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A STRUCTURAL CHANGE ANALYSIS OF THE COST EFFICIENCY OF FARMS IN SCOTLAND 1989-2008

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ABSTRACT

One of the aims of the reform of the Common Agricultural Policy (CAP) is to increase the competitiveness of farmers through increasing their exposure to markets. An aspect of competitiveness is the gains in economic efficiency. Thus, the purpose of this paper is to estimate indicators of farm efficiency for the period 1989 to 2008 by farm type and to analyse what the effect on efficiency of changes in the CAP has been. In terms of the methodology, the information used comes from the Scottish Farm Account Scheme (FAS) survey, which allows us to assemble panel dataset and to construct cost efficiency indicators. The results indicate while mixed farms and lowland farms have maintain their levels of efficiency. LFA farms have seen their efficiency reduced since approximately 2004 or 2005 (especially LFA sheep farm specialists). Also, the analysis shows that there seems to be an increase in the dispersion of farmers in terms of efficiency for some farm types in periods of change in agricultural policy.

KEYWORDS: Farm efficiency, stochastic cost frontier, Scottish agriculture.

1. Introduction

Since 1992 the European Common Agricultural Policy (CAP) has been in a process of reform, in order not only to reduce the budgetary outlays destined to agriculture but also to adapt the CAP in order to achieve tasks such as the promotion of rural development and improvement of the environmental conditions of rural areas. In addition, the reform of the subsidies regime towards one where payments are decoupled from production was aimed to push farmers to respond to market forces and to become more competitive. Therefore, there is the need to analyse the evolution of farm efficiency due to the impact of the policy reform which was implemented in Scotland in 2005.

In this context, the purpose of this paper is twofold: first, to estimate indicators of cost efficiency for Scottish agriculture for the period 1989 to 2008 by farm type and second, to analyse their trend, structural changes and efficiency dispersion amongst farms.

The structure of the paper is as follows: it starts presenting the constructed dataset, which is based on Scottish farms surveys from 1989 to 2008, next an overview of the methodology used is provided, followed by the analysis of the obtained results. Finally, we present some conclusions.

2. Data and methodology used in the cost efficiency estimation

This section starts with the description of the data used followed by a brief presentation of the estimation methodology.

2.1 Data and creation of variables

The Farm Accounts Scheme (FAS) annually records a wide range of financial and non-financial data for a selection of full-time farms across Scotland. It is part of the Farm Accounts Data Network, which monitors farm performance across the EU. The data used for our analysis cover the period of 1989/90 to 2008/09, which allows us to assemble an unbalanced panel of 10,245 observations. Table 1 summarises this sample by farm types. Eight farm types were considered in the estimation, namely: cereals, general cropping, dairy, Least Favoured Area (LFA) specialist sheep, LFA cattle, LFA cattle and sheep, lowland cattle and sheep and mixed farms. The FAS dataset does not include information on pigs, poultry or horticultural producers.

Table 1 - Sample by farm type

Farm types	Number of farms
Cereals	866
General cropping	1,066
Dairy	1,494
LFA specialist sheep	1,176
LFA cattle	2,067
LFA cattle and sheep	1,890
Lowland cattle and sheep	244
Mixed farms	1,442
Total	10,245

Source: Scottish Government

Costs and outputs by farm type were computed directly from the FAS data. Costs were allocated to one of five groups: materials (e.g., feed, fertiliser); energy (e.g., fuel and electricity used); labour (e.g., all labour used including that of the farmer, farm family, business partners and hired workers); land (e.g., rent) and capital (e.g., machinery, buildings). Due to the diversity of outputs, in contrast to our previous work (Revoredo-Giha et al., 2009) we decided to consider two aggregated outputs: output from crops and outputs from livestock, both were deflated using Defra's output price indices.

The estimation of cost functions requires input prices. However, a shortcoming of the FAS data for the estimation of cost functions (and also of other similar datasets such as the Farm Business Survey for England and Wales) is that it only presents input expenditures and not the prices paid for inputs (or quantities used). Therefore, Defra's input price data for the United Kingdom, with a base year of 2000, were used for agricultural materials (in this case a price weighted average of the materials used by the different farms was computed), energy and capital, as an estimate of those prices paid by FAS farmers over the study period (Defra, 2009). Labour and land input prices were estimated from FAS data.

2.2 Cost frontier methodology

Efficiency indicators were derived using a stochastic frontier analysis.[1] This is motivated by the fact that it incorporates random errors avoiding their inclusion as elements of inefficiency. Furthermore, this approach 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).

[1] A detailed literature review on stochastic frontier analysis can be found in Revoredo-Giha et al. (2009).

Berger et al. (1997) in their review of methods to estimate efficiency, suggested the use of profit efficiency (i.e., derived from a stochastic profit frontier analysis, see also Kumbhakar and Knox Lovell, 2003, chapter 5). However, in the context of EU agriculture, the presence of quotas (e.g., dairy quotas) generates problems for the estimation of profit functions. An alternative approach, used in this paper, is that of stochastic cost frontiers. This has the advantages that it can deal with farms producing multiple outputs, can consider the effect of input prices and it is not restricted by the constraints imposed by the Common Agricultural Policy (CAP).

