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Productivity and the Determinants of Efficiency in Irish Agriculture (1996-2006)

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The competitiveness and productivity of Irish agriculture has been at the forefront of debate in recent times given successive and impending changes to agricultural policy. This paper examines the trend in total factor productivity in Irish agriculture over the recent past and explores the effects of specific variables on relative efficiency levels. The findings of this research have shown that productivity growth was highest in the Cattle Rearing sector followed by the Dairy, Cattle Finishing, Sheep and Cereals sectors during the period 1996 to 2006. The research has also shown that efficiency levels are, in general, positively correlated with extension use soil quality, the overall size of the farm, the level of intensification and the level of specialisation. The use of artificial insemination was also positively correlated with efficiency in the Dairy sector.

Keywords and JEL codes (if available)

Introduction

The Irish agricultural sector has long been supported by protectionist policy interventions that have distorted incentives for farmers to produce at the optimum from a market perspective. However, recent reforms of the Common Agricultural Policy and continuous moves toward further trade liberalisation have meant that the competitiveness of agricultural markets has been at the forefront of debate in recent times. If we want to understand changes in relative competitiveness over time we need to look at the relative movements in the three factors which contribute to competitive positioning: relative productivity growth rates, relative changes in costs and relative changes in price of output. Over any time period other than the very short tem, the main source of change in competitiveness comes from differences in the rate of productivity growth. This motivation provided the rationale for the examination of the productivity performance of Irish agriculture.

This research employed Stochastic Frontier Analysis (SFA) for the construction of Total Factor Productivity (TFP) indices for each of the main farming types in Ireland, using National Farm Survey data from 1996 to 2006. Annual changes in TFP were also decomposed into changes in technical change, technical efficiency change and scale efficiency change. In addition to changes in TFP and its components and determinants of technical efficiency were also explored using the same dataset. The methods used in the analysis are outlined in the next section of the paper. The data employed is then outlined, followed by the results of the analysis and finally conclusions from the research are presented.

Methodology

Papers by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) led the field of stochastic frontier analysis (SFA). From an output orientated perspective, SFA essentially estimates a production frontier representing the boundary or highest possible level of production given input levels for a sample of similar firms. Individual firm inefficiency is then calculated as the potential proportional increase in output (to the frontier). Assuming a Cobb-Douglas production technology, the stochastic frontier model is written as:

$$\ln y_i = \beta_0 + \sum_{k=1}^{K} \beta_k \ln x_{ki} + e_i \qquad \text{where} \qquad e_i = v_i - u_i \tag{1}$$

where y_i is the farm's output level and x_{ki} is a vector of k production inputs (capital, labour etc). The composite error term (e_i) is made up of a statistical noise component (v_i) and a non-negative technical inefficiency component (u_i). The model is usually estimated by maximum likelihood after assuming a distribution for both components. The panel data extension of this model assuming a time-invariant inefficiency term is proposed by Pitt and Lee (1981):

$$\ln y_{it} = \beta_0 + \sum_{k=1}^{K} \beta_k \ln x_{kit} + v_{it} - u_i \tag{2}$$

The assumption of time-invariance may hold in short panels but becomes less plausible when the number of years/periods increases. For example, it is possible that inefficient farms become more efficient over time (or visa versa). Similarly, in unbalanced panels, it is likely that some farms become less efficient through time before leaving the sample entirely (shutting down). The temporal assumption that is imposed will depend upon the length of the panel, the nature of the sample (balanced or unbalanced) and also on the competitive structure of the sector in question. Highly uncompetitive sectors may be characterised by highly fluctuating efficiency trends. This paper employs eleven years of unbalanced data from a highly protected and subsidised sector which has undergone considerable structural change in recent years. In such circumstances the assumption of time-invariance seems unlikely. The following time-varying inefficiency specifications have been proposed in the literature:

$$u_{it} = u_i / \left[1 + \exp(\alpha t + \gamma t^2)\right] \qquad \text{Kumbhakar (1990)} \tag{3}$$

$$u_{it} = u_i \times \exp\left[-\eta(t - T)\right] \qquad \text{Battese and Coelli (1992)} \tag{4}$$

where $t=1,2,....,T$ is time and α, γ and η are parameters to be estimated. Both models essentially assume a time-invariant inefficiency term (u_i) but allow this term to follow a temporal trend. The drawback of such specifications is that they impose the same temporal pattern of inefficiency on all farms. Again, this is a somewhat restrictive assumption.

The model proposed by Cuesta (2000) generalises the Battese and Coelli (1992) specification and allows each farm to follow its own temporal inefficiency pattern:

$$u_{it} = u_i \times \exp[-\xi_i (t - T)] \quad \textbf{(5)}$$

where ξ_i are farm-specific parameters responsive to different patterns of temporal variation. The model, although conceptually appealing, has proved difficult to convergence in practice, particularly when the number of farms is large.

