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Number 14. Technical Efficiency Estimates of Scottish Agriculture: Evidence from the dairy, sheep and cereals sector

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Technical Efficiency Estimates of Scottish Agriculture: Evidence from the dairy, sheep and cereals sector

Abstract: Technical efficiency, the ratio of physical inputs to outputs, is a popular means of assessing agricultural performance. Benchmarking of these efficiencies is a fundamental tool for the farming industry. More sophisticated techniques have been developed recently which offer a greater degree of complexity for measuring technical efficiency. This paper adopts a parametric approach, referred to as stochastic production frontiers (SPF), to study three major sectors the Scottish agricultural economy, namely i) cereals, ii) dairy, and iii) sheep, over the period 1989 to 2004.

Introduction

There are a wealth of technical efficiency studies concerned with agricultural production. Within the UK these studies have mostly focused on aspects of English farming (Thirtle *et al.*, 2004; Hadley, 2006). However, the bio-physical constraints of farm production have led to quite distinct pathways of development amongst the four countries of the UK. In addition, the devolved nature of policy decision-making, e.g. the administration of the single farm payment, requires that analysis focus on particular national levels.

To date the only two studies to examine technical efficiency in Scotland is Barnes and Oglethorpe (2004), who took a single year's data and applied non-parametric techniques to the dairy industry in the South West of Scotland, and Santarossa (2003). He takes data from 45 farms of varying types over the period 1983 to 2000 and applies paramteric methods to understanding financial sustainability within Scottish agriculture.

This paper takes the parametric approach to measuring technical efficiency and applies a number of years data to derive estimates for several important sectors of the Scottish agricultural economy, namely cereals, dairy and sheep. This helps to give a clearer understanding of Scottish agriculture and its constraints for future growth.

Conceptual Background

The background to measuring efficiency is based on the work of Farrell (1957). Essentially, Farrell's approach is based on an efficiency frontier which represents the best practice technology of that particular industry at a particular point in time. Once constructed farms can be measured relative to this frontier as a ratio. The farm which is technically efficient will have a score of 1 and be on the frontier. However, a farm which is technically inefficient will have a score of less than 1, which represents that firm's distance from the frontier.

There are two popular methods for constructing this frontier. Data Envelopment Analysis is based on linear programming methods. It has the major benefit of offering detail from an advisory point of view, as each farm's level of input excess can be identified. However, its major drawback is that all deviance from the frontier is attributed to technical inefficiency, with no account for variance due to soil type and climate etc. The alternative measure is Stochastic Production Frontiers (SPF), which is based on econometric estimation of panel data, and allows for this variance to be removed from the efficiency measure. Whilst it offers less information and also requires several assumptions about the construction of the frontier, it seems to be the preferred method for measuring efficiency within agriculture. Furthermore, Battesse and Coelli (1995) offer a model which allows the estimation of 'inefficiency effects', i.e. to explain the causes of inefficiency such as the age and education of farmer, within the estimation of the technical efficiency measure. This is useful as the inefficiency parameters can be estimated in a 1-stage procedure and avoids some of the statistical problems of estimating with a 2-stage procedure.

Data Requirements

FAS data were used to construct the three enterprise sectors and the SEERAD code provided within the FAS for the appropriate enterprise groups. A number of enterprises were ignored, principally cattle and general cropping producers. This is due to the heterogeneous nature of output as, within a relative technical efficiency framework, like has to be compared with like. Hence, in to offer a fair assessment of a farm's position, a similar level of technology has to be present within the operation of the business to offer a relative assessment of efficiency.

Sixteen years of data, running from 1989 to 2004 were available. To offer a true estimate of technical efficiency these were deflated into constant prices to provide indications of quantities and avoid some of the fluctuation in price changes over these years.

Inefficiency Effects Variables

The FAS also includes information that could be used for explanatory variables on inefficiency. Unfortunately, the FAS has only recently collected age and educational data, factors which, most commentators agree, have the greatest influence on efficiency. Consequently, measuring inefficiency is restricted by the paucity of the data. However, a number of other variables which may have an effect on efficiency were included which are available for all farms over the 16-year period. These, along with their values, are outlined in Table 1 below.

Table 1. Inefficiency Effects Variables

Variable	Value	
LFA	0 = Non-LFA	1 = LFA, or Mixed LFA
ESA	0 = Not in ESA	1 = ESA, or Mixed ESA
TENURE	0 = Owner-occupied	1= Tenanted or other
SIZE	Agricultural Area in Ha	
DEBT	The ratio of short and long term debt to net worth	
TIME	A variable representing time period, running from 1 to 16	

The LFA series is a dummy variable representing LFA status. Farms with no land within a LFA are given a value of 0, compared to farms with at least some land which is classified as LFA. The ESA variable is also a dummy, with 0 representing farms which have no land within an environmentally sensitive area and a value of 1 with some or all land within an ESA. TENURE represents either owner-occupied status, or some form of tenanted agreement within the farming structure. SIZE is agricultural area in ha of the farm, DEBT is the ratio of short-term and long-term debt to a farm's net worth, this variable is aimed at capturing some of the farmer's attitude towards risk. Finally, TIME is a time trend variable which aims to represent the growth in experience and learning of the farmer over the 16-year time period.

