooled (UK) dataset for comparison. A likelihood ratio test rejects the null hypothesis that these regions operate under a common frontier which may indicate bias in previous attempts to measure dairying efficiency at the country level. Mean technical efficiencies are high for the period 2005 to 2008, though there is some indication that little technical progress has occurred since decoupling of CAP payments from production in all regions. The metafrontier presents estimates against a common technology and mean scores range from below 0.50 for the English regions and Northern Ireland, 0.52 for Wales and 0.56 for Scotland. This paper promotes the application of the deterministic metafrontier approach for similar sub-country studies.

Keywords: Stochastic Production Frontiers, Metafrontiers, UK Farm Account Data, Dairy farming.

JEL classification: Q12, D24, C23,C51.

1. INTRODUCTION

Agricultural production is characterised by its regional heterogeneity. Whilst differences in performance vary from a farm to farm basis, regions tend to present significant biophysical constraints under which farmers operate. A key example for grazing livestock is rainfall, which varies by sub-country region, but which will affect the quality of grass and thus have an impact on the efficiency of the production system. Any measure of efficiency should, therefore, attempt to negate these constraints in order to provide an accurate measure for policy makers. The most popular technique applied within agricultural economics is the stochastic production frontier approach (SPF) which removes some of the random errors related to stochastic variance through e.g. weather, disease and other factors from the measurement (Battese and Coelli, 1995; Coelli *et al.*, 1998). Nevertheless, the SPF approach is still an econometric estimation technique and variances should be negated where possible. Thus we argue that one element which can be controlled for is the errors associated with regional differences.

This paper applies a regional approach to measuring technical efficiency using the UK dairy industry as an example. The dairy industry, compared to other farm types, has useful properties for examination as they tend to be the most progressive farmers within the UK farming sector (e.g. Barnes et al., 2010) hence some of the variance in performance from socioeconomic and informational factors is negated. The UK dairy industry operates, like most sectors under no direct production subsidy but still experiences the quota system, which constrains supply. Recent EU documents have suggested the removal of quota in the next round of the Common Agricultural Policy and the subsequent effect on prices may lead to further necessities for improving efficiency. Secondly, dairy has been the focus of a number of UK government initiatives related to tackling greenhouse gas and other negative environmental effects (DSCF, 2008; Anon,2008). Thus the increases in technical efficiency that may be realised in this sector may lead to a reduction in resource wastage. Consequently, proper measurement of technical efficiency seems appropriate within a policy agenda which now has multiple goals.

Previous studies on the UK dairy sector have taken both the non-parametric Data Envelopment Analysis approach (Gerber and Franks, 2001) and the parametric SPF approach (Hadley, 2006; Barnes, 2008). However, all these studies have taken a country wide approach to measuring efficiencies. This is especially an issue for the DEA application, as it does not account for random errors due to stochastic variance the. The impact has usually been treated as a regional dummy within the parametric studies with most finding regional differences significant in affecting efficiency. Consequently, the aim of this paper is to use regions as discriminating technology within the estimation of the frontier by firstly deriving a number of 'super regions' in which to estimate efficiencies and then compare performance against a common technology. This is enabled by the recent introduction of the deterministic metafrontier technique (Battese et al, 2004; O'Donnell *et al*, 2008), which provides a basis for comparison of inefficiency under an assumed global technology set.

Consequently, the paper is structured as follows. Firstly, a description of the techniques, with a particular focus on the deterministic meta-frontier estimation is presented. Secondly, some discussion of data sources are presented and methods for transformation to allow an adequate comparison across regions. Thirdly, results are presented over the period 2005 to 2008 for the 6 separate regions and at the metafrontier level. Finally, a discussion and conclusions are presented, with suggestions for further work.