Underlying all the above models is the assumption that inefficiency is due to inadequacies in the production process, in essence, due to shortfalls in the skills and capabilities of those involved in the production process. A criticism of these models is that the estimated technical inefficiency levels are also capturing unobserved farm specific factors that are unrelated to inefficiency. For example, a farm that operates in an unfavorable microclimate (perhaps due to exceptionally high/low altitude) will, through no fault of its own (from a managerial perspective), appear more inefficient. Such differences can be difficult to quantify in empirical work and not controlling for such would produce biased inefficiency estimates. Recently, Greene (2004; 2005) proposed a new class of model termed 'True' Effects models which attempt to remove this unobserved heterogeneity from the inefficiency term, thus yielding an inefficiency measure that captures pure technical inefficiency. In the True Fixed Effects model, unobserved heterogeneity is modelled directly in the production function using farm-specific dummy variables and estimated in a one-step maximum likelihood approach:

$$\ln y_{it} = a_i + \sum_{k=1}^{K} \beta_k \ln x_{kit} + v_{it} - u_{it} \quad \textbf{(6)}$$

where a_i are farm-specific, time-invariant dummy variables and the inefficiency term is a time-varying random variable. Whether or not a_i captures time-invariant heterogeneity or heterogeneity combined with some time-invariant inefficiency is unsettled. For example, some of the effects of being an inferior manager may be removed from the inefficiency component by the fixed effect (if inferior management is a time-invariant characteristic of the farm). For such a farm, the estimated inefficiency level is likely to be biased downwards (appears more efficient). A similar reasoning can be applied to farms with consistently good management.

Greene's True Random Effects model is similar in motivation. The model adds a random farm-specific time-invariant constant term (assumed to be normally distributed) to the standard stochastic frontier model and estimates using Maximum Simulated Likelihood:

$$\ln y_{it} = \left(\beta_0 + w_i\right) + \sum_{k=1}^{K} \beta_k \ln x_{kit} + v_{it} - u_{it} \qquad \textbf{(7)}$$

where w_i is a time-invariant, farm-specific random term again intended to capture cross- farm time-invariant heterogeneity. Both models assume that the error term and the inefficiency term are independently and identically distributed normal and half-normal respectively.

In this paper, results of the True Effects Models (True Fixed Effects (TFE) and True Random Effects (TRE)) are compared to those of the standard models (Pitt and Lee 1981 (PL) and Battese and Coelli 1992 (BC)). In all specifications a translog production technology is assumed with annual time dummy variables to capture neutral technical change. The full specification is given by Equation 8.

$$\ln y_{it} = \alpha + \sum_{k=1}^{K} \beta_k \ln x_{kit} + 0.5 \sum_{k=1}^{K} \sum_{j=1}^{K} \beta_{kj} \ln x_{kit} \ln x_{nit} + \sum_{t=1}^{T} \delta_t D_t + v_{it} - \mu \qquad \textbf{(8)}$$

PL: $\alpha = \beta_o$ and $\mu = u_i$

BC: $\alpha = \beta_o$ and $\mu = u_i \times \exp\left[-\eta(t-T)\right]$

TFE: $\alpha = a_i$ and $\mu = u_{it}$

TRE: $\alpha = \beta_o + w_i$ and $\mu = u_{it}$

where D_t are annual time dummy variables.

The importance of the underlying theoretical consistency of stochastic frontiers has been highlighted by Sauer, Frohberg and Hockmann (2006). They test the monotonicity and concavity condition (first and second order derivatives with respect to each input are positive and negative respectively) of a number of prominent previous studies and could find none that fulfilled both.[1] It is emphasised that inconsistent frontiers can over/underestimate real relative inefficiency and hence potentially lead to biased conclusions. These properties are tested in Section 4 and employed to uncover the most appropriate model.

The estimated parameters and inefficiency estimates are used to construct a generalised Malmquist productivity index. The index is based on the approach outlined by Coelli et al. (2005) where TFP change from year s to t is the product of technical change (Equation 9), technical efficiency change (Equation 10) and scale efficiency change (Equation 11). The calculation of technical change follows that of Cuesta (2000) (due to Caves, Christensen and Swanson, 1981).

$$TC_{s,t} = \exp(\delta_t - \delta_s) \tag{9}$$

$$TEC_{s,t} = \frac{E(\exp(-u_{it})|e_{it}}{E(\exp(-u_{is})|e_{is}} \tag{10}$$

$$SEC_{s,t} = \exp\left\{0.5\sum_{n=1}^{N}[\varepsilon_{nis}SF_{is} + \varepsilon_{nit}SF_{it}]\ln(x_{nit} / x_{nis})\right\} \tag{11}$$

where $SF_{is} = (\varepsilon_{is} - 1)/\varepsilon_{is}$, $\varepsilon_{is} = \sum_{n=1}^{N}\varepsilon_{nis}$ (returns to scale) and $\varepsilon_{nis} = \frac{\partial \ln q_{is}}{\partial \ln x_{nis}}$ (input elasticity).

