Efficiency of Scottish Farms: A Stochastic Cost Frontier Analysis[1]

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Abstract

In this paper the relative cost efficiency of Scottish farms is determined, and variables that explain this efficiency by farm type are identified and implications discussed. A panel dataset from the Farm Accounts Scheme (FAS) survey for the period 1997-2004 was used for the estimation. A cost efficiency indicator was measured using a fixed effect panel data regression. Further analysis, to explain the efficiency results, indicated the presence of important farm size and regional effects. However, other variables, whilst statistically significant, did not produce a consistent effect across the different farm types.

Keywords: *Stochastic cost frontier analysis, cost efficiency, Scottish farms, Common Agricultural Policy*

JEL Classification: Q12

Introduction

For almost half a century, the European Union's (EU) Common Agricultural Policy (CAP) supported increases in farm production with great success. Eventually, however, unacceptable levels of overproduction, budget cost pressures, accusations of excessive market protection and distortion, and expansion of the EU, along with concerns about the environmental impact of agricultural intensification, all contributed to growing support for fundamental reform of the CAP.

The new agricultural policy measures adopted by EU farm ministers in 2003, seek to reform the CAP in ways that will enable EU farmers and their businesses to become more market orientated. One of the possible areas of adjustment is related to input use. This poses two questions that this paper tries to answer: first, how heterogeneous are Scottish farms in terms of their efficiency with respect to input use (i.e., cost efficiency) and second, if such heterogeneity exists, what are its causes?

Most farm efficiency estimates for the UK are for England and Wales (Dawson, 1985; Wilson et al., 1998; Wilson et al. 2001; Thirtle and Holding, 2003; Hadley, 2006). In the case of Scottish agriculture, Santarossa (2003) and Barnes (2005) used

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stochastic production frontiers to investigate efficiency using similar explanatory variables, but producing different results regarding farm size.

The purpose of this paper is to construct efficiency indicators for Scottish agriculture by farm type using a stochastic cost frontier approach that recognises the multi-output nature of farming, and offers certain advantages over the stochastic production frontier approach.[2] The paper starts by outlining the dataset used for the analysis and then describes the cost frontier estimation procedure. Thereafter, the cost efficiency results by farm type are presented, followed by an analysis of their determinants. The paper ends with a set of concluding remarks.

Measurement of Relative Cost Efficiency in Scotland

This section starts by presenting the data available to estimate the cost efficiency indices and then sets out the methodology used for computing these indices.

Data used for the estimation

The data used in the analysis are from Scotland's Farm Accounts Scheme (FAS), which annually records financial and non-financial data for a selection of full-time farms across Scotland. The dataset covers the eight year period of 1997/98 to 2004/5 (i.e., the crop years of 1997 to 2004). The criteria used to select the farms were that they should be present in the 2004/05 survey, and also that they were in the sample for at least five years. This resulted in an unbalanced panel dataset of 358 individual farms. Table 1 summarises this sample by farm types and their respective main outputs.

Table 1. Summary of sample by farm type

Farm type group	*Number of farms in the sample*	*Main outputs*
Dairy	50	Milk, cattle
Specialist sheep 1/	31	Sheep, cattle
Cattle and sheep	58	Cattle, sheep, cereals
Cereals and general cropping	65	Cereals
Mixed	154	Cereals, cattle, sheep
Total	358	

Source: **Derived from FAS data**
Notes: 1/ Specialist sheep farms are all located in less favoured areas (LFA). However, other farm types include farms in both the LFA and non-LFA.

Costs and outputs by farm type were computed directly from the FAS data. Costs were allocated to one of four groups: materials (e.g., feed, fertiliser); purchased services (e.g., contract work, crop protection costs); labour (e.g., all labour used including that of the farmer, farm family, business partners and hired workers); and capital (e.g., rent and depreciation). The outputs considered were cereals, potatoes, oilseed rape, cattle, sheep, milk and milk products, wool and eggs.[3] Input price data for the United Kingdom were used for agricultural materials, services and capital, as an estimate of those prices paid by FAS farmers over the study period (Defra, 2006). The labour input price was estimated from FAS data.

Cost frontier estimation

The use of a stochastic frontier analysis is motivated by the fact that it incorporates random errors, thereby avoiding their inclusion as elements of inefficiency. In addition, it may be the most appropriate choice in agricultural applications, where random errors due to weather, disease and pest infestation are likely to be significant (Coelli, Rao and Battese, 1998).

The approach followed in this paper follows a two-stage process consisting of, first, deriving efficiency measures and, second, analysing those variables which seemed to explain the relative distribution of efficiency amongst farms.

Data availability played an important role in our choice of methodology for estimating cost efficiency indices. The maximum number of periods available in our panel was 8 years (80 per cent of the sample), whilst 8 per cent of the sample had 6 consecutive years or less. Therefore, we chose to estimate a stochastic cost frontier using a panel data fixed effects model (i.e., the within estimator, Hsiao, 1993), which considers inefficiency as time invariant (Kumbakhar and Knox Lovell, 2003). In addition, in order to test the presence of possible technical change, we included a quadratic trend in the cost equation. The trend variable took the value of one in 1997, two in 1998 and so forth.

The fixed effects stochastic cost frontier model can be written in the following way (Kumbakhar and Knox Lovell, 2003), where i denotes farms and t the periods:

$$\ln E_{it} = \ln C\left(Q_{it}, W_{it}, \tau_t; \Omega\right) + v_{it} + u_i \quad (1)$$

In equation (1) $\ln E_{it}$ is the logarithm of the observed expenditure, $\ln C\left(Q_{it}, W_{it}, \tau_t; \Omega\right)$ is the logarithm of the deterministic cost function that depends on the outputs Q_{it}, the input prices W_{it}, a deterministic trend, τ_t, to capture technological change, and a vector of parameters Ω. 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 time invariant inefficiency term u_i is positive.