2. METHODS

2.1. Stochastic Production Frontier Technique

The stochastic frontier approach (Aigner et al, 1977; Meeusen and van der Broeck, 1977) has found wide acceptance within the agricultural economics literature (Battese and Coelli, 1992; Coelli and Battese, 1995), principally due to its ability to remove stochastic events from the efficiency estimator. We employ the standard stochastic frontier, indexed for a particular region (k) frontier (O'Donnell *et al*., 2008):

$$(1) \qquad y_{it} = f(x_{1it}, x_{2it}, ..., x_{Nit}; \beta^k) e^{v^k{}_{it} - u^k{}_{it}}$$

where x_{Nit} is the nth input quantity of the ith farm in the tth period; β^k is the estimated parameter for the kth region. The statistical error is represented by v_{it}, which is assumed to be independent and identically distributed with mean zero and variance σ_v^2. The inefficiency term u_{it} is positive and assumed to be half normal distributed with variance σ_u^2 (Coelli et al., 2005).[1] Assuming the exponent of the production frontier is linear in the parameter vector, then the technology can be represented by a suitable functional form for the deterministic part of the equation. A translog production function was selected because it imposes less a priori restrictions than other functional forms commonly used for the task:

$$(2) \qquad y_{it} = f(x_{1it}, x_{2it}, \ldots\ldots, x_{Nit}; \beta^k) e^{v^k{}_{it} - u^k{}_{it}} \equiv e^{x_{it}^{'}\beta^k + V_{it}^k - U_{it}^k}$$

where x_{it} is now a column vector of inputs for the ith farm in the t-th period associated with the k region. The estimation of equation *(2)* was carried out by the maximum likelihood method. This requires an assumption for the distribution of the inefficiency term, which was assumed to be half normal. Therefore, the entire error term is the sum of two random variables: a half normal (inefficiency part) plus a normal (noise part). As shown in Coelli et al. (2005), the technical efficiency indicator for farm i in period t for the k-th region is given by the ratio of the actual output to the output at the frontier such as in (3):

$$(3) \qquad TEI_{it}^k = \frac{y_{it}}{e^{x_{it}^{'}\beta^k + V_{it}^k}} = \exp(-u_{it}^k)$$

The procedure above is appropriate for studies focused on a particular region as the frontier represents the state of knowledge and technology pertinent to that industry. For the purposes of this study comparisons are needed across regions, both at the intra-country and inter-country level. Battese and Rao (2002) explored the concept of the metafrontier to study the impact of regional differences within technical efficiency measurement. They proposed a stochastic metafrontier using pooled data from all study regions to draw the frontier. However, this assumes that all regions are operating under the same ‘production set’, e.g. have access to the same technology and are affected by similar regulatory regimes etc. However, the few studies in this area have all rejected this assumption, which includes inter-country level (Nkamleu *et al*, 2006; Moreira and Bravo-Ureta, 2010) and intra-country level studies (Battese *et al*, 2004; Chen and Song, 2006). A framework was developed by Battese et al. (2004) to analyse regional differences under a deterministic metafrontier approach. A deterministic meta frontier can therefore be drawn as (O’Donnell et al, 2008):

Different assumed distributions may produce different results. However, rankings of firms according to their efficiency seem to be robust to the distribution assumption (Coelli et al, 2005, pp. 252).

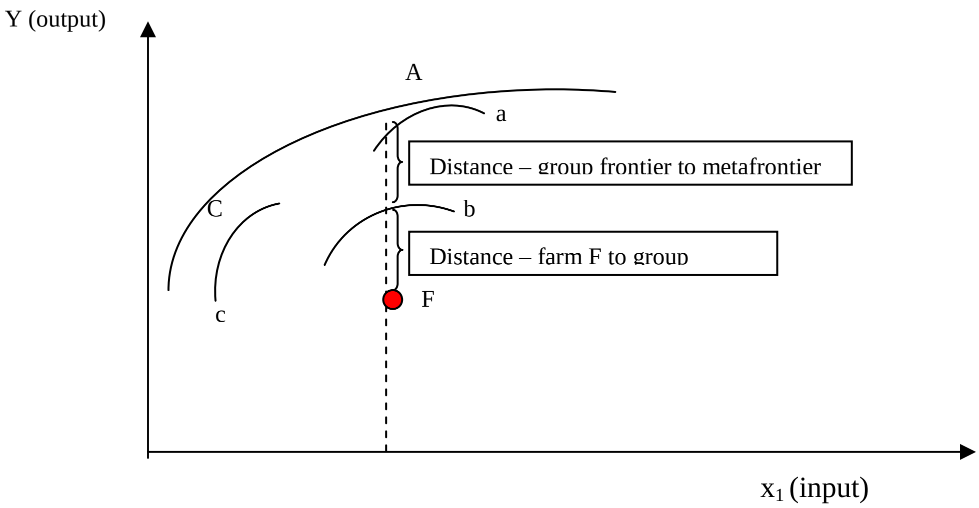
$$(4)\qquad y_{it}^{*} = f(x_{1it}, x_{2it}, ..., x_{Nit}; \beta^{k}) e^{v^{k}_{it} - u^{k}_{it}}$$