Estimation Procedure

As SPF is a parametric technique, a functional form needs to be adopted to represent the production technology involved. A number of forms exist, the most common seems to be the translog production function. This is usually preferred for SPF work in agriculture as it is a flexible functional form, making fewer assumptions over the transformation of inputs to outputs. Consequently, this form is adopted for the estimation. Hence, the functional form adopted is illustrated below,

$$\ln y_{it} = \alpha_0 + \sum_{k=1}^{16} \beta_k \ln x_{kit} + \sum_{k=1}^{16}\sum_{j=1}^{16} \beta_{kj} \ln x_{kit} \ln x_{jit} + \beta_t t + \beta_{tt} t^2 + \sum_{k=1}^{16} \beta_{kt} \ln x_{kit} t + v_{it} - u_{it}$$

where y represents revenues of the i-th farm in year t, (α) represents the intercept term, x's are the input variables, which vary by enterprise, (β) are the parameters to be estimated, t is a linear time trend from 1989 to 2004, *v* is the random error and assumed to be identical and independently distributed and the technical inefficiency effects (*u*) are defined as in Table 1.

Results

Cereals

Relative to the remaining enterprise sectors, only a small number of cereal farmers are represented within the FAS. Due to restrictions in the estimation framework the same number of observations per year have to be used, i.e. a 'balanced' panel. However, some farms which appear in the earlier sample tend to disappear and be replaced by other farms, which would distort the estimates. Secondly, as the panel has to be balanced and the number of observations per enterprise varies each year the lowest number of observations from one of the 16 years has to be used. In this case, only 26 producers could be identified to represent cereal farming throughout the 16-year time span. Whilst this is acceptable it naturally imposes restrictions on the statistical robustness of the results. However, t-statistics are reported within the estimation of the production frontier. The variables used and their descriptive statistics are outlined in Table 2.

Table 2. Descriptive statistics for Scottish Cereal Farmers

	Mean	SD	Median
Revenue	63,095	52,985	47,182
Fertiliser	16,540	10,278	14,705
Labour	14,477	17,085	12,283
Machinery Cost	31,668	21,201	26,496
Rent	20,729	14,143	16,637

Table 3, for brevity, shows the partial results of the estimation procedure. The estimators (β_1-β_4) represent the four inputs used within the estimator. Notably only two of the inputs are significant, namely fertilisers and labour, with rent and machinery costs not significant. This may be a result of the small sample size, but also that rental charge and machinery running costs may not be as direct an input onto the system compared to labour and fertilisers.

Table 3: Results from the Maximum Likelihood Estimation for Cereals

		Coefficient	*Sig*
Intercept	α	-5.1069	**
Fertilisers	β_1	3.1931	**
Labour	β_2	-0.3061	**
Machinery Costs	β_3	0.6779	-
Rent	β_4	-1.5280	-
σ_s^2 =0.27**; γ=0.75**		Log Likelihood Function	-137.96

* 95% Significance; **99% Significance

The inefficiency effects model show the marginal effects (estimated at the means over the 16-year period of the major inputs). LFA status is not significant, which may be a result of low numbers of cereal farmers operating within a Less Favoured Area, due to soil requirements. Similarly ESA status is not significant. Finally, the debt ratio is not significant, indicating that the effect of 'financial security' may not be prescient to achieving technical efficiencies.

Table 4. Marginal Effects on Technical Efficiency[1]

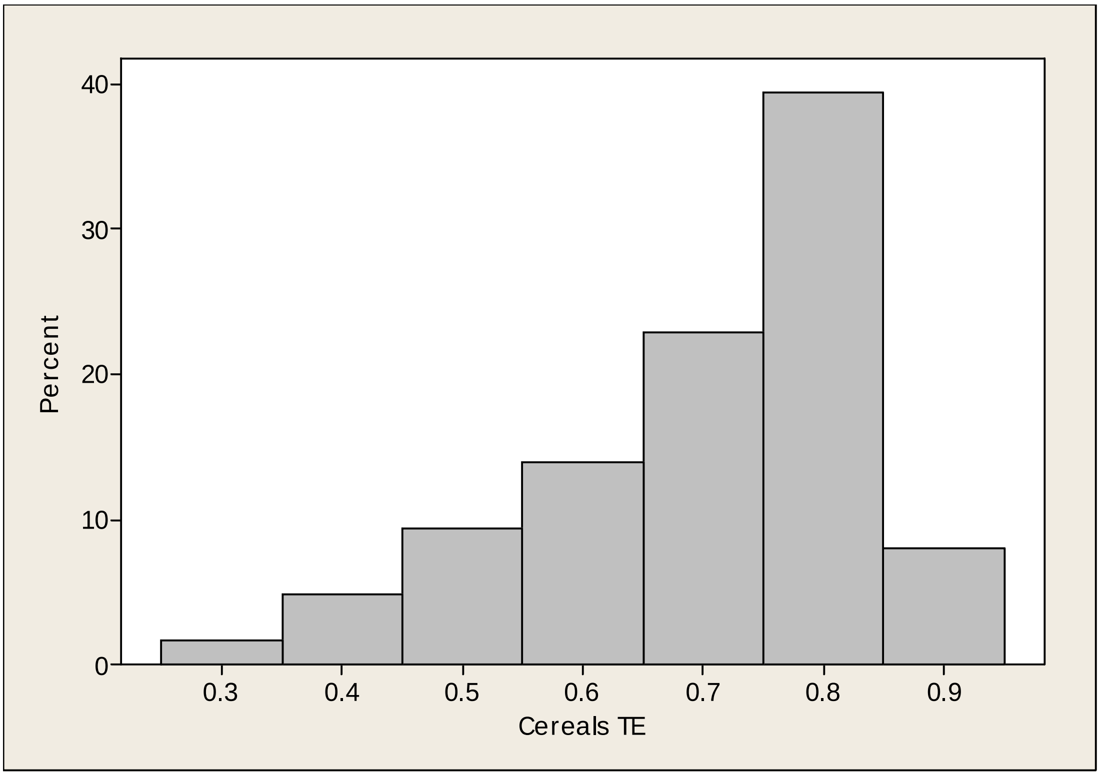
LFA	δ_1	-0.057%	-
ESA	δ_2	-0.114%	-
TEN	δ_3	-0.077%	**
Debt Ratio	δ_4	-0.0000123%	-
Area	δ_5	-0.013%	**
Time Trend	δ_6	0.026%	**