[1] Monotonicity implies that marginal products are non-negative (additional units of an input will not decrease output). Concavity implies that marginal products are non-increasing (the law of diminishing marginal productivity) (Coelli, et al, 2005).

Finally, an additional model is employed to explore the determinants of efficiency. The model proposed by Orea and Kumbhakar (2004) is a generalisation of the Battese and Coelli (1992) approach and assumes a time-varying inefficiency term as the product of a nonnegative, time-invariant inefficiency term (u_i) and an exponential function of time-varying efficiency variables (z_{it}):

$$u_{it} = u_i \times \exp(z_{it}'\delta) \tag{12}$$

where δ are parameters to be estimated. The efficiency variables are assumed to influence the efficiency of production only (education, herd genetics etc.). A form of this model has been employed by Alvarez, Arias and Orea, (2006) for the Spanish Dairy sector (latent class cost frontier). To further explore the effects of decoupling, a dummy variable for years 2005 and 2006 enters the model alongside these efficiency variables.

Data

Data from the Irish National Farm Survey (NFS) (conducted annually by Teagasc, the Irish Agricultural and Food Authority) is employed. In the survey, each farm animal and hectare of crop is assigned a standard gross margin and farms are then grouped into systems according to the dominant enterprise. Farms are selected so as to attain a representative sample of each system in Ireland. In this paper the NFS dairy, cattle rearing, cattle finishing, sheep and cereals systems are employed for the 11 year period, 1996 through 2006 (sheep sector 2000 through 2006). These systems are analysed independently using system specific outputs and inputs. Although farms have been grouped according to their dominant output type, the majority of farms are also involved in either or a number of the other systems. Where inputs are not explicitly assigned in the data (capital, labour, machinery operating costs), they are allocated according to the proportion of gross output that is attributable to the main output type (for example, in the dairy enterprise, this would be the proportion of total gross output that can be attributed to the dairy enterprise). In addition, all monetary figures are deflated according to annual Irish agricultural price indexes which are available from the Irish Central Statistics Office.

For the dairy system, output is milk in litres and the standard production inputs are capital, labour, direct costs, herd size and land. Capital includes the stock of machinery and buildings which is based on the market value as estimated by the farmer. Labour is measured in standard man days representing the number of eight hour days supplied by persons over 18 years of age. Direct costs comprise of concentrates, feed costs, machinery operating costs and lime costs. Herd size is the average number of dairy cows and land is the forage area (acres).

Farms in the cattle rearing system are mainly involved in providing cattle for the finishing and other cattle related systems. Output in this system equals total annual weanling, store and breeding cattle sales. Livestock production differs to that of dairy and cereal production in that it is not strictly an annual process. Annual sales are often determined by production activity in the previous year (cattle born this year may not be sold until sometime the following year). To account for this, the level of closing and opening stock (trading) is added and subtracted to and from annual output respectively. The standard production inputs are similar to those employed in the dairy system. Direct costs differ slightly and also include the value of milk and substitutes (used in the rearing of calves). Furthermore, the value of the breeding herd is considered a capital input and is estimated as the sum of opening breeding stock plus any breeding cattle purchases made during the year. This variable is added to the capital input already outlined.

The cattle finishing system is predominantly involved in purchasing store and weanling cattle (accounting for an average of 91 per cent of total cattle purchases in this system), adding to their value, and then selling them on as either finished or store cattle (accounting for 90 per cent of total cattle sales). Output in this system is therefore the sum of annual finished and store cattle sales plus the level of closing trading stock. The herd input is the sum of store and weanling purchases plus the level of opening trading stock. Opening trading stock is added to this input as it is assumed that cattle in this category are not necessarily animals ready for sale but will be at some unknown stage of production. The remainder of the production process (and value added) will be completed during the current year. The remaining inputs are identical in construction to the cattle rearing system.

Output in the sheep system equals total annual sheep and wool sales less closing stocks (trading and wool) plus opening stocks (trading and wool). Labour and land inputs are identical in construction to previous systems. The capital input is similar in construction to that proposed for the cattle rearing system: the breeding herd (breeding stock + breeding purchases) is considered a capital input and is added to the standard variables (buildings and machinery). Furthermore, total sheep purchases (less breeding purchases) are added to the standard direct costs variables.

The final sector to be analysed is the cereals sector. Like the dairy sector (and unlike the livestock sectors), this sector is essentially an annual process and is therefore relatively more straightforward. There are 11 main crop types in the cereals sector: winter wheat, spring wheat, winter barley, spring barley, malting barley, winter oats, spring oats, oilseed rape, peas and beans, potatoes and sugar beet. Annual output therefore equals the sum of sales from each crop. Direct costs comprise of seeds, fertilisers, crop protection costs, machinery hire and operating expenses and lime. In the NFS, the number of mandays and the amount of land associated with each crop is recorded. Total labour and land inputs are therefore the summation of these respectively. Capital is again the value of machinery and buildings (as estimated by the farmer).