where *y** is the meta- frontier output and β is a vector of metafrontier parameters which satisfy the condition:-

$$(5)\qquad x'_{it}\,\beta \geq x'_{it}\,\beta^{k}$$

Effectively, this provides a constraint so that an individual *k-th* region frontier will not be any greater than the metafrontier. Whereas all farms can be measured relative to their own frontier (a,b,c), representing the feasible limits of technical efficiency growth within that region at a particular time, a meta-frontier (C,A) can be constructed which envelopes all the regional frontiers and provides some parity in measurement between regional technical efficiency scores. The metafrontier for the stochastic production frontier is constructed deterministically by solving a linear programming problem, which minimises the distance between a region's frontier and the metafrontier. Thus a farm in region *b* can be both measured relative to its own frontier and to the metafrontier. This can be described graphically as Figure 1:

Figure 1. Graphical description of metafrontier



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

Hence in order to construct the metafrontier an optimisation problem is needed in which the distance between the *k-th* region frontier is minimised to the metafrontier. Battese *et al* (2004) provide the following optimisation problem:

$$(6) \qquad \min_{\beta} \sum_{i=1}^{L} \sum_{t=1}^{T} \left[\ln f(x_{1it}, x_{2it}, \ldots, x_{Nit}; \beta) - \ln f(x_{1it}, x_{2it}, \ldots, x_{Nit}; \hat{\beta}^{k} \right]$$

$$(s.t) \qquad \ln f(x_{1it}, x_{2it}, \ldots, x_{Nit}; \beta) \geq \ln f(x_{1it}, x_{2it}, \ldots, x_{Nit}; \hat{\beta}^{k})$$

for all i and t;

where $\hat{\beta}$ is the estimated coefficient vector associated with the group-k stochastic frontier. The assumption of log-linearity, as is the case here, simplifies to a linear programming problem (Battese et al., 2004):

$$(7) \qquad \min_{\beta} \bar{x}'\beta$$

$$s.t. \qquad x_{it}^{'}\beta \geq x_{it}^{'}\hat{\beta}^{k}$$

for all i and t

There are three stages to be followed for this approach (Battese et al, 2004). Firstly, separate frontiers for each region (*k*) are estimated. The metatechnology ratio (MTR) is then identified based on the linear programming problem specified in (7). The MTR identifies the ratio of the output for the frontier production function for each region relative to the potential output that is defined by the metafrontier function, given the observed inputs. We adopt the definition of the metatechnology ratio (MTR) which indicates that *''increases in the metatechnology ratio imply a decrease in the gap between the group frontier and the meta-frontier''* (O'Donnell et al. 2008, p. 236). In effect, the MTR takes the value of between 0 and 1, where 1 indicates no gap between the farm in a particular region and the metafrontier. The technical efficiency for each region relative to the metafrontier can be found as the product of each farm in each time period (*it*) MTR against each farm's TE for each region (*k*), namely:

$$TE^{*}_{it} = TE^{k}_{it} \text{ x } MTR^{k}_{it}$$

2.2. Data description

The UK can be divided into 6 so called 'super' regions, namely Northern, Eastern and Western England, Wales, Northern Ireland and Scotland. To cover the UK there are three administrative collective regions. Firstly, England and Wales collects farm account data on an annual basis, and comprise around 2,500 businesses of various types. Data are collected from farm business units within administrative centres in England and Wales, usually associated with major universities within that region. These data could be further sub-divided into more specific regions, e.g. county level, however the need for adequate observations within the SPF estimation restricts this. The data provide detailed information on quantities and financial inputs into each farming business. Dairy farms are defined as those businesses generating at least 2/3rds of their income from dairying activity. The same definition holds for the Scottish and Northern Irish Farm accounts data, which cover similar definitional boundaries as those for the English and Welsh sectors. All UK data are collected under FADN quality assurance guidelines and consequently we are assured of the correspondence across the regions. Where possible, quantities were applied, however a drawback in using farm account data is that most data are only given in financial values. Hence to convert to quantities deflators are used. An advantage of focusing on the UK is that a single currency is used, namely pounds sterling. This eases concerns regarding deflation and comparison issues. An alternative are EU FADN data in which values are converted into Euros which adds a further complication to the expansion of this approach across other regions. Data were compiled for the 2005 to 2008 periods for those dairy farms within the 6 super regions and a description of the data variables used are presented in Table 1 below.

Table 1. Technical Efficiency Estimation Variables

Variable	Description
OUTPUT	The value of main output less subsidies deflated into 2008 prices. We therefore assume full decoupling from production activity.
MATERIALS	The values of all materials in 2008 prices. This 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	Total cost of energy consumed on the farm, comprising fuel and oil, and electricity
LAND	Total area used for agricultural production
LABOUR	Total full time equivalent units operating on the farm
CAPITAL	The running and maintenance costs, depreciation and interest of capital stock (taken at 3% p.a) deflated into 2008 prices

Furthermore, a time trend variable was employed to represent the technological change over the period, and a squared time trend to indicate the speed in which technical change is operating. The analysis was undertaken using SHAZAM (v10), which was also used to estimate the metafrontiers, using base code provided by Battese *et al* (2004).

The value of output tends to range from £367,039 in the East of England, compared to Northern Ireland which has an average of £218,889. Inputs are consistent across the 6 regions aside from Northern Ireland which indicate an average lower level of inputs and a lower average size of farm, which is also reflected in the lower levels of output. Some variance is noted across the three English regions where output in the North of England is worth around £85 thousand less than those on the East, though this is reflected in smaller input levels and area. An interesting factor of production is Energy use, which is comprised of fuel and electricity for heating and transport. In the North of England and Scotland this is much higher than other regions and may be reflective of the lower levels of light and temperature experienced in higher latitudes which may lead to greater housing of cattle.

Table 2. Average inputs and value of output without subsidies by super region, 2005 to 2008, 2008 prices

	N	Output (£2008)	Materials (£2008)	Energy (£2008)	Area (Ha)	Labour (FTE)	Capital (£2008)
North England	420	283,421.0	130,989	13,018	107.3	3.0	86,105
SD		*305,587.3*	*132,719*	*66,987*	*82.5*	*3.2*	*71,569*
West England	483	329,366.8	142,070	8,069	103.6	3.7	103,092
SD		*313,674.6*	*138,550*	*13,295*	*78.8*	*3.0*	*87,685*
East England	571	367,039.1	166,793	7,952	130.4	4.1	125,006
SD		*385,651.3*	*209,493*	*7,339*	*110.3*	*3.0*	*117,626*
Wales	324	254,952.5	122,760	6,526	101.4	2.6	88,279
SD		*217,766.5*	*118,481*	*5,952*	*62.7*	*1.2*	*66,072*
North. Ireland	450	218,889.9	60,505	3,394	67.2	1.7	44,802
SD		*173,022.6*	*54,705*	*2,535*	*78.3*	*0.7*	*32,896*
Scotland	241	252,819.9	134,362	16,603	119.6	2.6	64,079
SD		226,754	85,844	9,782	51.3	1.1	28,274