*Sig at 95%, ** Sig at 99%

The AREA variable is significant, and a 1% increase in area would lead to a 0.013% decrease in technical efficiency. This may tentatively indicate decreasing returns to scale within cereal production. Similarly, tenure shows that a movement from owner-occupier status to non-owner occupied would lead to a decrease in technical efficiency of 0.08%. Finally, the time trend variable is significant. Thus, as this variable captures the benefits of experience and learning by doing, the figure is positive and makes up 0.03% of total efficiency growth.

Figure 1 shows the distribution of the technical efficiency scores. A mean technical efficiency of 0.75 was reported, with a standard deviation of 0.14. The minimum score was 0.31.

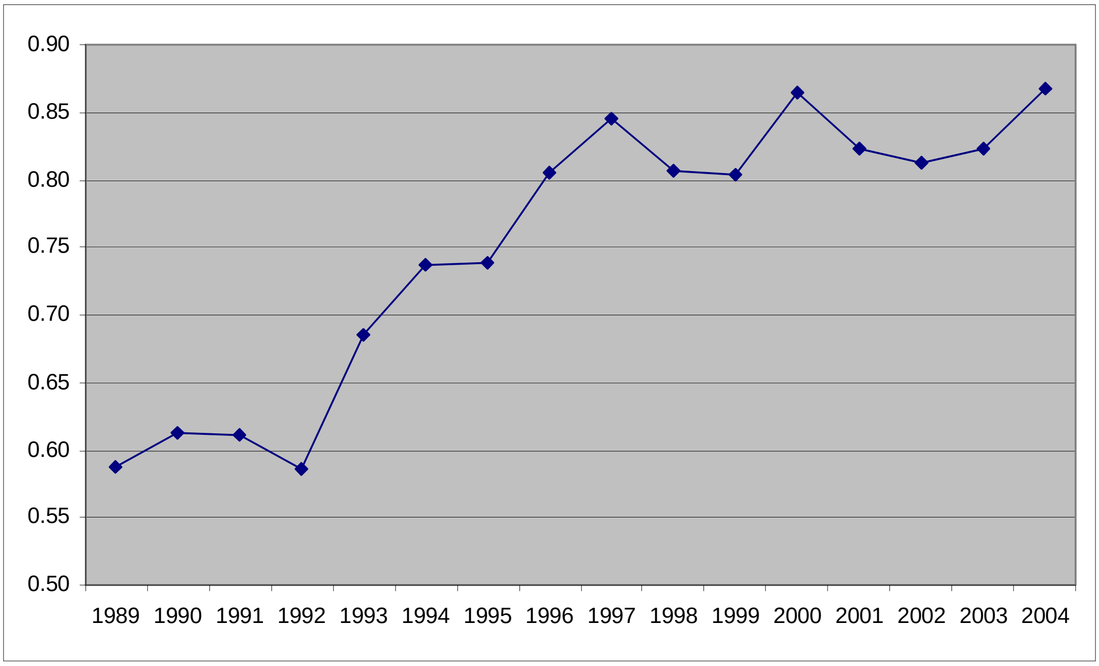
Figure 1. Distribution of Technical Efficiency Scores Cereals



Analysis can be taken over time taking the average technical efficiency score for each year to give an indication of how the mean technical efficiency has changed over time. However, as pointed out by Thirtle *et al*. (2004), average technical efficiency in any one year is that farm's efficiency relative to a technical frontier. The frontier changes each year and hopefully advances forward as technology improves. Thus, whilst it does provide an indication of change, it is difficult to disaggregate the technical change from the technical efficiency score. These changes are indicated in the figure below.