The final datasets employed are quite unbalanced – in total, the final samples consist of 3,593 observations (representing 787 farms) in the dairy system, 2,087 observations (551 farms) in the cattle rearing system, 2,164 observations (693 farms) in the cattle finishing system, 890 observations (264 farms) in the sheep system and 1,016 observations (271 farms) in the cereals system for the eleven year period (7 year period for sheep system).

The variables considered for the Orea and Kumbhakar (2004) efficiency effects model are: the farm's soil quality, the use of the extension service, the presence of an off-farm job, the use of artificial insemination (all dummy variables), the total farm size (acres), the age of the farmer (years), and the degree of specialisation and intensification The degree of specialisation refers to the proportion of total gross output that is attributable to the main system output. The degree of intensification applies to the livestock systems and is calculated as the number of livestock units per forage acre.

A further development of the model is currently under construction whereby the inclusion of weather related variables is being considered. The inclusion of weather related variables in the model is a significant model development given that the NFS data as it is collected has no geospatial information. This means one cannot associate a farm with climatic, geo-demographic or environmental data that are referenced via position, i.e. the NFS cannot be used within a GIS. This has been remedied by using address matching techniques; matching the NFS farms with points from the An Post/OSI Geo-Directory (the national geo-referenced address point database). The nature of addresses in rural Ireland is such that the final resolution for postal delivery is achieved through names of recipients and not unique building identification, so coupled with Irish / English place name alternatives and different spellings, address matching in this context is not trivial. The work achieves spatial resolution for each farm to ~ 3km^2 cell. This scale is not published outside of the NFS in order to ensure that confidentially is maintained. The now geospatially enabled national farm survey (GNFS) is then exploited within the RERC GIS system to populate the GNFS with ancillary data that could not be allocated otherwise. In the case of this study specific historical local weather data is tagged to each farm using standard GIS intersection techniques[2].

Results

Model Choice

All models are estimated in *LIMDEP* version 8.0 (Greene, 2003). Descriptive statistics for the inefficiency estimates from each model and sector are presented in Table A1 (Appendix A). It is apparent that the mean inefficiency estimates differ considerably with the PL model generally showing the highest mean level (i.e. least efficient) followed by the BC, TFE and TRE models. This result is similar to that found by Farsi, Filippini and Greene (2006) and it is suggested that this is due to the presence of unobserved heterogeneity in the inefficiency term of the standard models (PL and BC)

[2] The authors would like to acknoeldge Met Eireann for the provision of rainfall data

and its exclusion in the True Effects models (TRE and TFE). Although mean inefficiency estimates across systems are not strictly comparable, the inefficiency estimates in the sheep and cattle rearing systems are particularly large which suggests either considerable production problems or a degree of heterogeneity which the models fail to capture. Also of interest in Table A1 are the standard deviations from the True Effects models which are considerably smaller than those of the standard models. It is evident that the inefficiency estimates from the True Effects models are considerably less dispersed and less than the standard models. Correlation matrices of each model's inefficiency estimates are displayed in Table A2 for all sectors. While the mean inefficiency estimates for the PL and BC models are significantly different, it is apparent that these two models are capturing very similar effects (mean correlation coefficient of 0.83 across sectors). This is also the case for both True Effects models which display a mean correlation coefficient of 0.89 (mean across all sectors). However, the correlation between the former and latter groups of models is very low, highlighting the differences between these two methodologies.

These results are not surprising given the very different inefficiency assumptions underlying each model. The Pitt and Lee model assumes that inefficiency is time-invariant while the Battese and Coelli model assumes that all farms follow an identical inefficiency trend. Both of the True Effects models allow inefficiency to vary freely through time but also attempt to separate and remove any time-invariant unobserved heterogeneity from the inefficiency term. The time-invariant inefficiency term assumed in the Pitt and Lee model is clearly restrictive. Despite its drawbacks, the model is useful when unbalanced panel datasets are employed, in that it sheds some light on the efficiency levels of new entrants and exits to and from the sample (on average, 23 per cent of farms in each year are new to the sample). In the model, annual increases/decreases in efficiency would only be observed if the sample entrants are more/less efficient than the farms they are replacing. With the exception of the dairy sector, all sectors show the highest growth in efficiency in either 2005 or 2006 (Table 1). Furthermore, the highest mean efficiency level across all sectors occurs in 2006.