The estimation of the stochastic cost frontier (i.e., $\ln C\left(Q_{it}, W_{it}, \tau_t; \Omega\right) + v_{it}$) and the inefficiency terms (i.e., u_i) requires the choice of a functional form for the deterministic part of the stochastic cost frontier (i.e., $\ln C\left(Q_{it}, W_{it}, \tau_t; \Omega\right)$). A generalised multiproduct translog cost function (Caves, Christensen and Tretheway, 1980) was selected because it imposes less a-priori restrictions than other functional forms commonly used for the task. In the context of multiproduct estimation, some outputs might not be present on a farm, and therefore the logarithm used in the translog function will produce an error. Instead, they propose the use of a Box-Cox transformation to substitute for the logarithm of the output terms. Thus, for the case of n inputs and m outputs, and naming $\mathrm{f}(\cdot)$ as the Box-Cox transformation with parameter λ[4], the cost function is given by:

$$\mathbf{ln} C\left(Q_{it}, W_{it}, \tau_t; \Omega\right) = \alpha_0 + \varphi_0 \tau_t + \varphi_0 \tau_t^2 + \sum_{j=1}^{n} \alpha_j \, \mathbf{ln} W_{jt} + \frac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} \, \mathbf{ln} W_{jt} \, \mathbf{ln} W_{kt} +$$

$$+\frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{n}\delta_{jk}f(Q_{jit})\ln W_{kt}+\sum_{j=1}^{m}\gamma_j f(Q_{jit})+\frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{m}\rho_{jk}f(Q_{jit})\times f(Q_{kit}) \qquad (2)$$

Price homogeneity and symmetry were directly imposed in (2) through the following restrictions to the parameters (3):

$$\sum_{j=1}^{n}\alpha_j=1;\ \sum_{j=1}^{n}\delta_{jk}=0;\ \sum_{j=1}^{n}\beta_{jk}=0;\ \sum_{k=1}^{n}\beta_{jk}=0;\ \sum_{j=1}^{n}\sum_{k=1}^{n}\beta_{jk}=0;\beta_{jk}=\beta_{kj} \qquad (3)$$

Prices were introduced assuming that all the farmers face the same input prices within a year (i.e., across farms), but that prices change over time. Furthermore, the parameters associated with input prices were estimated from the cost share equations. Then, the equation to be estimated is presented in (4), where the intercept in (4) is $\alpha_{0i}=\alpha_0+u_i$.

$$\ln E_{it}=\alpha_{0i}+\varphi_0\tau_t+\varphi_0\tau_t^2+\sum_{j=1}^{n}\alpha_j\ln W_j+\frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n}\beta_{jk}\ln W_j\ln W_k+\frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{n}\delta_{jk}f(Q_{jit})\ln W_k$$
$$+\sum_{j=1}^{m}\gamma_j f(Q_{jit})+\frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{m}\rho_{jk}f(Q_{jit})\times f(Q_{kit})+v_{it} \qquad (4)$$

Equation (4) was estimated for four inputs (i.e., n) and a maximum of eight outputs (i.e., m). Given the high number of parameters to be estimated (i.e., 97 parameters in the maximum case) and the fact that the Box-Cox transformation added a non-linear component to the estimation, the following econometric procedure was employed.

First, the Box-Cox parameter λ was estimated through a grid-search routine. For each given value of λ, the log-likelihood of the system of $(n-1)$ cost shares was computed, using iterative Seemingly Unrelated Regression Equations (SURE) imposing the constraints in (3). This produced a relationship between log-likelihoods and alternative values of λ, from which the λ with the maximum log-likelihood value was selected. This step also provided the values for all the terms in (4) that were associated to input prices.

Second, all the remaining parameters -except the fixed effect terms- of the cost function, i.e., output terms not associated with prices, were estimated using the within estimator (ordinary least square applied to the variables expressed as deviations of the means by farm, Hsiao, 1993).

Finally, the fixed effect terms used in the construction of the relative cost efficiency indices were estimated from equation (4) by evaluating the function at the mean value of the variables by farm (Kumbakhar and Lovell, 2003). The estimated equations are presented in Table A.1 in the Annex.[5]

As shown in Kumbhakar and Knox-Lovell (2003), the relative cost efficiency index (CEI_i) for a sample size N was computed as (5) based on the estimated fixed effect intercepts (i.e., $\hat{\alpha}_{0i}$), where for the most cost efficient producers it has a value equal to one:

$$CEI_i = \exp\left\{-\left(\hat{\alpha}_{0i} - \min_i\left\{\hat{\alpha}_{0i}\right\}\right)\right\} \qquad i = 1,\ldots,N \tag{5}$$

Relative cost efficiency results

The distribution of individual farm, cost efficiency levels by farm type are shown in Figures 1a to 1e. All are skewed to the right, having a higher mean than median cost efficiency level.

The mean value of the relative cost efficiency indices for a farm type can give an indication of how dispersed the farms are in terms of cost efficiency. Thus a low mean value indicates that most of the farms are relatively distant (in terms of cost efficiency) from the most efficient farmer of the farm type group.

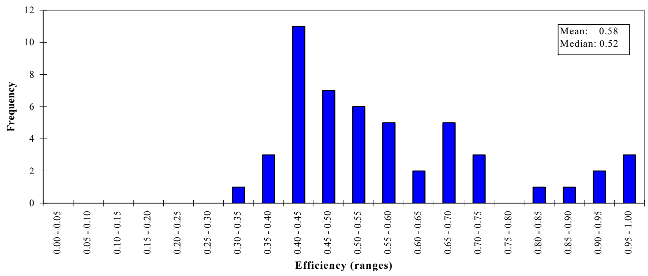

Figure 1a: Distribution of relative cost efficiency for dairy farms (50 farms)

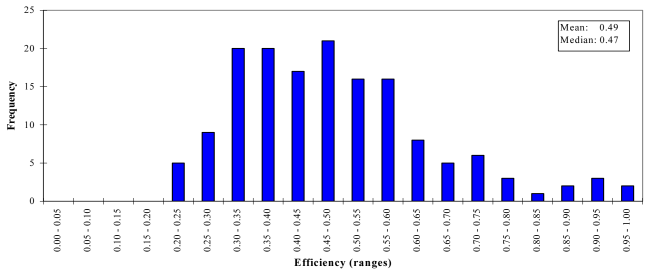

Figure 1b: Distribution of relative cost efficiency for mixed farms (154 farms)