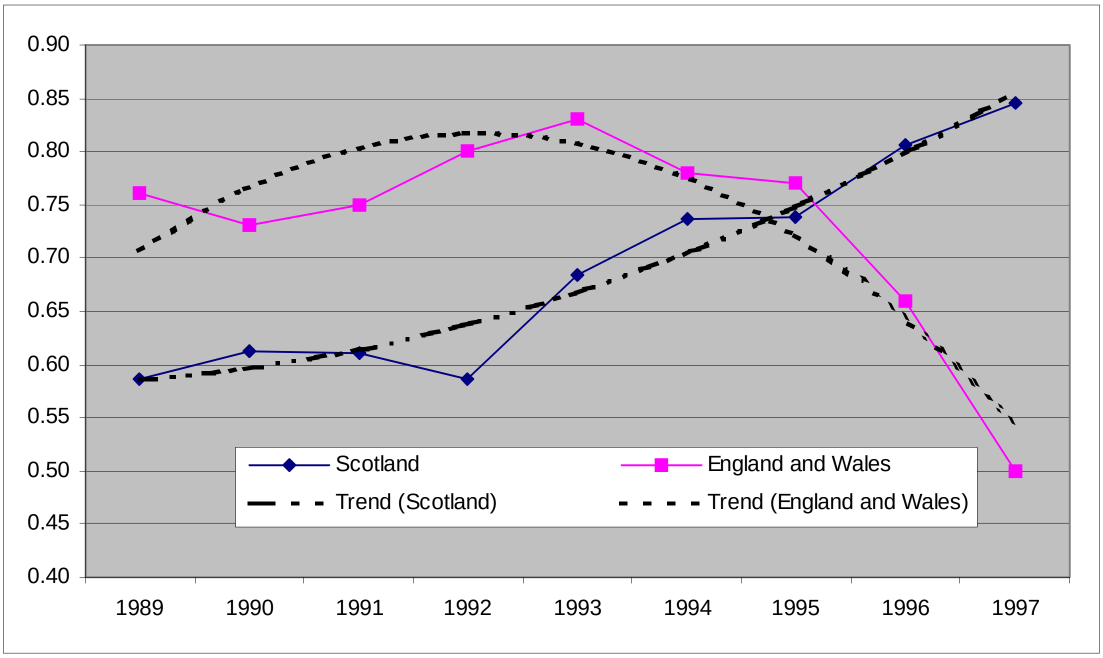
[1] Originally this measures the effect of a variable on inefficiency, to avoid confusion the signs have been reversed to show their effect on efficiency.

Figure 2. Mean Technical Efficiency over the Period



From 1989 onwards cereal farming shows very positive trend, from 0.59 in 1989 to 0.87 in 2004, a growth rate of just below 50%. Whilst relatively flat until 1992, there is a growth in efficiency until 1998. A number of factors could be behind this, the most prominent being the MacSharry changes to the CAP, in particular the introduction of set-aside, which may have put less productive land out of production. However, it should also be stressed that as the time trend variable was strongly significant and positive, hence embedded within this growth is technical change along with technical efficiency improvements.

Figure 3. Comparison between Scotland and England and Wales TE



Source: Thirtle et al (2003) and own data.

Figure 3 shows these trends compared to the study for England and Wales. Again it has to be stressed that farms are being measured relative to their own technology and cannot indicate better or worse performance. However, some indication of trend can be examined. Figure 3 shows that the trends within Scotland are diametrically opposite those for England over this period, indicating that as English and Welsh farms have decreased technical efficiency, Scottish efficiencies have improved. A tentative explanation for this may be the role of R&D and advisory services within both states. Thirtle et al. (2004) argued that the fall observed in productivity over this period may be caused by the privatisation of ADAS which has had a negative effect on efficiencies. However, the SAC system of advisors have not been so affected. Similarly it may be indicative of better technology transfer tools within Scotland, or the focusing of public research which is more ‘near-market’ compared to that within England.

Dairy Industry

58 diary farms were chosen for the 16 year period, equalling 928 observations in total. Using four variables proved problematic and fertilisers were added into the feed series. To further increase degrees of freedom, rent was combined with machinery costs. Descriptive statistics are outlined below.

Table 5. Descriptive Statistics for Dairy Farming

	Mean	Standard Deviation	Median
Revenue	47,632	34,405	41,368
Feed & Fertiliser	50,334	21,010	47,127
Labour	26,700	19,756	23,030
Mech Cost & Rent	51,446	25,026	48,109

The results of the estimation procedure proved all variables strongly significant at the 1% level. Partial results are outlined in Table 6 below.

Table 6. Results from the Maximum Likelihood Estimation for Dairy

		Coefficient	*Sig*
Intercept	α	-8.7850	**
Feed	β_1	1.5451	**
Labour	β_2	-0.5535	**
Machinery and Rental Costs	β_3	2.0234	**
σ_s^2 = 0.29**; γ = 0.57**		Log Likelihood Function = -557.30	

The three variables all proved significant at the 1% level. Of these labour proved negative, a result which seems to occur in a number of studies (Wilson *et al*, 1998). Thus, whilst increases in machine and rental costs, alongside feed and fertiliser, will have a positive effect on technical efficiency, an increase in labour cost will have the opposite effect. The results of the inefficiency effects model are outlined below.