Table 1: Annual Percentage Increase in Mean Efficiency for the Pitt and Lee Model

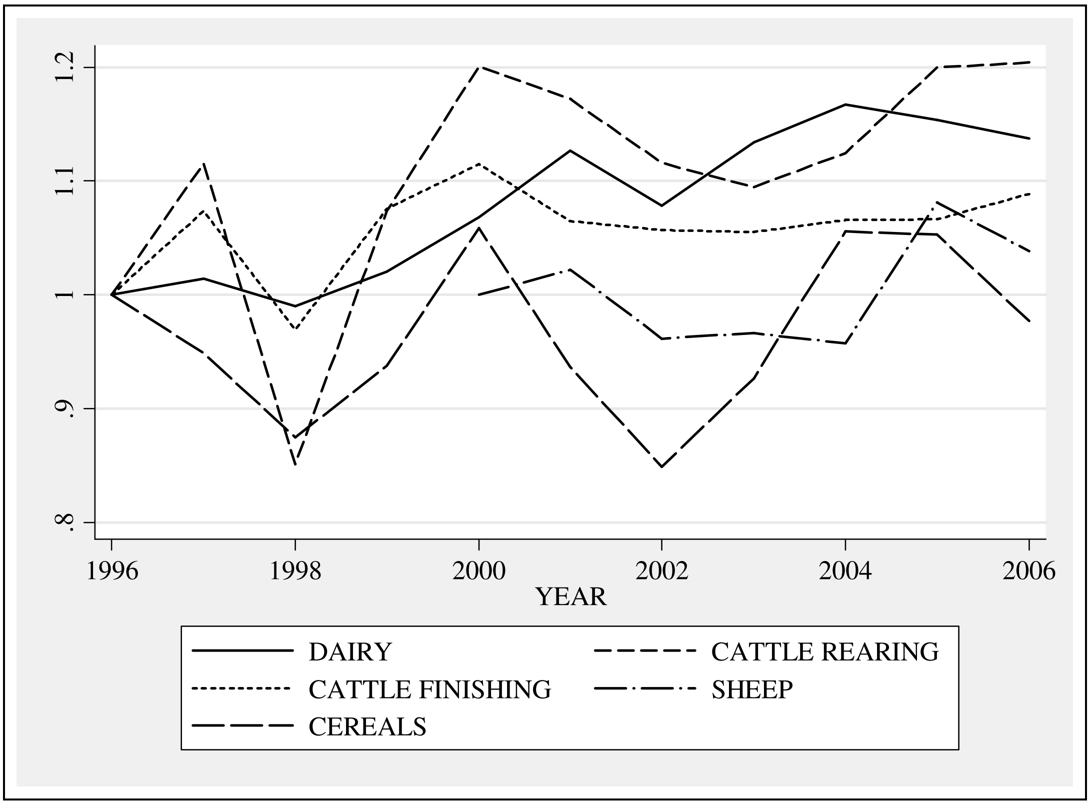
	Dairy	Cattle Rearing	Cattle Finishing	Sheep	Cereals	Mean All Sectors
1996	-	-	-	-	-	-
1997	-1.060	-0.842	-0.432	-	-3.921	-1.564
1998	-0.550	-2.095	-0.786	-	-0.462	-0.973
1999	0.709	0.431	-0.485	-	-1.753	-0.274
2000	0.056	-1.285	-0.403	-	-0.941	-0.643
2001	0.380	-0.037	0.321	-0.123	0.156	0.139
2002	-0.586	3.273	0.103	-2.262	1.736	0.453
2003	0.394	-2.566	0.318	0.515	-0.206	-0.309
2004	-0.383	1.664	-0.033	1.268	0.642	0.632
2005	0.311	1.434	1.054	0.327	-0.750	0.475
2006	0.505	2.161	0.564	1.786	1.812	1.365

In an effort to uncover the most appropriate model, the theoretical consistency (monotonicity and concavity) of each are tested. Ideally, concavity and monotonicity should be observed at every observation. In practice, conformity at the mean is normally sufficient. Furthermore, it is essential that inputs with a higher weight on the frontier (higher relative elasticity) are theoretically consistent. For example, it is important that the herd input in the cattle finishing system is consistent as it is the most important determinant of output (highest elasticity). Results from these tests are presented in Appendix A. While theoretical violations are observed in all models, it is evident that the True Effects models perform significantly better with fewer inconsistencies in all systems. Overall, the True Fixed effects model is found to be the most appropriate approach for the cereals system while the True Random Effects model appears to be the most consistent in all remaining systems. It is apparent that controlling for unobserved heterogeneity has produced more theoretically consistent results.

TFP Estimates and Components

The overall TFP results for these preferred models are presented in Figure 1.

Figure 1: Cumulative Total Factor Productivity growth by System, 1996-2006.[3]



TFP growth is the highest in the cattle rearing system followed by the dairy, cattle finishing, sheep and cereals systems. Average annual TFP growth rates are 2 per cent, 1.4 per cent, 0.9 per cent, 0.4 per cent and -0.2 per cent respectively. The cattle and dairy systems show broadly similar trends for the period.