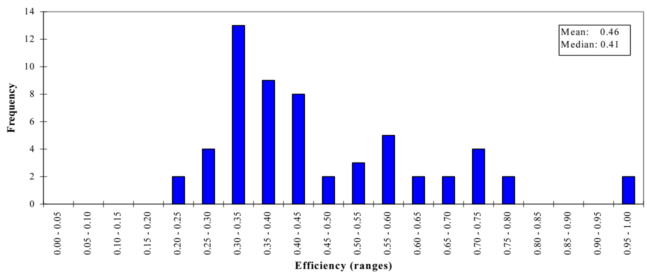

Figure 1c: Distribution of relative cost efficiency for cattle and sheep farms (58 farms)

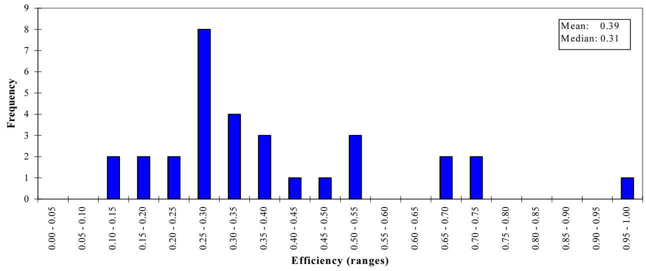

Figure 1d: Distribution of relative cost efficiency for specialist sheep farms (31 farms)

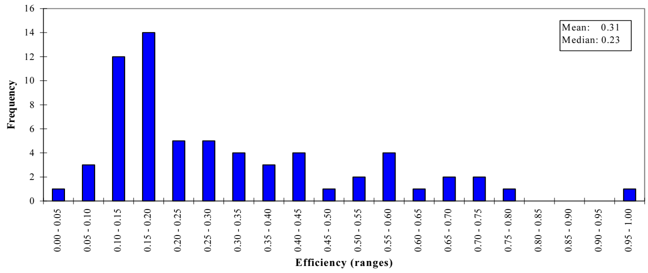

Figure 1e: Distribution of relative cost efficiency for cereals and general cropping farms (65 farms)

The highest mean (also median) of the relative cost efficiency estimates was apparent for dairy farms (mean of 0.58). Dairy farms are thus generally closer in terms of efficiency to the most efficient dairy farm, than is the case for the other farm type groups. This can also be seen in Figures 1a to 1e, where the lowest band of efficiency index is in the range of 0.3 to 0.35 for dairy farms and below this level for other farm type groups.

The intermediate situation with respect to relative cost efficiency levels is achieved by mixed farms and cattle and sheep farms, with mean indices of 0.49 and 0.46 respectively, see Figures 1b and 1c. However, the distribution for cattle and sheep has a more distinct modal band (i.e., the range encompassing the most typical value) of 0.3 to 0.35, whilst that for mixed farms is less pronounced and is in the range of 0.3 to 0.6.

At the lower end of the efficiency spectrum are specialist sheep, and cereal and general cropping farms, with mean cost efficiency indices of 0.39 and 0.31 respectively, see Figures 1d and 1e. It is interesting to note that in both cases the value of the median is far below that of the mean (the median for the cereal and general cropping farms is 0.23, whilst for the specialist sheep group it is 0.31), indicating that a large part of the group has low efficiency scores. This is also reflected in the coefficient of variation (i.e., mean to standard deviation ratio) of both groups, which are equal to 68.7 per cent for the former and 52.4 for the latter. Furthermore, the cereals and general cropping group has a mode that is quite low (in the range of 0.15 to 0.2 as shown in 1e), whilst the mode for specialist sheep is between 0.25 and 0.3 (see Figure 1d).

Overall, these findings indicate a wide spread in the cost efficiency of Scottish farms and that there is considerable scope for efficiency improvement. Those sectors which have had high levels of direct subsidy, such as cereals, general cropping, and specialist sheep (cereals, general cropping, and LFA sheep farms had direct subsidies during the 2003/04 crop year equal to 225 per cent (cereals), 130 per cent (general cropping), and 248 per cent (LFA specialist sheep) of Net Farm Income (NFI), respectively),[6] appear to have experienced the greatest levels of relative inefficiency. In contrast, the dairy sector, where direct subsidies represented 60 per cent of NFI in 2003/04, has had relatively less of an inefficiency problem. It should be noted, however, that not all farms can achieve the efficiency levels of the most efficient, because of differences in their resource attributes and the business objectives of their owners / managers.

Explaining cost efficiency in Scotland

The purpose of this section is to identify and analyse those variables that may explain the relative cost efficiency results. A database of possible explanatory variables, based on the literature, was constructed.[7] Table 2 provides a description of the variables used in the analysis, whilst Table A.2 in the Annex presents their descriptive statistics.

The variables were grouped according to different categories: farm size, region, less favoured area status, tenure, production diversification, contracting and participation in associations, financial situation and farmers' personal characteristics. Linear regressions were estimated between the cost efficiency indicators by farm type and the possible explanatory variables. The results are presented in Table 3.

The first point to note from Table 3 is that each farm type has a different set of explanatory variables. Despite several of these variables being statistically significant, they change their signs across farm types (non significant variables were excluded from the final regressions). It may be that their effects are either moderated by unobserved influences, or they are restricted to a specific farm type.

As shown in Table 3, four of the farm types (dairy, cereals and general cropping, cattle and sheep and mixed farms) have strong farm size effects. Small farms exhibit greater efficiency than medium or large farms. These results coincide with those obtained by Barnes (2005) for Scotland using a stochastic production frontier approach. The reason for greater efficiency of the small farms in this sample is not known but it may be associated with a greater flexibility in resource allocation particularly at times of peak demand.

A regional effect was identified for all farm types. Dairy and cereal and general cropping farms in the Northeast and Southeast showed higher efficiency than in other regions. The opposite effect was observed for cattle and sheep, specialist sheep and mixed farms in the Southwest, which showed lower efficiency. This result tends to conform with the observation that more productive and versatile land exists in the Northeast and Southeast of Scotland (SEERAD 2006).

The relationship between cost efficiency and land quality, as defined by LFA (Less Favoured Area) classification, is more complex. For most farm types, farms which are either wholly non-LFA or wholly LFA show a positive effect on cost efficiency relative to those farms that have mixed areas (both LFA and non LFA). This possibly indicates that production on more homogeneous land is easier to manage and thereby more efficient. The positive relationship found between LFA status and efficiency is similar to that reported in Scotland by Santarossa (2003). Moreover, our result of a strong negative effect of LFA status on efficiency for specialist sheep farms was also reported by Barnes (2005).