The model to be estimated is shown in (1), where i denotes farms and t the periods:

$$(1) \quad \ln C_{it} = \ln C(Q_{it}, W_{it}, \tau_t; \Omega) + v_{it} + u_{it}$$

In equation (1) $\ln C_{it}$ is the logarithm of the observed cost, $\ln C(Q_{it}, W_{it}; \Omega)$ is the logarithm of the deterministic cost function that depends on the outputs Q_{it}, the input prices W_{it} and a vector of parameters Ω. To test the presence of possible technical change, we included a quadratic trend τ_t in the cost equation. The trend variable takes the value of one in 1989, two in 1990 and so forth. 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).[2]

The estimation of the stochastic cost frontier (i.e., $\ln C(Q_{it}, W_{it}, \tau_t; \Omega) + v_{it}$) and the inefficiency term (i.e., u_{it}) requires the choice of a functional form for the deterministic part of the stochastic cost frontier (i.e., $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$). A generalised multiproduct translog cost function (Caves, Christensen and Tretheway, 1980, Pulley and Braunstein, 1992) was selected because it imposes less apriori restrictions than other functional forms commonly used for the task. As explained by Caves, Christensen and Tretheway 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 not be defined. Instead, they propose the use of a Box-Cox transformation instead of the logarithm for the output terms. However, this choice is only one of the possibilities. Instead we use $f(Q_t) = Q_t$, which gives us a function that is a hybrid between the translog and the quadratic cost function. Thus, for the case of n inputs and m outputs the cost function is given by:

$$(2) \quad \ln C(Q_{it}, W_{it}; \Omega) = \alpha_0 + \varphi_0 \tau_t + \varphi_0 \tau_t^2 + \sum_{j=1}^{n} \alpha_j \ln W_{jt} + \frac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} \ln W_{jt} \ln W_{kt}$$
$$+ \frac{1}{2} \sum_{j=1}^{m} \sum_{k=1}^{n} \delta_{jk} Q_{jit} \ln W_{kt} + \sum_{j=1}^{m} \gamma_j Q_{jit} + \frac{1}{2} \sum_{j=1}^{m} \sum_{k=1}^{m} \rho_{jk} Q_{jit} \cdot Q_{kit}$$

[2] 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).

As the stochastic cost frontier is a cost function, it has to satisfy the properties of any cost function (Chambers, 1988). Price homogeneity and symmetry were directly imposed in (2) through the following restrictions to the parameters (3):

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

As previously noted, the dataset does not contain input prices for each farm. In the context of cross section estimation, the approach is to assume that all farmers face the same prices (e.g., Alvarez and Arias, 2003). However, for estimating a cost function using panel data it is possible to introduce prices, assuming that all the farmers face the same input prices within a year (i.e., across farms), but that prices change over time.[3] Then, the equation to be estimated is presented in (4):

$$(4)\quad \ln C_{it} = \alpha_0 + \varphi_0 \tau_t + \varphi_0 \tau_t^2 + \sum_{j=1}^{n} \alpha_j \ln W_j + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} \beta_{jk} \ln W_j \ln W_k + \frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{n} \delta_{jk} Q_{jit} \ln W_k$$
$$+ \sum_{j=1}^{m} \gamma_j Q_{jit} + \frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{m} \rho_{jk} Q_{jit} \cdot Q_{kit} + v_{it} + u_{it}$$

Equation (4) was estimated for five inputs (i.e., n) and two outputs (i.e., m). The estimation was carried by the maximum likelihood method, where the likelihood function is given by:

$$(5)\quad \ln L(y \mid \beta, \sigma, \lambda) = -\frac{N}{2}\ln\left(\frac{\pi\sigma^2}{2}\right) + \sum_{i=1}^{N} \ln \Phi\left(-\frac{\varepsilon_i \lambda}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_{i=1}^{N} \varepsilon_i^2$$

Where N is the number of observations, $\sigma^2 = \sigma_v^2 + \sigma_u^2$, $\lambda = \sigma_u^2 / \sigma_v^2$, $\varepsilon_i = \ln C_{it} - \ln C(Q_{it}, W_{it}, \tau_t; \Omega)$ and $\Phi(.)$ is the cumulative distribution function.

As shown in Coelli et al. (2005), the cost efficiency indicator for farm i (CEI_i) is given by:

$$(5)\quad CEI_i = \left[\Phi\left(\frac{u_i^*}{\sigma_*} - \sigma_*\right) \Big/ \Phi\left(\frac{u_i^*}{\sigma_*}\right)\right] \exp\left\{\frac{\sigma_*^2}{2} - u_i^*\right\} \qquad i = 1,\ldots,N$$

Where $u_i^* = -(\ln C_{it} - \ln C(Q_{it}, W_{it}, \tau_t; \Omega))\sigma_u^2 / \sigma^2$ and $\sigma_*^2 = \sigma_v^2 \cdot \sigma_u^2 / \sigma^2$. $(1-\alpha)\times 100\%$ confidence intervals for the efficiency indicator can be constructed such as (6):

$$(6)\quad \exp\left(-u_i^* - \sigma_* \Phi^{-1}\left(\left(\frac{\alpha}{2}\right)\Phi\left(\frac{u_i^*}{\sigma_*}\right)\right)\right) < CEI_i < \exp\left(-u_i^* - \sigma_* \Phi^{-1}\left(\left(1 - \frac{\alpha}{2}\right)\Phi\left(\frac{u_i^*}{\sigma_*}\right)\right)\right) \qquad i = 1,\ldots,N$$

The results from the estimation (i.e., the cost functions, the values of the cost efficiency and the dispersion of the cost efficiency) are presented in the annex.

[3] In a different context, similar assumptions can be found in the estimation of demand systems, where price elasticities are sometimes estimated from time series because of the lack of variability of prices in cross sectional datasets (Hsiao, 1993, p.206).

3. Farm efficiency results and discussion

Figure 1 presents the coefficients of efficiency together with confidence intervals by farm type. It should be noted that the efficiency coefficient takes values from 0 to 1, being 1 the fully efficient case.