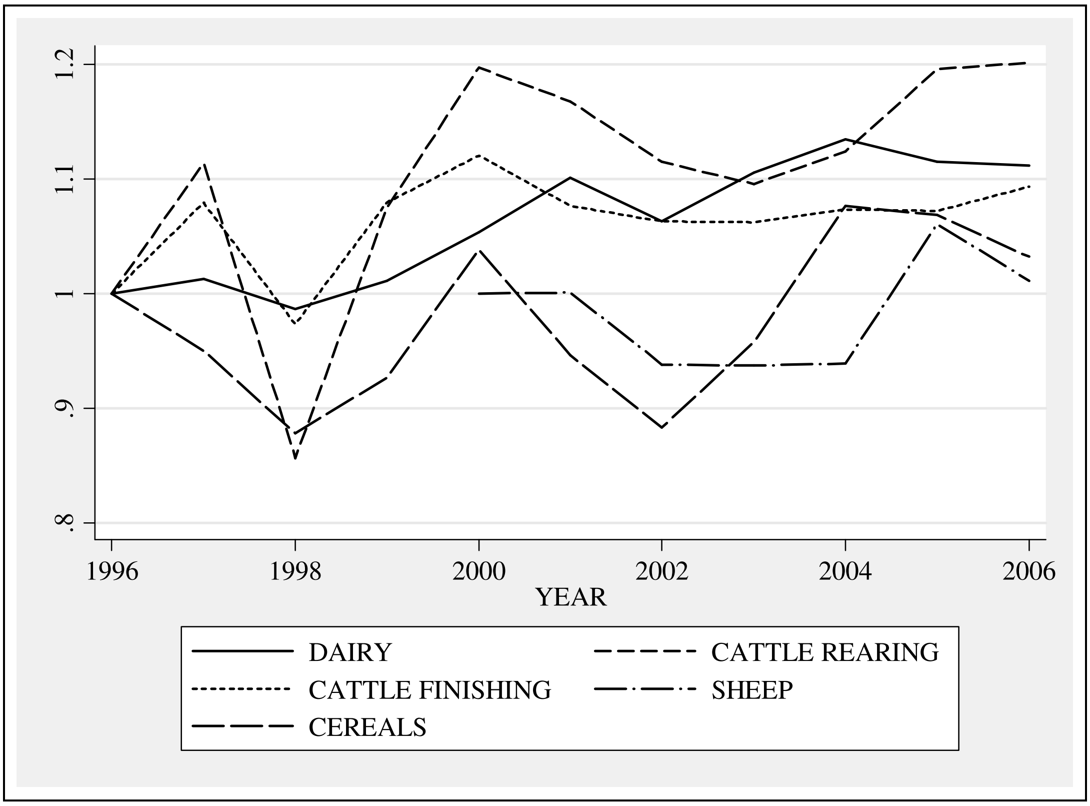
TFP fluctuations can largely be attributed to the weather, and in this regard, trends in the Cereals System give a reasonable approximation of prevailing conditions. In 2000, excellent growing conditions lead to record crop yields for all mainline crops (Department of Agriculture and Food, 2001). Comparable circumstances also prevailed in 2004 and again record yields were observed (Department of Agriculture and Food, 2005b). Similarly, TFP declines in 1998 and 2002 are due to adverse weather conditions in these years. In 1998, lack of sunshine and persistent rain significantly delayed sowing and harvesting. The potato crop was particularly affected in this year with severe frost damage in the first half of the year followed by further

[3] The Cereals sector trend is based on results from the True Fixed Effects model. All remained sectors are based on the True Random Effects model.

harvesting problems (Department of Agriculture and Food, 1999). Although slightly less reliant on the weather, the livestock system are also highly dependent – favourable weather leads to good grass growth which in turn increases feed intake and reduces feeding costs. The TFP trends in these systems are, in general, complementary to that observed in the Cereals Systems. 1998 was a difficult year for the cattle systems, where a prolonged and wet spring, a poor grazing season and limited winter feed supplies relative to requirements created difficulties (Dunne, 2000). Furthermore, productivity in the cattle systems from 1996 was likely affected by the outbreak of BSE in March of this year. Further BSE worries in the UK in late 2000 coupled with the outbreak of Foot and Mouth disease in 2001, have both no doubt added to low productivity growth in the livestock systems from around this time. Further examination of the influence of weather related factors on productivity shifts in under way at present with the linking of NFS individual farm data with weather data. This model development should help identify factors influencing shifts in TFP over time.

The components of TFP change – technical change, scale efficiency change and technical efficiency change – are displayed in Figures 2 through 4. Given the similarities of Figures 1 and 2, it is apparent the technical change is the main determinant of TFP in Ireland.

Figure 2: Cumulative Technical Change by System, 1996-2000



Increasing returns to scale are prevalent in the dairy, cattle rearing (slight) and cereals systems while very slight decreasing returns to scale are evident in the cattle finishing and sheep systems. Increases in average size would therefore lead to improvements in scale efficiency in the former systems. However, the only notable improvements in scale efficiency are evident in the dairy system (Figure 3). This is expected given that the average size of operations is increasing (the average number of cows increased from 45 in 1996 to 57 in 2006). Improvements are also evident in the cereals system up until 2000 but subsequently decline. This is also consistent with the trends in mean input use which generally increase until 2000 and declined thereafter. Technical efficiency improvements (Figure 4) are only evident in the sheep system while significant declines in mean efficiency are observed in the cereals system. The remaining systems show little movement. No significant increase in technical efficiency is evident in either 2005 or 2006, the years of decoupled support.