Table 2. Definition of the variables used in the analysis

Farm Size
Medium - takes the value of 1 if the farm is medium size, 0 otherwise. Large - takes the value of 1 if the farm is large size 0, otherwise.
Region
Northeast - takes the value of 1 if the farm is in the Northeast, 0 otherwise. Southeast - takes the value of 1 if the farm is in the Southeast, 0 otherwise. Southwest - takes the value of 1 if the farm is in the Southwest, 0 otherwise.
Less Favoured Area (LFA)
Farmland is not in LFA - takes value of 1, 0 otherwise. Farmland is totally in LFA - takes value of 1, 0 otherwise.
Tenure
Farmer is the owner - takes value of 1, 0 otherwise. Farmer is a tenant - takes value of 1, 0 otherwise. If the farmer has a family partnership - takes value of 1, 0 otherwise.
Productive Diversification
Diversification index (Herfindahl index based on share of revenues). Specialisation - takes the value of 1 if one of the outputs explains more than 70 percent of the total income. Number of farm outputs (number from 1 to 8).
Contracting and Participation in Co-operatives
If has a production contract - takes value of 1, 0 otherwise. Farm is part of a group or co-operative - takes value of 1, 0 otherwise. Farm participates in a marketing group - takes value of 1, 0 otherwise. The farm uses productive services from group - takes value of 1, 0 otherwise.
Financial Situation
Total indebtedness to net worth (ratio of all farm debts, i.e., short, medium and long term, to farm net worth).
Farmer's Personal Characteristics
Farmer's age. Education (categorical). Farmer possesses agricultural education - takes value of 1, 0 otherwise. Farm has a personal computer (PC) - takes value of 1, 0 otherwise. Farm uses PC for business - takes value of 1, 0 otherwise. Farm uses PC for specialised enterprises - takes value of 1, 0 otherwise. Farmer uses Internet - takes value of 1, 0 otherwise. Farmer uses Internet for business - takes value of 1, 0 otherwise.

Tenure variables showed a mixed effect on efficiency, as they were not significant for all of the farms types and their signs changed from one farm type to another. This lack of consistency is also reflected in a variety of studies (Thirtle and Holding, 2003; Barnes, 2005).

Table 3. Regressions Explaining Relative Cost Efficiency by Farm Type

Variables 1/	Farm Types														
	Dairy			Cereals and General Cropping			Cattle and Sheep			Specialist Sheep			Mixed Farms		
	Coeffi-cient	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*
Number of observations	50			65			58			31			154		
Adjusted R^2	0.778			0.759			0.641			0.780			0.545		
Intercept	0.790	4.971	0.000	0.379	4.511	0.000	0.578	15.233	0.000	1.708	11.075	0.000	0.698	20.830	0.000
Farm Size															
Medium (d)	-0.334	-9.310	0.000	-0.299	-6.269	0.000	-0.221	-7.935	0.000	--	--	--	-0.157	-9.537	0.000
Large (d)	-0.456	-10.841	0.000	-0.365	-7.785	0.000	-0.254	-4.817	0.000	--	--	--	-0.209	-8.076	0.000
Region															
Northeast (d)	0.096	2.482	0.018	0.071	1.657148	0.104	--	--	--	--	--	--	--	--	--
Southeast (d)	0.216	9.739	0.000	0.046	1.618	0.112	--	--	--	--	--	--	--	--	--
Southwest (d)	--	--	--	--	--	--	-0.051	-1.951	0.057	-0.258	-5.024	0.000	-0.092	-5.145	0.000
Less Favoured Area (LFA)															
Farmland is not in LFA (d)	0.063	2.504	0.017	0.078	2.379	0.022	0.190	1.778	0.082	--	--	--	0.061	1.843	0.067
Farmland is totally in LFA (d)	0.096	3.973	0.000	0.174	5.455	0.000	0.086	2.370	0.022	-0.529	-10.271	0.000	--	--	--
Tenure															
Farmer is the owner (d)	--	--	--	--	--	--	--	--	--	0.145	3.308	0.005	--	--	--
Farmer is a tenant (d)	--	--	--	0.092	4.514	0.000	--	--	--	0.224	8.425	0.000	--	--	--
If the farmer has a family partnership (d)	0.113	4.419	0.000	--	--	--	-0.050	-1.751	0.086	-0.135	-3.505	0.003	-0.047	-2.702	0.008
Productive Diversification															
Diversification index (Her-findahl index)	0.341	2.267	0.030	--	--	--	--	--	--	--	--	--	--	--	--
Specialisation (d)	-0.144	-4.598	0.000	--	--	--	--	--	--	--	--	--	--	--	--
Number of farm outputs (1 to 8)	0.029	1.756	0.088	-0.015	-1.981	0.054	--	--	--	-0.166	-6.421	0.000	-0.022	-2.170	0.032

Variables 1/	Farm Types														
	Dairy			**Cereals and General Cropping**			**Cattle and Sheep**			**Specialist Sheep**			**Mixed Farms**		
	Coeffi-cient	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*	*Coeffi-cient*	*t-statistic*	*Signifi-cance*
Contracting and Participation in Co-operatives															
If has a production contract (d)	--	--	--	0.152	3.346	0.002	--	--	--	--	--	--	-0.121	-2.533	0.012
Farm is part of a group or co-operative (d)	--	--	--	-0.023	-3.900	0.000	--	--	--	--	--	--	--	--	--
Farm participates in a marketing group (d)	--	--	--	--	--	--	0.101	2.921	0.005	-1.495	-4.836	0.000	--	--	--
The farm uses productive services from group (d)	--	--	--	0.066	1.902	0.063	--	--	--	--	--	--	-0.052	-3.046	0.003
Financial Situation															
Total indebtedness to net worth (ratio)	--	--	--	-0.082	-2.411	0.020	--	--	--	--	--	--	0.023	1.941	0.054
Farmer's Personal Characteristics															
Farmer's age	-0.004	-3.800	0.001	0.002	1.816	0.076	--	--	--	-0.003	-2.061	0.057	--	--	--
Education (categorical)	--	--	--	0.015	1.911	0.062	--	--	--	-0.057	-3.667	0.002	--	--	--
Farmer possesses agricultural education (d)	--	--	--	-0.119	-3.801	0.000	0.078	2.583	0.013	-0.187	-4.448	0.001	0.043	1.761	0.080
Farm has a personal computer (PC) (d)	--	--	--	--	--	--	--	--	--	0.227	4.600	0.000	-0.054	-2.960	0.004
Farm uses PC for business (d)	0.229	7.336	0.000	-0.119	-3.776	0.000	--	--	--	1.605	4.358	0.001	--	--	--
Farm uses PC for specialised enterprises (d)	0.071	1.809	0.079	--	--	--	--	--	--	-0.510	-3.439	0.004	--	--	--
Farmer uses Internet (d)	--	--	--	--	--	--	--	--	--	-0.243	-4.434	0.001	--	--	--
Farmer uses Internet for business (d)	-0.291	-7.071	0.000	0.081	3.265	0.002	-0.070	-2.706	0.009	-1.683	-4.507	0.000	--	--	--

Notes: -- stands for either not applicable or not significant. Errors computed using a heteroskedasticity-consistent, variance-covariance matrix
1/ (d) stands for dichotomous variable.