Table 7. Marginal effects on Technical Efficiency[2]

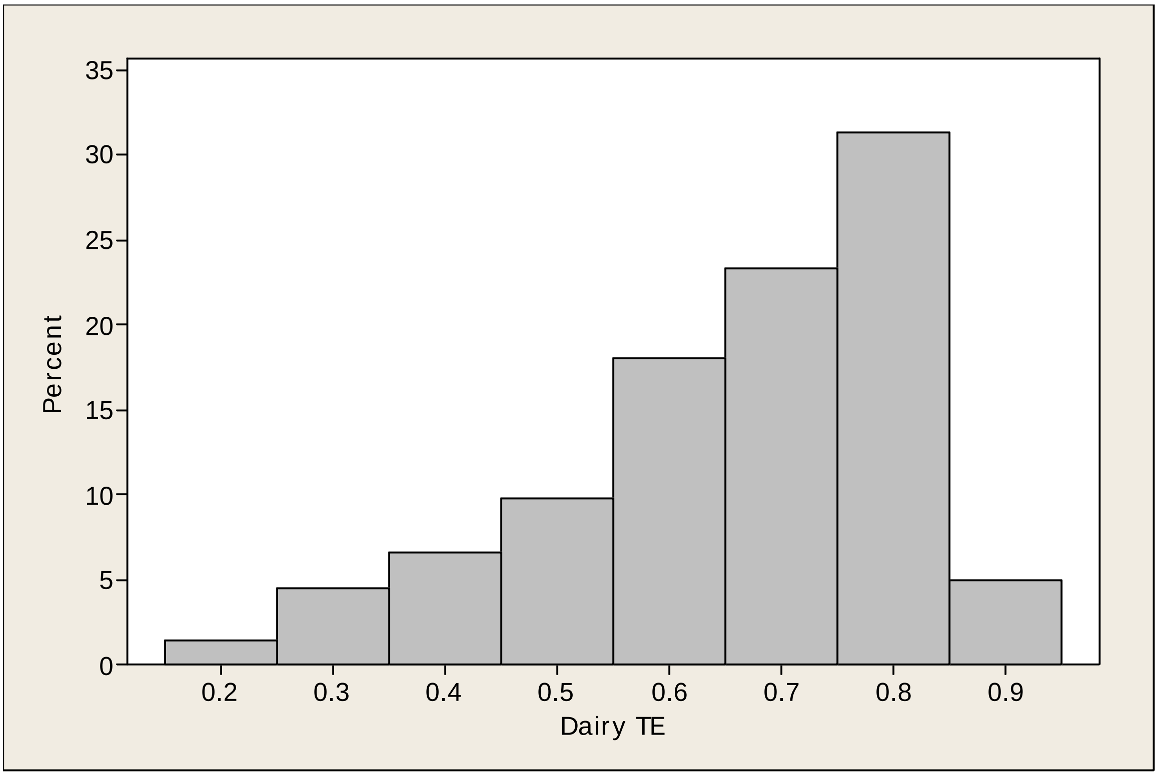
LFA	δ_1	-3.474%	**
ESA	δ_2	3.381%	**
TEN	δ_3	1.117%	-
Debt Ratio	δ_4	0.137%	**
Area	δ_5	-1.632%	**
Time Trend	δ_6	1.665%	**

The marginal effects are illustrated in Table 7. Generally, all variables, except type of tenure were strongly significant. The two negative effects on efficiency would be a movement from non-LFA to LFA status, along with an increase in area. However, the other variables have a positive effect on efficiency. A movement to ESA status would, it would seem, improve efficiency. An increase in the debt ratio would also have a positive effect on efficiency, perhaps indicative of the increasing capital investment within dairy. Finally, the time trend is positive, indicating that experience has contributed to improvements in efficiency throughout this period.

Figure 4 shows the distribution of technical efficiency scores for the dairy sector. Average efficiency over the period was 0.71, with a standard deviation of 0.16 and a minimum score of 0.12.

[2] Originally this measures the effect of a variable on inefficiency, to avoid confusion the signs have

Figure 4. Distribution of Technical Efficiencies for Dairy Sector



Again the average technical efficiencies over the 16-year period can be presented with the caveats outline above. Generally, the series fluctuates in the first part of the series, reaching its peak in 1992 with a score of 0.80. However, from here there is a strong trend down. In particular, 1997 began a decrease in efficiency which may coincide with the BSE crises which began in 1996 (reflecting data collected). Similarly, after BSE there as has been a substantial loss in income from restrictions on the sale of calves. Thus, it may indicate that, as this is a measure of inputs to outputs, the industry has not reacted positively to the possible effects of restructuring that BSE may have heralded. However, in the latter stages this efficiency settles and begins to rise again, however there is some concern that efficiencies have greatly reduced over the period from 0.77 in 1989 to 0.60 in 2004.