The results can be divided into two sets according to the observed evolution: the first set includes the cases of cereals, general cropping, dairy, LFA specialist sheep, LFA cattle and LFA cattle and sheep. The second set considers lowland cattle and sheep and mixed farms.

As regards the first aforementioned set, it is possible to distinguish three phases, which approximately can be summarised as: decrease in the cost efficiency until about the years 1995-1996, followed for growth in the cost efficiency until approximately the years 2004-2005 to decrease again after 2005. It should be noted that the described pattern is more pronounced in some cases such as in LFA sheep specialist and LFA cattle and sheep farms and less in the case of general cropping.

In terms of explanation, one could associate the three observed phases in cost efficiency with the underlying agricultural policy, i.e., before the Mac Sharry reform, after the reform (considering a transition period of approximately two years for fully implementation of the policy) and after the introduction of single farm payment (effective in Scotland since 2005).

The second mentioned set (i.e., lowland cattle and sheep and mixed farms) shows high levels of efficiency and in comparison with the previous set they seem to be very stable.

An interesting point from the analysis comes from the fact that in periods where inefficiency seems to rise, also greater degree of dispersion of the efficiency is observed (as measured by the coefficient of variation amongst the farmers of the year)[4]. This is illustrated in Figure 2 for the cases related to LFA. In the three panels of the Figure it is possible to see a negative relationship between the coefficient of efficiency and the variability.

One possible explanation of the aforementioned phenomenon is associated to the effect that policy reform might have on the efficiency of farmers. Given farmers' heterogeneity in terms to their response to policy, policies that affect efficiency do not affect all in the same way, increasing the dispersion of the coefficient of efficiency.

[4] A similar result in a quite different context comes from the increase in the variability of relative prices during periods of high inflation (see Blejer, 1983).

Figure 1 – Evolution of the cost efficiency indicator 1989-2008 by farm type

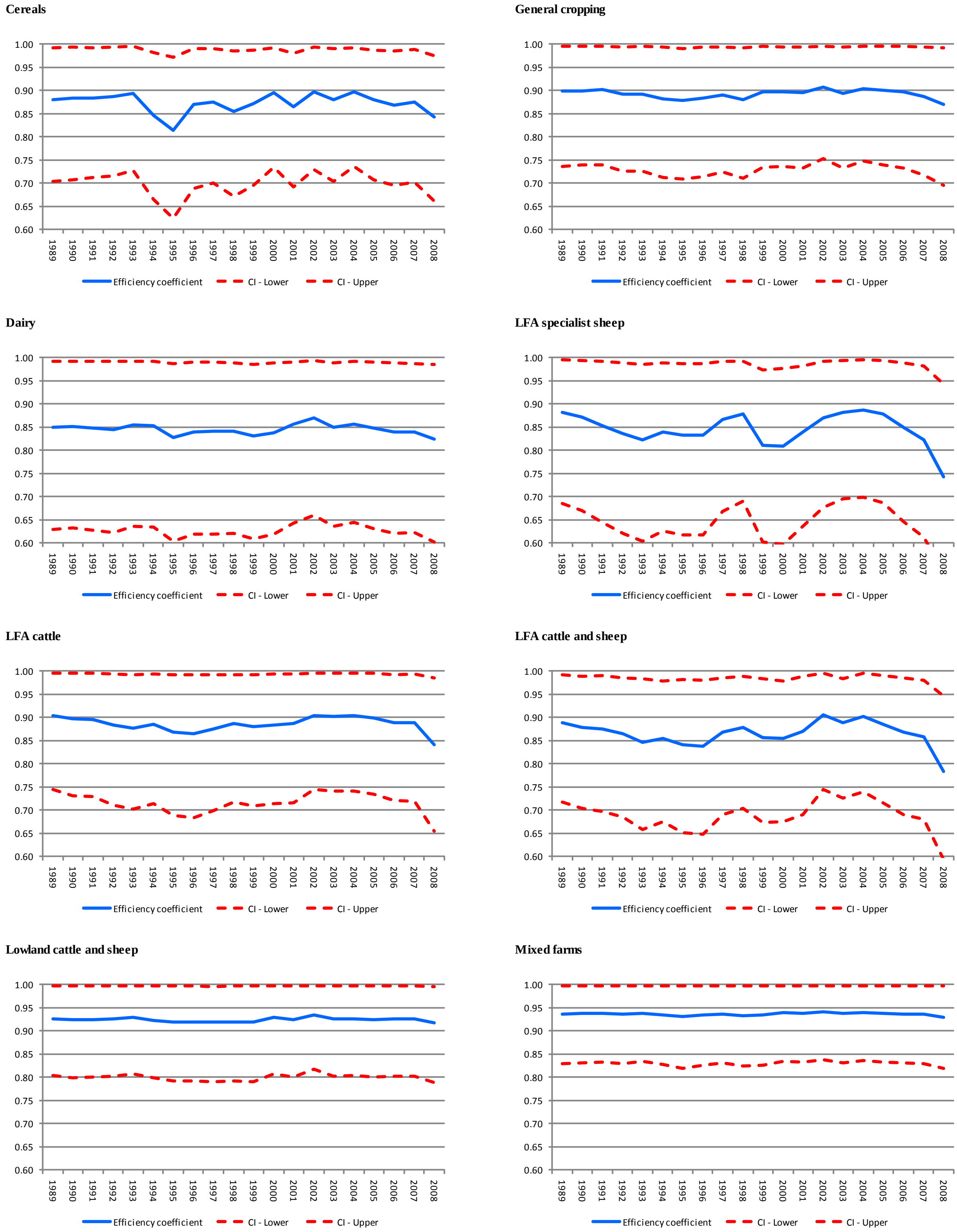
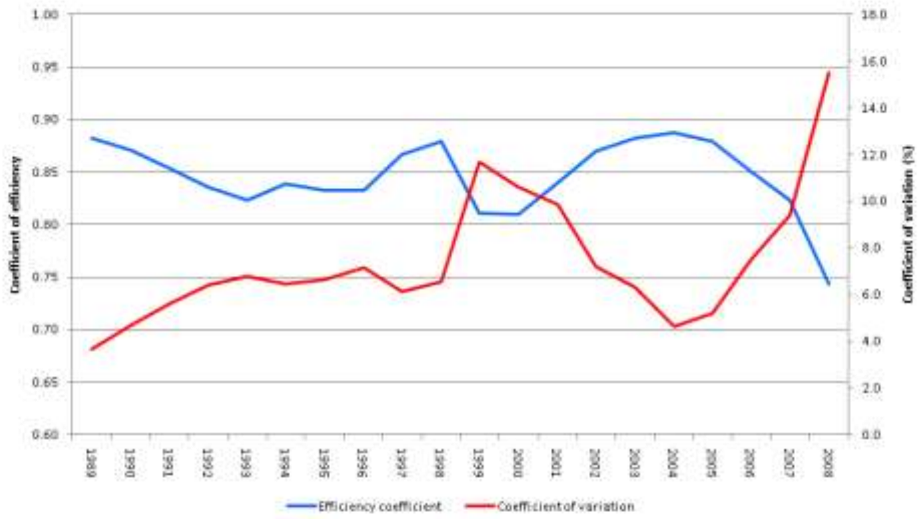
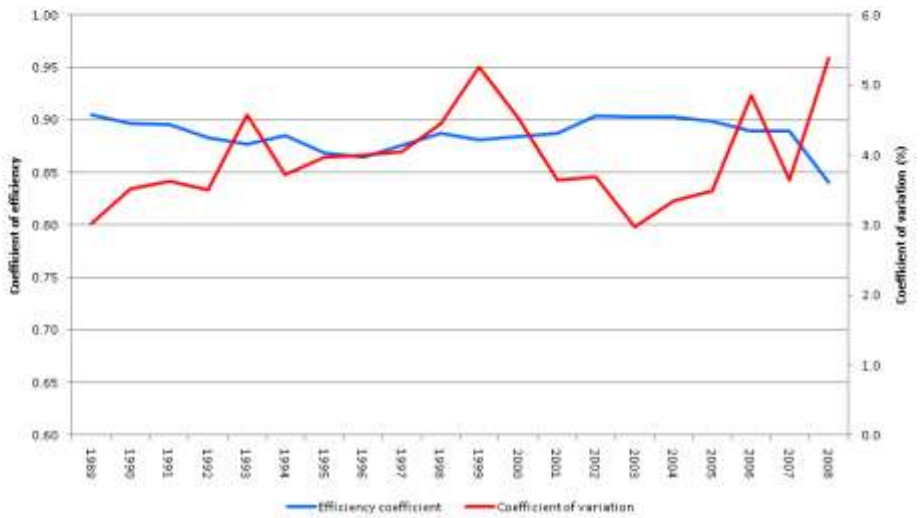