With respect to product diversification, the diversification index and the specialisation variable were only significant in the case of dairy farms and indicated that the higher the specialisation level (i.e., the fewer the outputs produced by the farm), the lower the relative cost efficiency. Thirtle and Holding (2003) reported similar findings for England and Wales across all farm types. Hadley (2006) found for England and Wales that those farms that were more specialised in one enterprise were consistently less efficient than farms that were less specialised. In the case of cattle and sheep there was no statistically significant relationship and in all the other cases (cereals and general cropping, specialist sheep and mixed farms) the effect of diversification was negative, indicating a positive effect of specialisation on efficiency, a finding also reported for Scotland by Santarossa (2003).

The contracting and participation in co-operatives variables suffer from the problem that they are represented by only a few cases, and this is probably the reason why they give rise to contradictory responses across farm types.

Financial variables have been used in other studies for Scotland (Santarossa, 2003 and Barnes, 2005). The 'degree of indebtedness' ratio is used here as an approximation of financial health. The results obtained, as reported in the literature, are mixed; they appear negative in the case of cereals and general cropping, but positive for mixed farms.

Among personal characteristics, we considered the farmer’s age, education, agricultural education, presence and use of a computer, and presence and use of the internet. Despite the fact that the mean age of all the groups was very similar (around 55 years old), age showed a negative effect on efficiency in the case of dairy farms and specialist sheep farms, but positive for cereals and general cropping farms. The level of education showed a positive effect for cereals and general cropping farms, but negative in the case of specialist sheep farms. Similar results were obtained for agricultural education, which was only positive for cattle and sheep farms and for mixed farms. The use of a personal computer (PC) for business had mixed results.

Conclusions

The profiles of relative cost efficiency produced for each farm type indicate a wide variation in the cost efficiency levels achieved within and between farm type groups. Moreover, those sectors that have been most heavily supported by direct subsidies at the farm level, exhibit the greatest variation in cost efficiency performance.

Further analysis of the efficiency results indicates the presence of important farm size and regional effects, and for some farms the eventual reaction to CAP reform may be an increase in scale. However, the analysis here suggests that an increase in scale by itself may not achieve cost efficiency improvements. It is suggested that it will need to be matched by improved resource utilisation, and improved production management and marketing practices. It is important to note that the selected variables seem to explain the achievement of cost efficiency across the farm types, and therefore their effects can only be associated with particular farm types.

Notes

1 This paper derives from a Scottish Executive Environment and Rural Affairs Department (SEERAD) funded project on the implications of CAP reform (IMCAPT) (SAC, 2006), conducted between April 2004 and June 2006. The first three authors are members of the Scottish Agricultural College's (SAC) Land Economy Research Group and Dr. Woong J. Cho is a member of the Korean Food Research Institute.

2 The efficiency estimation could have also been undertaken using the output distance-function. However, we considered that the use of a cost function had, in our case, two advantages with respect to such an approach. First, the output-distance function is a generalisation of a production function and therefore it only measures technical efficiency, i.e., no effects of input or product prices are considered. The cost function approach allowed us to introduce the effect of input prices. Second, our data present expenditure on the different inputs and therefore it is straightforward to formulate the cost function estimation.

3 The sample farms produced minimal quantities of pigs, poultry and vegetables.

4 The Box-Cox transformation with parameter λ is given by: $f(x) = \begin{cases} \frac{x^{\lambda} - 1}{\lambda} & \lambda \neq 0 \\ \log(x) & \lambda = 0 \end{cases}$

5 We tested share positiveness and negative semifiniteness of the cost functions. All the predicted cost shares were positive and the negative semidefiniteness of the Hessian matrices was satisfied for most of the points of the sample.

6 In 2004/05 subsidies as a percentage of NFI increased substantially to 2,510 per cent for cereals, 790 per cent for general cropping and 300 per cent for LFA specialist sheep.

7 Dawson, 1985; Wilson, Hadley and Asby, 2001; Thirtle and Holding, 2003; Santarossa, 2003; Barnes, 2005; and Hadley, 2006.