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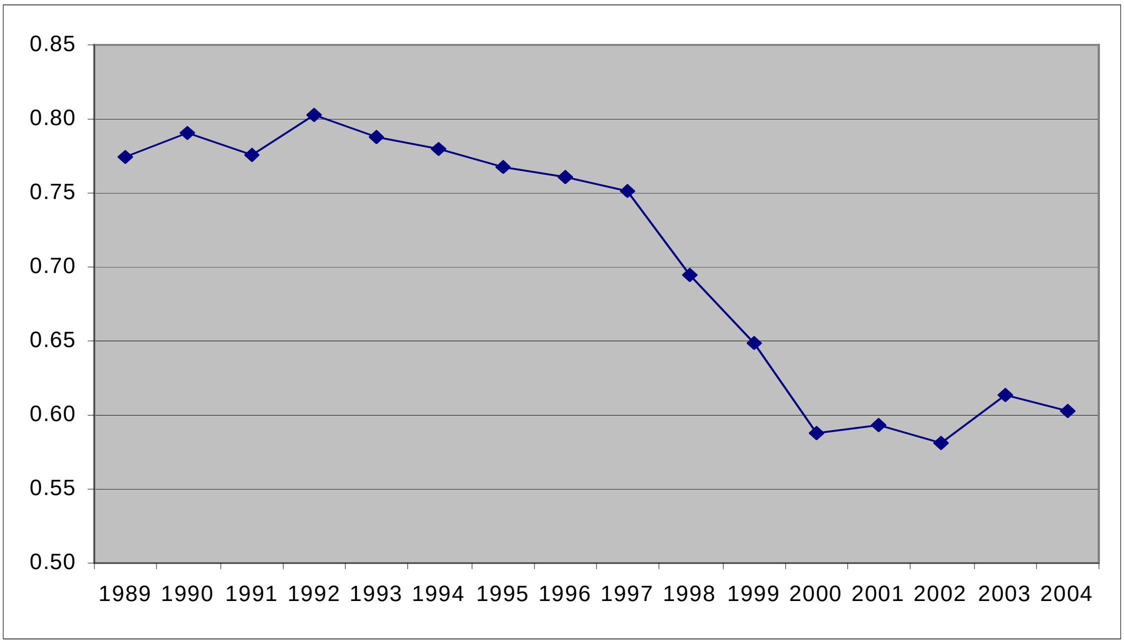
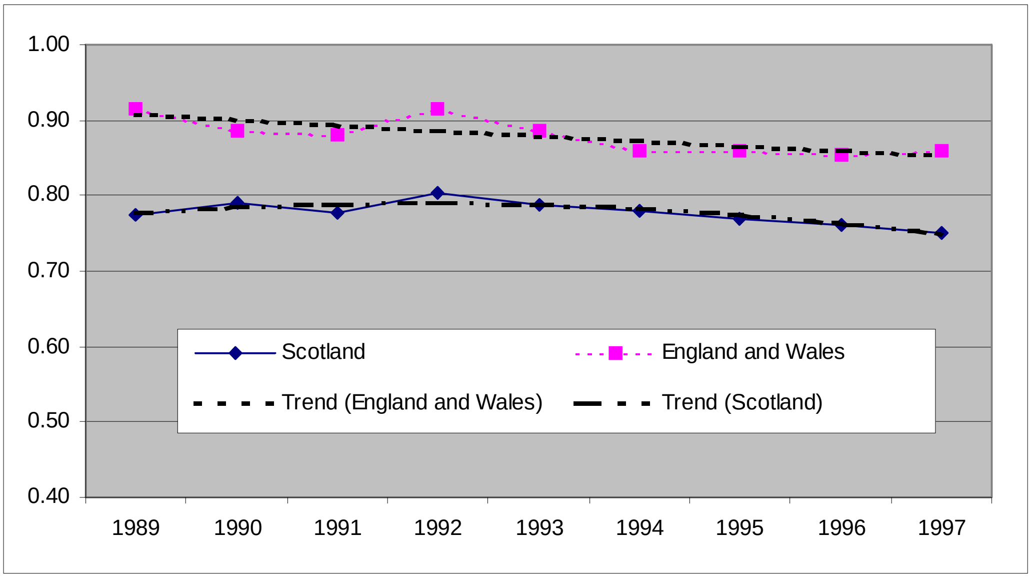
been reversed to show their effect on efficiency.

Figure 5. Trends in Average Efficiency Levels for Dairy Farming



Comparison with results from England and Wales can be presented, again with the caveat that only trends can be observed over the period. Figure 6 shows these trends.

Figure 6. Trends in Average Efficiency Levels for Dairy Farming



In comparison with England and Wales, Scotland seems to run parallel over the same period, perhaps indicating that both countries dairy systems are closely linked and affected by similar events on both sides of the border.

Sheep

Sheep farming consisted of 44 farms over the 16 year period, 704 observations in total. This proved less problematic to fit compared with dairy farming, however machinery costs and rent were combined, again to reduce restrictions with degrees of freedom. The descriptive statistics are shown below.

Table 8. Descriptive Statistics of Sheep Farming

	Average	Standard Deviation	Median
Revenue	61,460	40,775	50,638
Feed	10,670	8,766	8,495
Fertiliser	9,880	5,538	8,664
Labour	8,420	10,803	4,386
Machinery Cost & Rent	13,452	8,225	11,371

The results of the MLE are presented in Table 9 below.