Figure 2: Relationship between the coefficient of efficiency and the coefficient of variation for the LFA cases

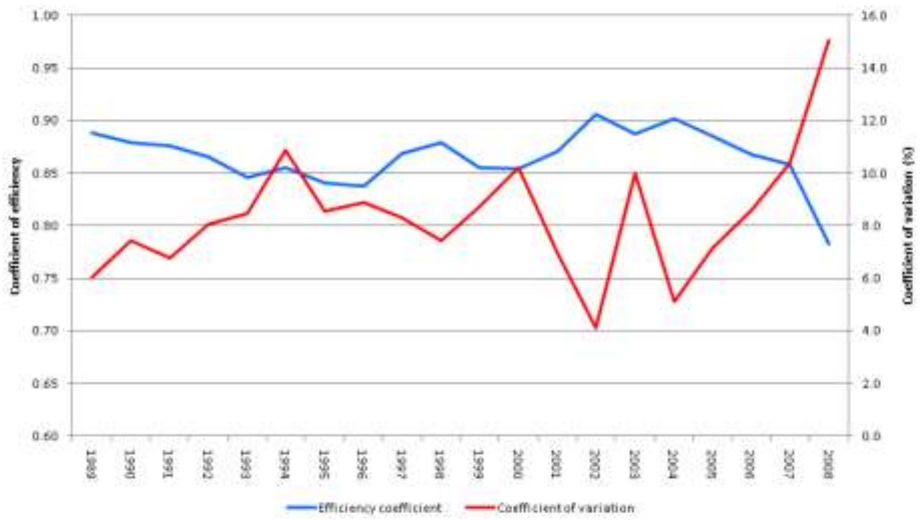
LFA specialist sheep



LFA cattle



LFA cattle and sheep



4. Conclusions

Overall, the analysis of cost efficiency by farms type indicates that agricultural policy seems to have considerable effect on the efficiency results.

Specifically, the results indicate that whilst mixed farms and lowland farms have maintained their levels of efficiency, LFA farms have seen their efficiency reduced since approximately 2004 (especially LFA sheep farm specialists). Therefore, similar to the results from the analysis in Revoredo-Giha et al. (2009), the analysis indicates that there is scope for cost efficiency improvement in several of the Scottish agricultural enterprises.

An interesting result is that, in all but mixed farms and lowland farms, efficiency seems to evolve according the following approximate phases during the sample: decrease until 1995 or 1996, recovery until 2004 or 2005 and decrease again after that. These phases can be associated to the reform of the agricultural policy.