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Appendix

Table A.1 Cost Functions by Farm Type

Variables	Farm type														
	Dairy			**Cereals and General Cropping**			**Cattle and Sheep**			**Specialist Sheep**			**Mixed Farms**		
	Coeffi-cient	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*
Observations	395			487			444			243			1188		
Number of Farms	50			65			58			31			154		
Hessian 3/	87.3			95.9			100.0			100.0			100.0		
Cost shares 4/	100.0			100.0			100.0			100.0			100.0		
Adjusted R^2	0.980			0.975			0.975			0.973			0.971		
Log likeli-hood	564.2			381.7			507.4			242.6			1294.1		
Box-Cox λ	0.550000			0.150000			0.150000			0.650000			0.400000		
Trend	-0.027213	0.005862	**	-0.010648	0.010256		-0.003882	0.007551		0.011762	0.011508		0.002612	0.004822	
Squared trend	0.002064	0.000634	**	-0.000160	0.001095		0.000752	0.000807		-0.001644	0.001244		-0.000051	0.000517	
W_1	0.213710	0.014505	**	0.188580	0.004384		0.198880	0.021029	**	0.200470	0.013769	**	0.198220	0.007418	**
W_1W_1	0.147470	0.031209	**	0.073537	0.020254	**	0.034131	0.034705		0.060874	0.051865		0.050148	0.023501	**
W_1W_2	-0.004703	0.022706		-0.063699	0.021393	**	0.019953	0.022854		-0.001699	0.032558		-0.030406	0.019273	
W_1W_3	-0.098141	0.018741	**	-0.032134	0.009275	**	-0.124070	0.022019	**	-0.030048	0.022661		-0.086150	0.013048	**
W_1W_4	-0.044624	0.029075		0.022296	0.017807	**	0.069982	0.029315	**	-0.029128	0.046557		0.066407	0.020131	**
$W_1f(Q_1)$	-0.000265	0.000190		-0.000015	0.000192		-0.000221	0.000489		0.000523	0.001237		0.000598	0.000195	**
$W_1f(Q_2)$	-0.006956	0.004781		0.000428	0.000254								-0.000720	0.000982	
$W_1f(Q_3)$	0.003199	0.003518		0.000674	0.000456								-0.001426	0.000988	
$W_1f(Q_4)$	0.000222	0.000482		0.005501	0.000300		0.018943	0.002733	**	0.001455	0.000436	**	0.002702	0.000494	**
$W_1f(Q_5)$	0.000631	0.000344		0.000289	0.000315	**	-0.001155	0.001387		0.000125	0.000105		0.000947	0.000309	**
$W_1f(Q_6)$	0.000423	0.000052	**	0.001323	0.000079		0.003944	0.000740	**				0.001007	0.000176	**
$W_1f(Q_7)$	-0.000378	0.000255		-0.000149	0.000263	**	-0.001871	0.001254		-0.000216	0.000077	**	-0.000230	0.000245	

Variables	Farm type														
	Dairy			Cereals and General Cropping			Cattle and Sheep			Specialist Sheep			Mixed Farms		
	Coeffi-cient	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*
$W_1f(Q_8)$	0.000006	0.000062		-0.000133	0.000226		-0.000472	0.001490							
W_2	0.072863	0.006863	**	0.117080	0.003409		0.089812	0.009192	**	0.063117	0.005797	**	0.087855	0.003895	**
W_2W_1	-0.004703	0.022706		-0.063699	0.021393	**	0.019953	0.022854		-0.001699	0.032558		-0.030406	0.019273	
W_2W_2	0.052992	0.040033		0.095016	0.038286	**	-0.075899	0.041273		-0.119390	0.056516	**	0.083258	0.034202	**
W_2W_3	0.002509	0.010984		-0.036073	0.007978	**	0.037834	0.011618	**	0.020916	0.010337	**	-0.029353	0.008158	**
W_2W_4	-0.050798	0.023083	**	0.004756	0.022070	**	0.018112	0.022378		0.100170	0.034379	**	-0.023500	0.018927	
$W_2f(Q_1)$	0.000508	0.000090	**	0.002310	0.000147		0.001441	0.000213	**	0.003340	0.000511	**	0.001376	0.000102	**
$W_2f(Q_2)$	0.004808	0.002257	**	0.001122	0.000195	**							0.001271	0.000514	**
$W_2f(Q_3)$	0.004191	0.001658	**	0.002172	0.000350	**							0.001571	0.000517	**
$W_2f(Q_4)$	-0.000939	0.000228	**	-0.000792	0.000230	**	-0.001320	0.001192		0.000404	0.000180	**	0.000220	0.000259	
$W_2f(Q_5)$	-0.000299	0.000163		-0.000709	0.000242	**	-0.000636	0.000606		-0.000085	0.000044		-0.000490	0.000162	**
$W_2f(Q_6)$	0.000121	0.000025	**	-0.000533	0.000061	**	-0.000841	0.000325	**				-0.000164	0.000092	
$W_2f(Q_7)$	0.000210	0.000120		-0.000412	0.000202	**	-0.000050	0.000547		0.000059	0.000032		0.000072	0.000129	
$W_2f(Q_8)$	-0.000037	0.000029		-0.000570	0.000173	**	0.000462	0.000649							
W_3	0.408820	0.015924	**	0.338470	0.004885	**	0.316560	0.024471	**	0.363930	0.012772	**	0.397970	0.008227	**
W_3W_1	-0.098141	0.018741	**	-0.032134	0.009275	**	-0.124070	0.022019	**	-0.030048	0.022661		-0.086150	0.013048	**
W_3W_2	0.002509	0.010984		-0.036073	0.007978	**	0.037834	0.011618	**	0.020916	0.010337	**	-0.029353	0.008158	**
W_3W_3	0.085975	0.023574	**	0.106400	0.011608	**	0.116410	0.028388	**	0.117220	0.024401	**	0.150440	0.016261	**
W_3W_4	0.009658	0.021186		-0.038195	0.010507	**	-0.030177	0.021398		-0.108090	0.021756	**	-0.034938	0.014060	**
$W_3f(Q_1)$	-0.000613	0.000209	**	-0.003284	0.000226	**	-0.002001	0.000573	**	0.000376	0.001273		-0.002688	0.000220	**
$W_3f(Q_2)$	-0.000815	0.005243		0.000149	0.000299	**							0.001225	0.001110	
$W_3f(Q_3)$	-0.004003	0.003862		-0.002916	0.000537								0.001548	0.001117	
$W_3f(Q_4)$	0.000057	0.000527		-0.002434	0.000353	**	-0.007919	0.003202	**	-0.001254	0.000448	**	-0.006096	0.000559	**
$W_3f(Q_5)$	-0.000063	0.000378		-0.000013	0.000370	**	-0.000341	0.001621		0.000241	0.000103	**	-0.000460	0.000349	
$W_3f(Q_6)$	-0.000630	0.000058	**	-0.000717	0.000093		-0.002277	0.000867	**				-0.000203	0.000198	
$W_3f(Q_7)$	-0.000217	0.000280		0.000365	0.000309	**	0.002028	0.001468		-0.000124	0.000077		0.000474	0.000277	
$W_3f(Q_8)$	-0.000018	0.000068		0.001151	0.000266		-0.001978	0.001745							
W_4	0.304600	0.014888	**	0.355870	0.004918	**	0.394750	0.020020	**	0.372490	0.013231	**	0.315960	0.007661	**
W_4W_1	-0.044624	0.029075		0.022296	0.017807	**	0.069982	0.029315	**	-0.029128	0.046557		0.066407	0.020131	**
W_4W_2	-0.050798	0.023083	**	0.004756	0.022070		0.018112	0.022378		0.100170	0.034379	**	-0.023500	0.018927	
W_4W_3	0.009658	0.021186		-0.038195	0.010507		-0.030177	0.021398		-0.108090	0.021756	**	-0.034938	0.014060	**