Figure 3: Cumulative Scale Efficiency Change, 1996-2006

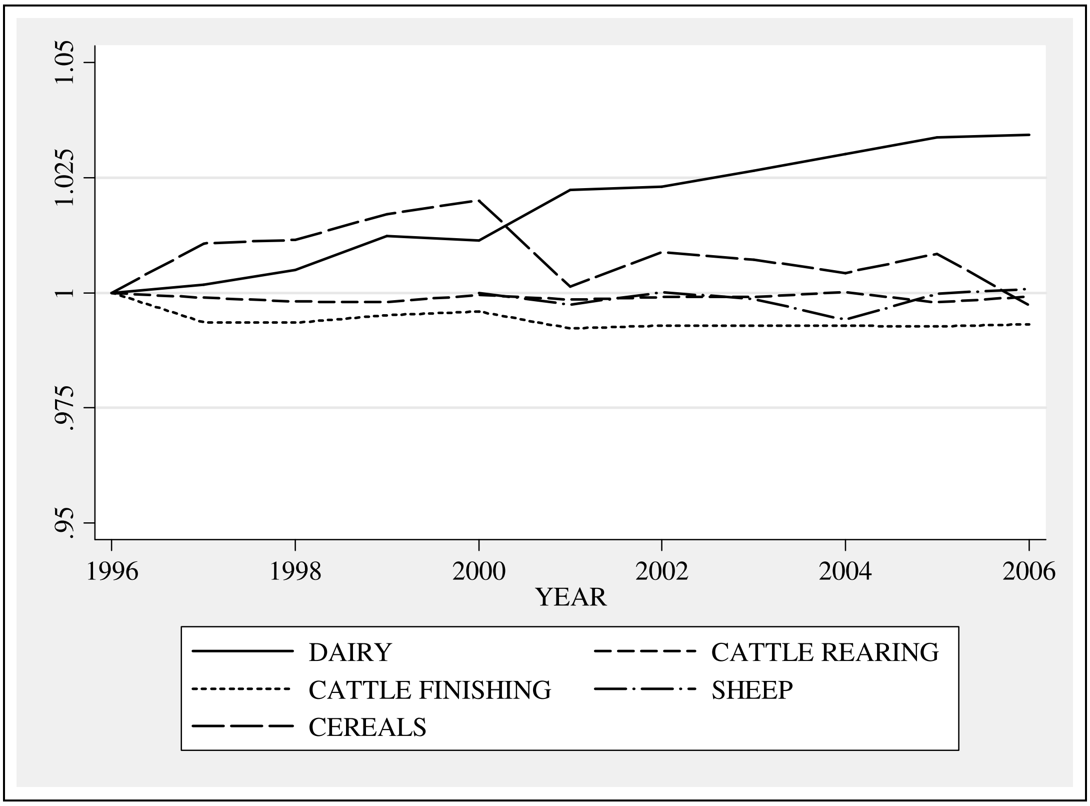
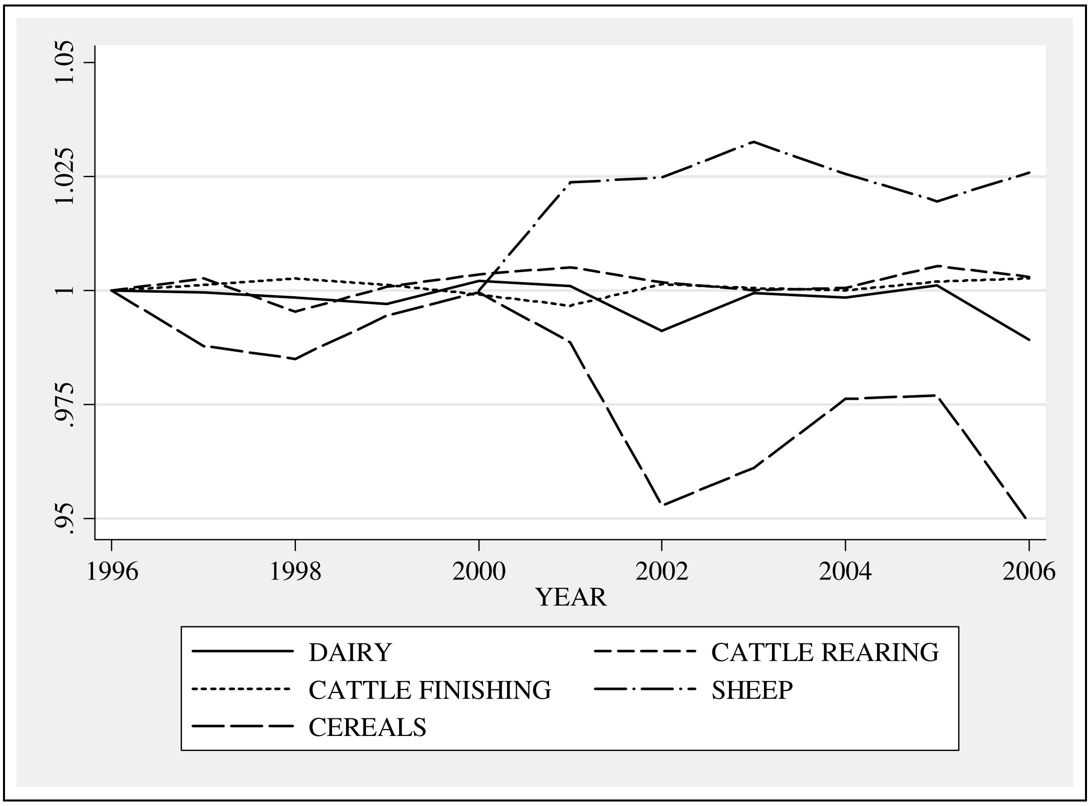