3. RESULTS

Table 3 shows the coefficients of the 6 super regions and the estimation of TE when pooling all regions into one frontier (UK). The results shows that the first order parameters are positive (aside from Eastern England, where labour is negative), and significant, which indicates that the condition of monotonicity for a well behaved production function is being met (Moreira and Bravo-Ureta, 2010). What is notable is the lack of significance of the non-linear translog terms with the Welsh and Northern Irish regions. A further field of investigation would therefore be to use mixed functional forms to estimate the meta-frontier. Finally, what is also notable is the lack of significance in the time trend variable, which infers no technology change effect over the period 2005 to 2008. This may represent restructuring for the single farm payment which decoupled subsidies from production (SAC, 2008). This should be explored in greater detail. Only the Welsh trend is significant and indicates a rise in the linear trend of around 1.3% per annum.

The estimation of the pooled (UK) model allows a formal test to estimate whether group frontiers are different. The generalised likelihood ratio test (Battese et al, 2004) gives a likelihood ratio of 2,324.1 which is a strongly significant rejection of the null hypothesis and indicates that regional frontiers are not the same. It is notable that all other studies applying the metafrontier have similarly rejected the null hypothesis, for example Battese et al (2004) found similarly high LRs for a study in inter-regional garment manufacturers. To test this further the pooled English data were estimated and compared with the LLF of the three English regions. As would be expected the LR is much smaller at 128.50, but with the reduction in degrees of freedom this still rejects the null hypothesis. This is a crucial result as previous models have estimated at a national level, whereas this may suggest that regional differences are strong within England and the standard SFA approach may be presenting bias results.

The means and the standard deviations for the TE, MTR and MFs are given in Table 4. There is little movement in scores for Northern and Western English farms, along with Welsh and Northern Ireland dairy farms. Lower scores were generated for Scotland and, most extremely, the East of England. However, it should be emphasised that these scores are only presented together for brevity. Thee next stage is to run the meta-frontier to compare these regions against a common technology. The parameters in Table 3 provide the basis for estimating the metafrontier using the transformed data from the translog for each region, and applying the optimisation problem outlined in (7).