Table 9. Results from the Maximum Likelihood Estimation for Sheep

		Coefficient	*Sig*
Intercept	α	9.0454	**
Feed	β_1	-0.2997	-
Fertiliser	β_2	-0.1811	**
Labour	β_3	-0.4174	**
Machinery Cost & Rent	β_4	0.5535	**
σ_s^2 = 0.15**; γ = 0.71**		Log Likelihood Function = -82.62	

Whilst a number of variables were significant it seems feed proved insignificant at the 95% level. This is a problematic result as feed would be expected to make a contribution to overall performance. However, the amount of grazing involved, imputed through fertiliser and rent variables may accommodate for this effect. Fertiliser and labour proved negative, indicating an increase in these factors would lead to more inefficiency. Machinery costs and rent combined is positive and an increase in these factors would have a positive effect on efficiency. This perhaps indicates a requirement for increased capital investment to release more efficiency. The results of the inefficiency effects model are outlined below.

Table 10. Marginal effects for Technical Efficiencies

LFA	δ_1	-8.049%	**
ESA	δ_2	-0.468%	-
TEN	δ_3	0.318%	-
Debt Ratio	δ_4	0.002%	-
Area	δ_5	-0.140%	**
Time Trend	δ_6	1.037%	**

Examining the marginal effects, only LFA and AREA prove significant factors when measuring efficiency. Both have a negative effect on efficiency. A movement from Non-LFA to LFA status has a strongly negative effect on efficiency, which perhaps reflects the large amount of activity on LFA type land within sheep farming. Similarly, an increase in area would have a negative effect on efficiency growth. Finally, the time trend, as with the other enterprises, is positive. This indicates that some learning and experience has been gained within sheep farming over the 16-year period.

Figure 7 shows the distribution of efficiencies. An average technical efficiency score of 0.80 was recorded for the sheep sector, with a standard deviation of 0.15 and a minimum score of 0.25.

Figure 7. Distribution of Technical Efficiencies for Sheep Farming

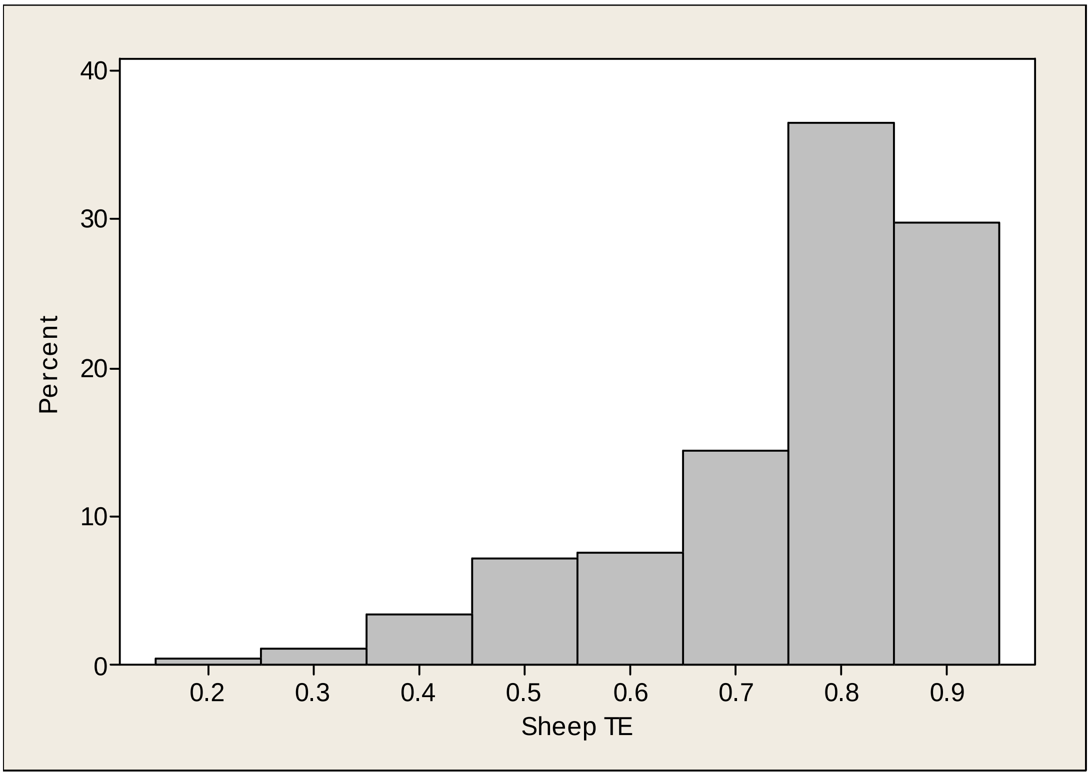
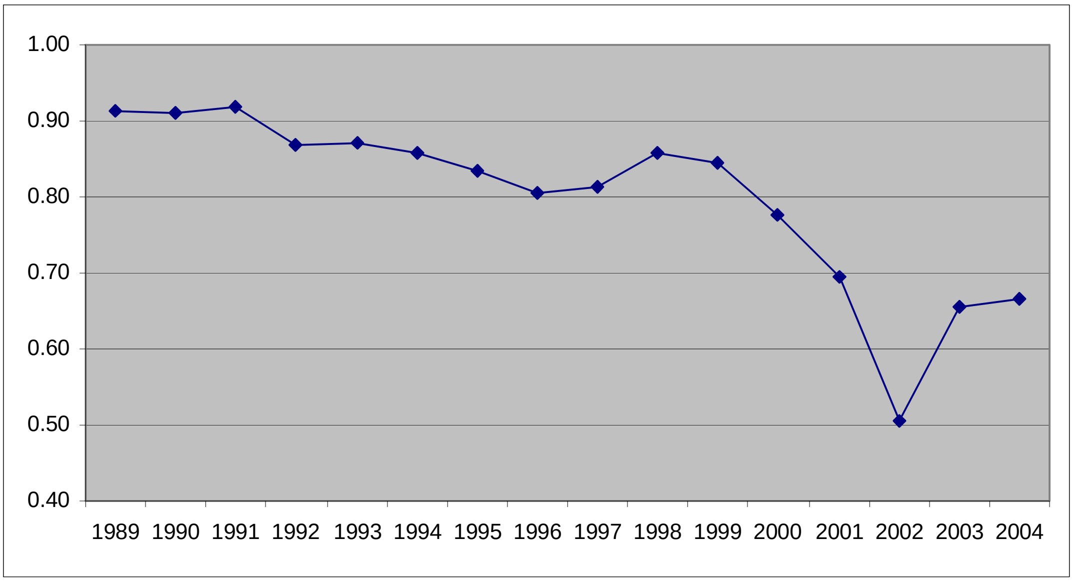