Another result from the analysis shows that there seems to be an increase in the dispersion of farmers in terms of efficiency for some farm types during periods of change in the agricultural policy. A possible explanation of this can be found on the heterogeneity within farmers in terms of their reaction to the reform of the agricultural policy.

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Table A.1 Generalised Translog Cost Functions by Farm Type

Variables	Farm Types																							
	Cereals			General cropping			Dairy			LFA specialist sheep			LFA cattle			LFA cattle and sheep			Lowland cattle and sheep			Mixed farms		
	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio	Coef.	St. Dev.	t-ratio
Intercept	9.454500	0.033	289.53	10.501000	0.031	342.61	8.466300	0.031	270.17	8.300300	0.031	264.37	9.665200	0.021	450.24	8.751300	0.021	413.79	0.000213	0.001	0.28	-0.000479	0.000	-1.87
Trend	0.036115	0.006	5.93	0.042248	0.006	6.71	0.049103	0.006	8.54	0.042972	0.006	7.10	0.045670	0.004	11.59	0.056461	0.004	13.94	0.000041	0.000	12.76	0.000027	0.000	29.91
Squared trend	0.000518	0.000	1.72	0.000866	0.000	2.65	-0.000888	0.000	-2.94	-0.000517	0.000	-1.61	0.000367	0.000	1.90	-0.000695	0.000	-3.24	0.000014	0.000	9.00	0.000012	0.000	22.23
ln(w2)	0.044578	0.001	38.15	0.044234	0.001	45.68	0.039315	0.001	74.30	0.038905	0.001	38.22	0.037438	0.001	63.72	0.040918	0.001	63.13	0.031887	0.001	21.54	0.038965	0.001	53.93
ln(w2)*ln(w1)	-0.016896	0.003	-5.53	-0.023702	0.003	-8.34	-0.004787	0.001	-4.33	-0.014600	0.002	-6.62	-0.015263	0.001	-10.74	-0.015728	0.001	-10.95	-0.008708	0.004	-2.10	-0.006879	0.002	-3.84
ln(w2)*ln(w2)	0.044768	0.004	11.57	0.041867	0.004	10.65	0.022897	0.002	13.42	0.019639	0.003	6.21	0.028257	0.002	15.90	0.029372	0.002	14.78	0.022249	0.005	4.62	0.034927	0.002	14.83
ln(w2)*ln(w3)	-0.010005	0.002	-4.41	-0.011071	0.002	-5.26	-0.005506	0.001	-4.36	-0.009271	0.001	-7.58	-0.009538	0.001	-7.05	-0.013195	0.001	-9.11	-0.016210	0.003	-4.71	-0.006621	0.002	-3.85
ln(w2)*ln(w4)	-0.005098	0.002	-2.77	-0.001531	0.002	-0.98	-0.004811	0.001	-8.73	-0.002282	0.001	-3.53	-0.001636	0.001	-2.63	-0.000725	0.000	-1.52	0.001067	0.002	0.61	-0.000361	0.001	-0.40
ln(w2)*ln(w5)	-0.012768	0.006	-2.30	-0.005563	0.005	-1.04	-0.007793	0.003	-3.03	0.006515	0.004	1.54	-0.001820	0.003	-0.64	0.000276	0.003	0.09	0.001602	0.007	0.23	-0.021066	0.004	-5.73
q1*ln(w2)	0.000000	0.000	7.02	0.000000	0.000	1.78	0.000000	0.000	2.61	0.000000	0.000	-0.25	0.000000	0.000	4.57	0.000000	0.000	1.82	0.000000	0.000	0.88	0.000000	0.000	1.72
q2*ln(w2)	0.000000	0.000	-2.13	0.000000	0.000	2.75	0.000000	0.000	-5.65	0.000000	0.000	-2.83	0.000000	0.000	-1.96	0.000000	0.000	-4.49	0.000000	0.000	0.86	0.000000	0.000	0.85
ln(w3)	0.270270	0.005	55.25	0.279440	0.004	67.86	0.308270	0.004	86.54	0.384230	0.005	81.30	0.348180	0.003	101.70	0.346250	0.004	86.58	0.320210	0.009	33.96	0.315120	0.004	77.74
ln(w3)*ln(w1)	-0.010221	0.007	-1.46	0.040704	0.007	5.59	-0.021026	0.006	-3.81	0.019396	0.005	3.56	0.021528	0.006	3.84	0.010969	0.006	1.87	-0.032885	0.018	-1.79	-0.026376	0.007	-3.91
ln(w3)*ln(w2)	-0.010005	0.002	-4.41	-0.011071	0.002	-5.26	-0.005506	0.001	-4.36	-0.009271	0.001	-7.58	-0.009538	0.001	-7.05	-0.013195	0.001	-9.11	-0.016210	0.003	-4.71	-0.006621	0.002	-3.85
ln(w3)*ln(w3)	0.056163	0.009	6.02	0.076659	0.009	8.94	0.038272	0.007	5.39	0.031212	0.006	5.01	0.057811	0.007	8.14	0.071649	0.008	9.02	0.041228	0.018	2.26	0.061422	0.009	7.11
ln(w3)*ln(w4)	-0.023166	0.004	-5.36	-0.048882	0.004	-12.05	-0.019833	0.003	-7.78	-0.001143	0.002	-0.52	-0.020806	0.002	-8.79	-0.020268	0.002	-9.11	-0.013289	0.006	-2.05	-0.007870	0.003	-2.58
ln(w3)*ln(w5)	-0.012771	0.010	-1.34	-0.057410	0.009	-6.64	0.008094	0.006	1.40	-0.040195	0.005	-7.57	-0.048996	0.007	-7.43	-0.049155	0.007	-6.91	0.021156	0.017	1.24	-0.020555	0.009	-2.41
q1*ln(w3)	0.000000	0.000	-9.68	0.000000	0.000	-7.67	-0.000002	0.000	-6.59	-0.000006	0.000	-3.41	-0.000003	0.000	-7.67	-0.000002	0.000	-8.03	-0.000001	0.000	-3.25	-0.000001	0.000	-9.52