Table 3. Parameter estimates for the 6 super regions and 1 pooled region

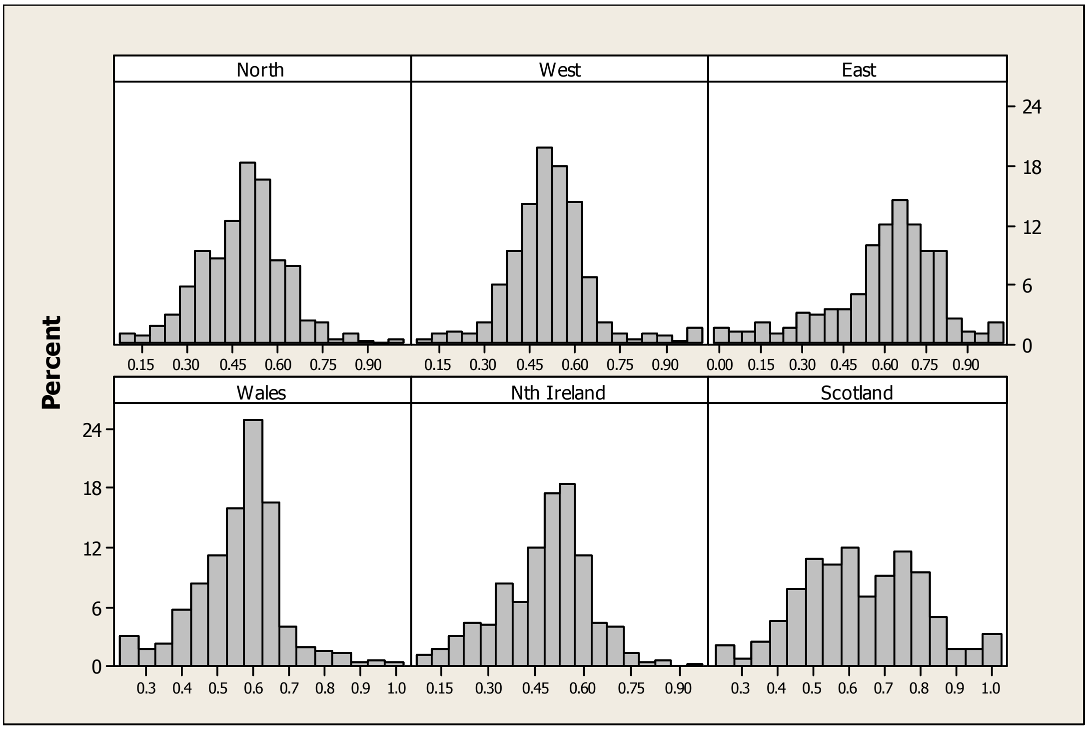
	North England		**Wales**		**West England**		**East England**		**Northern Ireland**		**Scotland**		**UK**	
Icpt	0.021	**	0.139	***	0.035	*	0.229	**	0.027	**	0.239	***	0.205	***
X1	0.649	***	0.666	***	0.756	***	0.850	***	0.514	***	0.240	***	0.719	***
X2	0.011	**	0.066	***	0.032	**	0.048	*	0.021		0.283	**	0.385	***
X3	0.224	***	0.231	***	0.271	***	-0.395	***	0.097	***	0.391	***	0.085	***
X4	0.040	*	0.053	**	0.029	***	0.286	***	0.429	***	0.707	***	0.275	***
X5	0.236	***	0.032		0.017		0.165		0.042		-0.331	**	0.412	***
X11	-0.061		-0.098	***	0.105	***	0.298	***	-0.108	***	0.240		0.061	***
X12	-0.100	**	-0.068		-0.014		-0.262	***	-0.066		-1.220	***	-0.016	
X13	0.036		0.045		0.160	**	-1.019	***	-0.020		-0.353		-0.218	***
X14	0.081	***	-0.060		0.090	***	-0.263	***	0.109		1.124	***	0.088	***
X15	0.078		0.156		-0.439	***	0.115		0.115		-0.593		-0.157	***
X22	-0.031		0.018		-0.009		0.077		0.096		1.033	***	0.120	***
X23	0.013		0.006		-0.035		-0.088		0.075		0.007		-0.193	***
X24	-0.006		-0.010		-0.012		-0.120	***	-0.129		-0.531		-0.088	***
X25	0.140	***	0.048		0.096		0.456	***	0.166		0.640		0.463	***
X33	0.099	***	0.088		0.099		0.085		0.068		0.342		0.025	
X34	-0.108	***	0.132		-0.165	***	-0.210		0.021		-0.978		-0.040	
X35	-0.044		-0.037		-0.041		1.326	***	-0.016		-0.292		0.276	***
X44	-0.021	***	-0.087		-0.019		0.044		0.030		0.010		0.114	***
X45	0.036		0.035		0.257	***	0.465	***	-0.112		-0.403		-0.246	***
X55	-0.137	***	-0.106		-0.039		-0.901	***	-0.080		0.090		-0.004	
TT	-0.011	*0.832*	0.013	**	-0.048	*0.411*	0.211	*0.232*	0.015	*0.744*	0.030	*0.065*	0.036	0.507
TT2	0.003	*0.772*	-0.029	***	0.012	*0.291*	-0.033	*0.343*	-0.009	*0.345*	-0.060	*0.063*	-0.007	0.488

1/ The dependent variable is the logarithm of the total output excluding subsidies. (*=P<0.05, **=P<0.01, ***=P<0.001)

2/ x1 stands for materials, x2 energy, x3 labour, x4 land and x5 capital.

Mean technical efficiency scores tend to show little variance and average scores are high with low levels of deviance, indicating the progressive nature of dairy farming within the UK. The meta-technology ratio is the mean gap between the metafrontier (the common technology) and the regional frontier (regional technology). What is noticeable is the growth over this period of Scotland (which grew from 0.60 to 0.66), whereas the remainder have tended to remain constant. Figure 2 shows the distributions of the meta-technology scores for all farms in the six super regions, indicating a fairly normal distribution for all region, though notably Scotland's distribution is somewhat flatter, indicating a more equitable spread of MTRs.