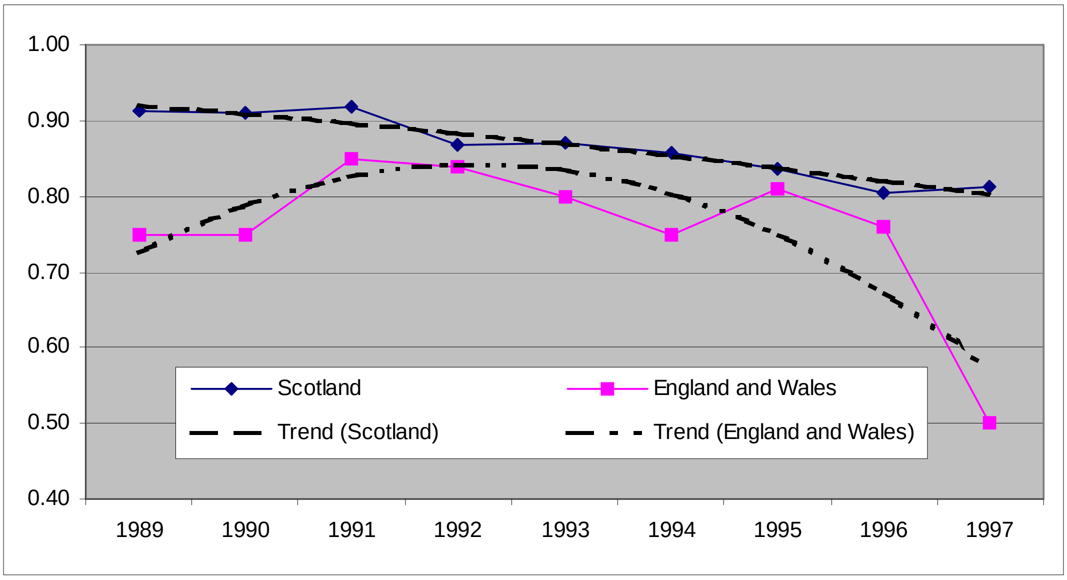
Figure 8 shows the average technical efficiencies over time and reveals a downward trend for most of the period. With increasing levels of low scores, 2002 seems to be a turning point when average technical efficiency reached 0.50. This could quite clearly be the results of the foot and mouth crises, as the data presented in 2002 are gathered in 2001. The Southern part of Scotland was the most affected and is where the most productive farms reside, and hence would seem to have the biggest effect on technical efficiency. However, in 2003 efficiency rises again. Nevertheless the trend is still downwards from over 0.90 in 1989 to below 0.70 in 2004.

Figure 8. Changes in Average Efficiency Levels



Finally, Figure 9 shows the trends in sheep farming compared to England and Wales over the same period. Both trends seem downward, however this is more marked in Scottish farms, perhaps indicative of climatic conditions.

Figure 9. Trends in Average Efficiency Levels for Sheep



Discussion

Results have been presented for the three sectors, cereal, dairy and sheep farming over the period 1989 to 2004. Trends in technical efficiency levels of the two livestock sectors decreased over the period, whereas cereals grew quite markedly from 1989 onwards. A number of factors appear to explain these inefficiencies, in particular type of tenure and LFA status seem the most prominent in determining efficiency growth.

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