Variables	Farm type														
	Dairy			Cereals and General Cropping			Cattle and Sheep			Specialist Sheep			Mixed Farms		
	Coeffi-cient	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*
W_4W_4	0.085764	0.037821	**	0.011144	0.023943	**	-0.057917	0.034301		0.037046	0.053690		-0.007970	0.025136	
$W_4f(Q_1)$	0.000370	0.000196		0.000989	0.000216		0.000780	0.000462		-0.004239	0.001194	**	0.000714	0.000202	**
$W_4f(Q_2)$	0.002963	0.004928		-0.001699	0.000286	**							-0.001776	0.001016	
$W_4f(Q_3)$	-0.003388	0.003625		0.000070	0.000515	**							-0.001692	0.001022	
$W_4f(Q_4)$	0.000660	0.000499		-0.002275	0.000338		-0.009704	0.002584	**	-0.000605	0.000421		0.003174	0.000512	**
$W_4f(Q_5)$	-0.000270	0.000355		0.000433	0.000356	**	0.002132	0.001316		-0.000281	0.000102	**	0.000003	0.000319	
$W_4f(Q_6)$	0.000086	0.000054		-0.000073	0.000089		-0.000826	0.000699					-0.000640	0.000182	**
$W_4f(Q_7)$	0.000385	0.000263		0.000196	0.000297		-0.000107	0.001187		0.000282	0.000074	**	-0.000316	0.000254	
$W_4f(Q_8)$	0.000048	0.000064		-0.000448	0.000255		0.001988	0.001409							
$f(Q_1)$	0.005153	0.001475	**	0.005193	0.002336		0.004063	0.004045		0.054488	0.008898	**	0.003847	0.002705	
$f(Q_2)$	0.012075	0.002011	**	-0.003129	0.002322	**							-0.001897	0.006860	
$f(Q_3)$	-0.012768	0.002083	**	-0.004009	0.004073								0.003042	0.005115	
$f(Q_4)$	0.000322	0.001152		-0.001733	0.004298		0.039044	0.013102	**	0.004533	0.001769	**	0.009009	0.002814	**
$f(Q_5)$	0.000007	0.000504		-0.001665	0.001253		0.000293	0.003395		0.000169	0.000354		0.004865	0.001073	**
$f(Q_6)$	0.000623	0.000391		-0.003290	0.001956		0.017419	0.003647	**				0.002063	0.000436	**
$f(Q_7)$	0.003631	0.000484	**	0.002871	0.001011		0.002018	0.002602		0.000980	0.000457	**	0.000527	0.001046	
$f(Q_8)$	-0.000308	0.000054	**	0.000270	0.000913	**	0.004221	0.001689	**						
$f(Q_1)f(Q_1)$	-0.000008	0.000070		-0.000156	0.000243		0.005013	0.001320	**	0.000001	0.000512		0.000722	0.000149	**
$f(Q_1)f(Q_2)$	-0.000453	0.000197	**	-0.000085	0.000052								0.000790	0.000353	**
$f(Q_1)f(Q_3)$	-0.000367	0.000054	**	0.000466	0.000122	**							-0.000295	0.000255	
$f(Q_1)f(Q_4)$	0.000008	0.000056		0.000223	0.000191		-0.001790	0.000808	**	-0.002972	0.001148	**	0.000130	0.000136	
$f(Q_1)f(Q_5)$	0.000055	0.000027	**	-0.000076	0.000105		0.000735	0.000369		0.000044	0.000053		-0.000002	0.000057	
$f(Q_1)f(Q_6)$	-0.000014	0.000008		-0.000064	0.000043		-0.001187	0.000397	**				-0.000103	0.000049	**
$f(Q_1)f(Q_7)$	-0.000056	0.000028		0.000057	0.000093		0.000129	0.000230		-0.000109	0.000038	**	-0.000003	0.000059	
$f(Q_1)f(Q_8)$	-0.000138	0.000075		-0.000989	0.000393	**	-0.000179	0.000277							
$f(Q_2)f(Q_2)$	0.003429	0.000571	**	-0.000138	0.000334								0.001815	0.000728	**
$f(Q_2)f(Q_3)$	0.001854	0.000866	**	-0.000855	0.000290	**							0.000366	0.001305	
$f(Q_2)f(Q_4)$	0.000235	0.000394		0.001087	0.000706								-0.000731	0.000518	
$f(Q_2)f(Q_5)$	0.000246	0.000107	**	0.000395	0.000449								-0.000145	0.000248	
$f(Q_2)f(Q_6)$	0.000024	0.000022		-0.000743	0.000225	**							-0.000818	0.000173	**
$f(Q_2)f(Q_7)$	-0.000212	0.000053	**	0.000383	0.000231								-0.000078	0.000092	