q2*ln(w3)	0.000000	0.000	-2.92	-0.000001	0.000	-8.51	-0.000001	0.000	-9.14	-0.000001	0.000	-9.43	-0.000001	0.000	-18.41	-0.000001	0.000	-14.29	-0.000001	0.000	-6.29	-0.000001	0.000	-7.44
ln(w4)	0.146040	0.003	56.94	0.142260	0.002	64.22	0.074367	0.002	45.34	0.142450	0.002	58.79	0.112880	0.001	78.42	0.128000	0.002	81.84	0.119570	0.004	31.24	0.125910	0.002	76.97
ln(w4)*ln(w1)	-0.051199	0.005	-10.98	-0.044325	0.005	-9.19	-0.033267	0.002	-13.57	-0.034301	0.003	-13.05	-0.027672	0.002	-11.15	-0.026086	0.002	-12.62	-0.014411	0.009	-1.60	-0.034207	0.003	-10.53
ln(w4)*ln(w2)	-0.005098	0.002	-2.77	-0.001531	0.002	-0.98	-0.004811	0.001	-8.73	-0.002282	0.001	-3.53	-0.001636	0.001	-2.63	-0.000725	0.000	-1.52	0.001067	0.002	0.61	-0.000361	0.001	-0.40
ln(w4)*ln(w3)	-0.023166	0.004	-5.36	-0.048882	0.004	-12.05	-0.019833	0.003	-7.78	-0.001143	0.002	-0.52	-0.020806	0.002	-8.79	-0.020268	0.002	-9.11	-0.013289	0.006	-2.05	-0.007870	0.003	-2.58
ln(w4)*ln(w4)	0.080100	0.004	19.64	0.067479	0.004	17.46	0.067487	0.002	37.64	0.034793	0.002	21.52	0.053486	0.002	34.26	0.039594	0.001	31.68	0.054142	0.005	11.50	0.064754	0.002	29.97
ln(w4)*ln(w5)	-0.000636	0.006	-0.10	0.027259	0.005	5.06	-0.009575	0.002	-4.23	0.002933	0.003	1.13	-0.003371	0.003	-1.28	0.007484	0.002	3.49	-0.027508	0.008	-3.54	-0.022316	0.004	-6.03
q1*ln(w4)	0.000000	0.000	3.13	0.000000	0.000	-5.80	0.000000	0.000	4.25	0.000002	0.000	2.97	0.000000	0.000	2.13	0.000000	0.000	-3.18	0.000000	0.000	-3.75	0.000000	0.000	8.00
q2*ln(w4)	-0.000001	0.000	-6.50	0.000000	0.000	-5.54	0.000000	0.000	2.06	0.000000	0.000	3.54	0.000000	0.000	7.80	0.000000	0.000	3.37	0.000000	0.000	-0.45	0.000000	0.000	-5.55
ln(w5)	0.334600	0.005	71.51	0.310660	0.004	83.06	0.215080	0.002	92.50	0.239450	0.004	56.99	0.267200	0.003	97.68	0.246610	0.003	82.38	0.251390	0.007	34.28	0.263080	0.003	77.03
ln(w5)*ln(w1)	-0.042176	0.011	-3.75	-0.107230	0.011	-9.68	-0.003420	0.005	-0.71	-0.074949	0.009	-8.58	-0.098373	0.007	-14.56	-0.054798	0.007	-8.25	-0.061358	0.021	-2.92	-0.048183	0.009	-5.60
ln(w5)*ln(w2)	-0.012768	0.006	-2.30	-0.005563	0.005	-1.04	-0.007793	0.003	-3.03	0.006515	0.004	1.54	-0.001820	0.003	-0.64	0.000276	0.003	0.09	0.001602	0.007	0.23	-0.021066	0.004	-5.73
ln(w5)*ln(w3)	-0.012771	0.010	-1.34	-0.057410	0.009	-6.64	0.008094	0.006	1.40	-0.040195	0.005	-7.57	-0.048996	0.007	-7.43	-0.049155	0.007	-6.91	0.021156	0.017	1.24	-0.020555	0.009	-2.41
ln(w5)*ln(w4)	-0.000636	0.006	-0.10	0.027259	0.005	5.06	-0.009575	0.002	-4.23	0.002933	0.003	1.13	-0.003371	0.003	-1.28	0.007484	0.002	3.49	-0.027508	0.008	-3.54	-0.022316	0.004	-6.03
ln(w5)*ln(w5)	0.068351	0.019	3.68	0.142950	0.017	8.49	0.012694	0.009	1.45	0.105700	0.012	9.02	0.152560	0.011	13.85	0.096193	0.011	8.55	0.066108	0.028	2.35	0.112120	0.014	7.99
q1*ln(w5)	0.000000	0.000	-2.73	0.000000	0.000	-0.79	0.000001	0.000	6.50	0.000000	0.000	-0.38	0.000002	0.000	8.05	0.000001	0.000	7.06	0.000001	0.000	5.08	0.000001	0.000	8.30
q2*ln(w5)	-0.000001	0.000	-7.87	-0.000001	0.000	-5.47	0.000000	0.000	-6.03	0.000000	0.000	-2.89	0.000000	0.000	-8.65	0.000000	0.000	-6.76	-0.000001	0.000	-4.48	-0.000001	0.000	-8.39
q1	0.000019	0.000	38.69	0.000012	0.000	52.35	0.000022	0.000	10.65	0.000031	0.000	2.63	0.000017	0.000	6.50	0.000029	0.000	14.51	0.000041	0.000	12.76	0.000027	0.000	29.91
q2	0.000018	0.000	13.18	0.000018	0.000	20.15	0.000030	0.000	24.43	0.000043	0.000	39.55	0.000025	0.000	46.53	0.000026	0.000	49.34	0.000014	0.000	9.00	0.000012	0.000	22.23
q1*q1	0.000000	0.000	-20.22	0.000000	0.000	-29.08	0.000000	0.000	2.14	0.000000	0.000	2.13	0.000000	0.000	1.25	0.000000	0.000	-1.11	0.000000	0.000	-2.62	0.000000	0.000	-8.32
q1*q2	0.000000	0.000	-8.43	0.000000	0.000	-10.85	0.000000	0.000	-4.39	0.000000	0.000	-4.24	0.000000	0.000	-3.96	0.000000	0.000	-9.73	0.000000	0.000	-4.10	0.000000	0.000	-6.27
q2*q2	0.000000	0.000	-2.16	0.000000	0.000	-6.50	0.000000	0.000	-12.69	0.000000	0.000	-22.63	0.000000	0.000	-20.70	0.000000	0.000	-22.87	0.000000	0.000	-2.52	0.000000	0.000	-0.22
Observations	866			1066			1494			1176			2067			1890			244			1442		
R^2	0.92			0.92			0.75			0.85			0.88			0.89			0.88			0.90		