Figure 2. Distribution of the Metatechnology Ratio for the 6 regions, percent



Also of note are the maximum values of the MTR, a maximum value of 1 indicates that the regional frontiers are tangent to the metafrontier (Battese et al., 2004). Hence, it is possible for farms within regions to attain efficiencies under the common technology of the metafrontier. Estimation of the MTR allows calculation of the Metafrontier scores and these are presented at the mean for the 6 super regions. Notably, the English and Northern Irish regions tend to have the lowest scores of below 0.50 throughout the period, whereas both Scotland and Wales generate higher scores at an average of 0.52 for Wales and 0.57 for Scotland.

Table 4. Mean estimates of technical efficiency, meta technology ratios, metafrontiers and maximum MTR score for 6 UK regions, 2005 to 2008

	England											
	North				West				East			
	TE	MTR	MF	Max MTR	TE	MTR	MF	Max MTR	TE	MTR	MF	Max MTR
2005	0.93	0.50	0.46	0.88	0.91	0.52	0.47	1.00	0.85	0.52	0.50	1.00
SD	*0.03*	*0.12*	*0.11*		*0.09*	*0.14*	*0.14*		*0.08*	*0.20*	*0.17*	
2006	0.93	0.47	0.44	0.84	0.92	0.51	0.47	0.98	0.86	0.51	0.52	1.00
SD	*0.03*	*0.13*	*0.13*		*0.03*	*0.13*	*0.12*		*0.05*	*0.18*	*0.16*	
2007	0.93	0.47	0.44	0.86	0.92	0.51	0.47	1.00	0.80	0.51	0.47	1.00
SD	*0.03*	*0.15*	*0.14*		*0.03*	*0.13*	*0.14*		*0.17*	*0.22*	*0.21*	
2008	0.93	0.51	0.47	1.00	0.91	0.52	0.47	1.00	0.83	0.52	0.48	1.00
SD	*0.03*	*0.15*	*0.14*		*0.09*	*0.14*	*0.13*		*0.14*	*0.22*	*0.20*	

	Wales				Northern Ireland				Scotland			
	TE	MTR	MF	Max MTR	TE	MTR	MF	Max MTR	TE	MTR	MF	Max MTR
2005	0.92	0.56	0.56	0.95	0.93	0.48	0.44	1.00	0.90	0.60	0.54	1.00
SD	*0.03*	*0.12*	*0.11*		*0.03*	*0.14*	*0.13*		*0.05*	*0.16*	*0.15*	
2006	0.92	0.55	0.51	0.92	0.93	0.47	0.44	1.00	0.88	0.62	0.54	1.00
SD	*0.03*	*0.13*	*0.12*		*0.02*	*0.14*	*0.13*		*0.13*	*0.18*	*0.18*	
2007	0.92	0.56	0.52	1.00	0.93	0.47	0.43	1.00	0.90	0.67	0.60	1.00
SD	*0.03*	*0.13*	*0.12*		*0.02*	*0.14*	*0.13*		*0.05*	*0.17*	*0.15*	
2008	0.92	0.57	0.53	0.94	0.93	0.50	0.46	1.00	0.90	0.66	0.59	1.00
SD	*0.04*	*0.11*	*0.10*		*0.02*	*0.15*	*0.14*		*0.06*	*0.16*	*0.15*	

4. CONCLUSIONS

The paper has presented the metafrontier approach for the post-decoupling period for a number of regions within the UK. An important advance is the division of country data into super regions for separate analysis and comparison, which negates some of the effects of inter-regional bias which may effect previous attempts at measuring technical efficiency in the UK. The UK presents a useful case study for comparison of data sources across the UK and these have found to compare across the three administrative farm account data set. The authors wish to extend this analysis to the European region, however this is complicated by the use of currency conversion and subsequent impacts on deflation of values into quantities.

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