Variables	Farm type														
	Dairy			**Cereals and General Cropping**			**Cattle and Sheep**			**Specialist Sheep**			**Mixed Farms**		
	Coeffi-cient	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*	*Coefficient*	*Std. Error*	*Signif. 2/*
$f(Q_2)f(Q_8)$	0.000159	0.000029	**	0.000247	0.000293										
$f(Q_3)f(Q_3)$	0.006986	0.000941	**	-0.003019	0.001446	**							-0.000343	0.000852	
$f(Q_3)f(Q_4)$	0.000100	0.000129		0.001057	0.000787								0.000393	0.000367	
$f(Q_3)f(Q_5)$	0.000065	0.000274		0.000048	0.000354								-0.000130	0.000150	
$f(Q_3)f(Q_6)$	-0.000038	0.000007	**	-0.000587	0.000170	**							-0.000832	0.000172	**
$f(Q_3)f(Q_7)$	-0.001928	0.000264	**	-0.000435	0.000313								0.000294	0.000157	
$f(Q_3)f(Q_8)$	0.000186	0.000029	**	0.000163	0.000308										
$f(Q_4)f(Q_4)$	0.000125	0.000100		-0.000067	0.000609		0.001453	0.002546		0.000325	0.000207		0.000712	0.000321	**
$f(Q_4)f(Q_5)$	0.000040	0.000032		0.000698	0.000135	**	0.000578	0.000456		0.000019	0.000013		-0.000066	0.000088	
$f(Q_4)f(Q_6)$	0.000000	0.000007		0.000023	0.000102		-0.003612	0.001057	**				-0.000110	0.000053	**
$f(Q_4)f(Q_7)$	-0.000040	0.000026		-0.000464	0.000132	**	-0.002599	0.000482	**	-0.000038	0.000012	**	0.000008	0.000066	
$f(Q_4)f(Q_8)$	0.000024	0.000006	**	-0.000471	0.000266		-0.000064	0.000275							
$f(Q_5)f(Q_5)$	-0.000108	0.000022	**	-0.000533	0.000149	**	0.000003	0.000610		-0.000003	0.000002		0.000009	0.000048	
$f(Q_5)f(Q_6)$	0.000002	0.000005		0.000096	0.000033	**	0.000546	0.000171	**				0.000019	0.000036	
$f(Q_5)f(Q_7)$	0.000022	0.000012		-0.000113	0.000074		0.000030	0.000221		0.000001	0.000001		-0.000107	0.000033	**
$f(Q_5)f(Q_8)$	0.000134	0.000057	**	0.000413	0.000305		0.000263	0.000171							
$f(Q_6)f(Q_6)$	0.000006	0.000002	**	-0.000037	0.000046		0.003286	0.000791	**	-0.000002	0.000001	**	0.000054	0.000034	
$f(Q_6)f(Q_7)$	-0.000015	0.000004	**	-0.000059	0.000027	**	-0.000147	0.000124					-0.000052	0.000028	
$f(Q_6)f(Q_8)$	-0.000001	0.000001		-0.000018	0.000021		-0.001611	0.000268	**						
$f(Q_7)f(Q_7)$	-0.000020	0.000022		0.000334	0.000153	**	0.003730	0.000802	**				0.000141	0.000037	**
$f(Q_7)f(Q_8)$	-0.000361	0.000064	**	-0.000924	0.000274	**	-0.000420	0.000165	**						
$f(Q_8)f(Q_8)$	-0.000001	0.000000	**	0.000086	0.000083		-0.003554	0.001086	**						

Notes

1/ Q_1=cereals, Q_2=potatoes, Q_3=oilseed rape, Q_4=cattle, Q_5=sheep, Q_6=milk and products, Q_7=wool, Q_8=eggs, W_1=material price, W_2=services price, W_3=labour price, W_4=capital price. Prices are expressed in logarithm. Two consecutive variables such as f(Qi)f(Qj) indicate a variable made of the product of f(Qi) and f(Qj).

2/ ** denotes significantly different than zero at 5 per cent.

3/ Indicates the percentage of total number of observations that satisfies the semi-negative definiteness of the Hessian matrix.

4/ Indicates the percentage of the total number of observations that produce positive shares.

Table A.2 Descriptive Statistics of the Main Variables Used in the Analysis

Variables	Statistics			
	Mean	*St. Deviation*	*Minimum*	*Maximum*
Efficiency indices				
Dairy	0.57	0.17	0.33	1.00
Cereals and General Cropping	0.31	0.21	0.04	1.00
Cattle and sheep	0.46	0.18	0.22	1.00
Sheep specialist	0.39	0.20	0.12	1.00
Mixed farms	0.49	0.16	0.21	1.00
Farm Size				
Small (d)	0.47	0.50	0.00	1.00
Medium (d)	0.41	0.49	0.00	1.00
Large (d)	0.12	0.33	0.00	1.00
Region				
Northwest (d)	0.16	0.37	0.00	1.00
Northeast (d)	0.24	0.43	0.00	1.00
Southeast (d)	0.18	0.39	0.00	1.00
Southwest (d)	0.41	0.49	0.00	1.00
Less Favoured Area (LFA)				
Farmland is not in LFA (d)	0.23	0.42	0.00	1.00
Farmland is totally in LFA (d)	0.62	0.49	0.00	1.00
Tenure				
Farmer is the owner (d)	0.47	0.50	0.00	1.00
Farmer is a tenant (d)	0.24	0.43	0.00	1.00
If the farmer has a family partnership (d)	0.54	0.50	0.00	1.00
Productive Diversification				
Diversification index (Herfindahl index)				
Dairy	0.57	0.13	0.34	0.87
Cereals and General Cropping	0.64	0.25	0.00	1.00
Cattle and sheep	0.52	0.12	0.38	1.00
Sheep specialist	0.81	0.16	0.50	0.97
Mixed farms	0.63	0.19	0.29	1.00
Specialisation (d)				
Dairy	0.52	0.50	0.00	1.00
Cereals and General Cropping	0.52	0.50	0.00	1.00
Cattle and sheep	0.12	0.33	0.00	1.00
Sheep specialist	0.84	0.37	0.00	1.00
Mixed farms	0.53	0.50	0.00	1.00
Number of farm outputs				
Dairy	3.24	1.08	2.00	6.00
Cereals and General Cropping	2.48	1.28	0.00	6.00
Cattle and sheep	3.22	0.70	1.00	4.00
Sheep specialist	2.52	0.51	2.00	3.00
Mixed farms	2.99	1.06	1.00	5.00
Contracting and Participation in Co-operatives				
If has a production contract (d)	0.01	0.12	0.00	1.00
Farm participates in a marketing group (d)	0.02	0.14	0.00	1.00
The farm uses productive services from group (d)	0.23	0.42	0.00	1.00

Variables	Statistics			
	Mean	*St. Deviation*	*Minimum*	*Maximum*
Financial Situation				
Total indebtedness to net worth (ratio)	0.07	0.40	-5.09	4.06
Farmer's Personal Characteristics				
Farmer's age	56.78	11.05	32.00	83.00
Education (categorical)	2.32	1.39	1.00	7.00
Farmer possesses agricultural education (d)	0.19	0.40	0.00	1.00
Farm has a personal computer (PC) (d)	0.74	0.44	0.00	1.00
Farm uses PC for business (d)	0.61	0.49	0.00	1.00
Farm uses PC for specialised enterprises (d)	0.06	0.24	0.00	1.00
Farmer uses Internet (d)	0.68	0.47	0.00	1.00
Farmer uses Internet for business (d)	0.52	0.50	0.00	1.00

Notes: 1/ (d) stands for dichotomous variable.