Table A.2 – Efficiency coefficient and confidence intervals at $\alpha=0.05$

		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Cereals	Lower	0.70	0.71	0.71	0.72	0.73	0.66	0.63	0.69	0.70	0.67	0.70	0.73	0.69	0.73	0.70	0.74	0.71	0.70	0.70	0.66
	Efficiency	0.88	0.88	0.88	0.89	0.89	0.85	0.81	0.87	0.87	0.85	0.87	0.90	0.86	0.90	0.88	0.90	0.88	0.87	0.88	0.84
	Upper	0.99	0.99	0.99	0.99	0.99	0.98	0.97	0.99	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.97
	Cases	34	41	40	42	37	41	45	34	45	44	34	27	28	41	53	47	55	57	61	60
General cropping	Lower	0.74	0.74	0.74	0.73	0.73	0.71	0.71	0.71	0.72	0.71	0.73	0.74	0.73	0.75	0.73	0.75	0.74	0.73	0.72	0.70
	Efficiency	0.90	0.90	0.90	0.89	0.89	0.88	0.88	0.88	0.89	0.88	0.90	0.90	0.90	0.91	0.89	0.90	0.90	0.90	0.89	0.87
	Upper	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.99	0.99
	Cases	54	58	54	55	61	64	57	60	57	50	62	61	53	56	48	47	42	44	43	40
Dairy	Lower	0.63	0.63	0.63	0.62	0.64	0.64	0.60	0.62	0.62	0.62	0.61	0.62	0.64	0.66	0.64	0.64	0.63	0.62	0.62	0.60
	Efficiency	0.85	0.85	0.85	0.84	0.85	0.85	0.83	0.84	0.84	0.84	0.83	0.84	0.86	0.87	0.85	0.86	0.85	0.84	0.84	0.82
	Upper	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	Cases	93	94	94	88	81	78	77	76	83	79	74	69	65	67	67	66	63	63	59	58
LFA specialist sheep	Lower	0.69	0.67	0.65	0.62	0.60	0.63	0.62	0.62	0.67	0.69	0.60	0.60	0.64	0.68	0.69	0.70	0.69	0.65	0.61	0.54
	Efficiency	0.88	0.87	0.85	0.84	0.82	0.84	0.83	0.83	0.87	0.88	0.81	0.81	0.84	0.87	0.88	0.89	0.88	0.85	0.82	0.74
	Upper	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.98	0.94
	Cases	68	75	76	75	72	64	62	63	68	65	61	59	51	56	47	46	48	44	40	36
LFA cattle	Lower	0.74	0.73	0.73	0.71	0.70	0.71	0.69	0.68	0.70	0.72	0.71	0.71	0.72	0.74	0.74	0.74	0.74	0.72	0.72	0.65
	Efficiency	0.90	0.90	0.90	0.88	0.88	0.89	0.87	0.86	0.88	0.89	0.88	0.88	0.89	0.90	0.90	0.90	0.90	0.89	0.89	0.84
	Upper	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.99	0.99
	Cases	68	76	78	91	86	99	103	103	102	109	111	110	111	109	122	120	118	125	119	107
LFA cattle and sheep	Lower	0.72	0.70	0.70	0.68	0.66	0.68	0.65	0.65	0.69	0.70	0.67	0.67	0.69	0.74	0.73	0.74	0.72	0.69	0.68	0.59
	Efficiency	0.89	0.88	0.88	0.87	0.85	0.86	0.84	0.84	0.87	0.88	0.86	0.85	0.87	0.91	0.89	0.90	0.89	0.87	0.86	0.78
	Upper	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.98	0.99	1.00	0.98	0.99	0.99	0.99	0.98	0.95
	Cases	107	124	120	116	111	104	101	99	107	112	102	104	88	86	69	65	72	69	69	65
Lowland cattle and sheep	Lower	0.80	0.80	0.80	0.80	0.81	0.80	0.79	0.79	0.79	0.79	0.79	0.81	0.80	0.82	0.80	0.80	0.80	0.80	0.80	0.79
	Efficiency	0.93	0.92	0.92	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.92	0.93	0.93	0.93	0.92	0.93	0.93	0.92
	Upper	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Cases	12	19	16	15	17	13	15	12	9	8	8	10	12	11	9	9	12	11	13	13
Mixed farms	Lower	0.83	0.83	0.83	0.83	0.83	0.83	0.82	0.83	0.83	0.82	0.83	0.83	0.83	0.84	0.83	0.84	0.83	0.83	0.83	0.82
	Efficiency	0.94	0.94	0.94	0.94	0.94	0.93	0.93	0.93	0.94	0.93	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.93
	Upper	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Cases	60	64	77	90	77	86	76	85	84	77	72	69	65	60	71	63	68	68	67	63

Table A.3 - Variation in farm efficiency 1989-2008

		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Cereals	Min	0.7	0.8	0.7	0.8	0.8	0.6	0.6	0.7	0.7	0.6	0.6	0.7	0.5	0.7	0.7	0.7	0.5	0.5	0.6	0.5
	Max	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	1.0	1.0	1.0	1.0	0.9
	CV	5.1	4.7	6.0	5.1	4.8	8.6	9.8	5.7	6.6	7.7	7.5	6.2	10.3	4.8	6.1	6.5	7.8	8.8	7.3	10.9
	Range	29.2	23.4	27.3	23.8	19.7	67.3	65.3	27.0	34.1	53.0	53.1	30.2	79.8	27.5	43.6	43.6	101.1	110.7	50.7	88.0
General cropping	Min	0.8	0.8	0.9	0.8	0.8	0.8	0.7	0.8	0.8	0.7	0.8	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Max	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	CV	3.0	3.1	2.1	3.3	2.6	3.7	5.5	3.7	2.9	3.9	3.5	3.9	3.4	3.1	4.1	3.3	2.8	2.5	3.2	3.8
	Range	17.0	19.2	10.4	23.1	11.2	20.6	41.7	18.9	16.8	23.5	20.8	27.3	24.5	19.6	23.1	22.0	15.7	12.3	18.2	18.4
Dairy	Min	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.7	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.6	0.6
	Max	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	CV	4.8	5.0	5.2	5.2	4.6	4.9	7.7	6.6	6.3	7.2	7.9	7.3	6.4	4.2	7.2	6.1	6.4	6.8	8.0	8.5
	Range	29.5	38.8	30.1	29.1	26.5	40.6	57.9	35.2	42.2	52.7	57.5	58.6	42.0	19.1	59.5	42.4	39.7	42.6	43.4	47.9
LFA specialist sheep	Min	0.8	0.7	0.7	0.7	0.6	0.7	0.7	0.6	0.7	0.7	0.5	0.5	0.5	0.7	0.7	0.8	0.8	0.6	0.6	0.5
	Max	0.9	1.0	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
	CV	3.7	4.7	5.6	6.4	6.8	6.5	6.6	7.1	6.1	6.5	11.7	10.6	9.9	7.2	6.3	4.7	5.2	7.5	9.4	15.5
	Range	19.1	30.2	31.9	40.8	46.4	42.5	41.5	54.0	38.0	43.5	100.7	102.5	92.2	50.0	37.3	23.1	25.8	47.9	48.8	101.5
LFA cattle	Min	0.8	0.8	0.8	0.8	0.7	0.8	0.7	0.8	0.7	0.6	0.6	0.7	0.7	0.8	0.8	0.7	0.8	0.6	0.8	0.7
	Max	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	0.9	0.9	0.9	0.9	0.9
	CV	3.0	3.5	3.6	3.5	4.6	3.7	4.0	4.0	4.0	4.5	5.3	4.5	3.6	3.7	3.0	3.4	3.5	4.9	3.6	5.4
	Range	16.8	20.9	22.6	17.1	31.6	21.1	28.5	23.9	29.6	50.9	50.8	28.8	25.6	24.8	17.2	27.0	24.9	60.7	19.3	37.8
LFA cattle and sheep	Min	0.7	0.5	0.6	0.5	0.6	0.3	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.8	0.5	0.7	0.6	0.6	0.4	0.4
	Max	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9
	CV	6.0	7.4	6.8	8.0	8.4	10.9	8.6	8.9	8.3	7.4	8.7	10.2	6.9	4.1	10.0	5.1	7.1	8.6	10.4	15.0
	Range	42.8	81.7	65.2	84.0	60.6	211.8	90.9	69.0	78.0	76.8	88.6	86.6	52.2	21.8	108.5	36.8	54.6	53.9	140.0	120.5
Lowland cattle and sheep	Min	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Max	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9
	CV	1.1	1.2	1.3	1.0	0.9	1.4	1.2	1.3	1.8	1.2	1.0	1.0	0.9	0.8	0.9	1.1	1.5	1.2	1.1	1.2
	Range	3.5	4.7	5.4	3.9	3.6	4.5	3.7	4.1	6.8	3.8	2.7	3.8	2.8	2.5	3.0	3.0	6.6	4.7	4.3	4.6
Mixed farms	Min	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Max	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9
	CV	1.0	1.0	1.1	1.3	1.1	1.0	1.1	1.1	0.9	1.1	1.1	0.8	0.9	0.8	1.0	0.7	1.1	0.8	0.9	1.2
	Range	5.9	5.8	7.2	7.9	7.1	4.9	6.6	7.0	4.9	5.6	7.0	4.3	5.5	3.3	4.4	3.1	8.4	3.9	4.3	5.7

Notes:
C.V stands for coefficient of variation (i.e., the ratio of the standard deviation to the mean) and Range the relative change from the smallest to the larget value in the sample. Both CV and CDS are measured in percentages.