1.05
1.025
1
.975
.95
1996
1998
2000
2002
2004
2006
YEAR
DAIRY
CATTLE REARING
CATTLE FINISHING
SHEEP
CEREALS

Figure 4: Cumulative Technical Efficiency Change, 1996-2006



Efficiency Determinants

Table 2 presents a summary of the efficiency results from the Orea and Kumbhakar (2004) model for all systems. These are displayed as percentage effects for the dummy variables and elasticities for the continuous variables.[4] The results show each variable's effect on *inefficiency* levels and as such, a negative coefficient implies a positive influence on *efficiency*. It is evident that efficiency levels are, in general, positively correlated with extension use (although only significantly in the dairy system), soil quality, the overall size of the farm, the level of intensification (livestock systems) and the level of specialisation. The use of artificial insemination (AI) is also explored in the dairy and cattle rearing systems but is only significant in the dairy system.

[4] Percentage effects for the dummy variables are calculated as the percentage change in inefficiency resulting from a movement in the variable from zero to one. Elasticities are calculated by differentiating equation 4.2 with respect to each efficiency input and dividing by mean inefficiency.

Table 2: Percentage Effects (Dummy Variables) and Elasticities (Continuous Variables) of Efficiency Variables

	Dairy	Cattle Rearing	Cattle Finishing	Sheep	Cereals
SOIL2 (D)[5]	* 9.658	*** 27.797	** 19.421	*** 67.727	*NR*
SOIL3 (D)	** 26.355	*** 57.180	*** 60.505	*** 103.677	*NR*
EXTENSION (D)	**-4.435	-3.937	8.450	-12.702	-1.836
OFF-FARM (D)	2.985	0.794	-0.367	12.820	2.968
AI (D)	***-7.256	0.582	*NR*	*NR*	*NR*
DECOUPLING (D)	*** 8.209	-6.556	-11.441	-2.342	1.526
FARMSIZE	***-0.177	***-0.223	**-0.150	-0.004	***-0.449
AGE	*** 0.264	-0.029	-0.063	*** 0.876	0.196
SPECIALISE	***-0.796	0.057	-0.180	** 0.317	***-0.502
INTENSIFICATION	-0.019	***-0.636	***-0.412	***-0.250	*NR*

The coefficient for off-farm employment is positive in all but the cattle finishing system, which would imply that those with off-farm employment are less efficient. However, this effect is not significant in any sector and therefore implies that farms with an off-farm job are no less efficient than farms without. This result highlights the need for farmers to critically analyse their on-farm time management to explore the viability of pursuing part-time employment outside of the farm.

The importance of the scale of operations is of particular interest. The analysis of previous section highlights that increasing returns to scale are present in all but the cattle finishing and sheep systems. Results from this model also show that larger farms

[5] Where 'NR' means the variable is not relevant to the sector. *** indicates significance of 1 per cent, ** at 5 per cent and * at 10 per cent. All inputs have been divided by their means and converted into logs

are more efficient. This implies that increasing scale would likely lead to increases in productivity though two separate routes: higher technical efficiency levels and also higher scale efficiency levels.

The degree of specialisation is also significant in the majority of sectors. Higher levels of specialisation are associated with higher efficiency levels in the dairy, cereals and cattle finishing systems but to lower efficiency levels in the cattle rearing and sheep systems (not significant in the cattle systems). This may be due to the poor financial position of the latter systems and the need to expand into other sectors where possible.

Conclusions

A number of stochastic frontier models for panel data were employed in this analysis. These models are divided into standard approaches (Pitt and Lee, 1981 and Battese and Coelli, 1992) and also a newer set of models recently proposed by Greene (2005) which are designed to remove unobserved heterogeneity from the technical inefficiency estimates (True Fixed and Random Effects models). The main difference in these models is in their underlying assumptions regarding the inefficiency component: The Pitt and Lee model assumes that inefficiency is time-invariant while the Battese and Coelli model assumes that all farms follow an identical inefficiency trend. Both True Effects models allow inefficiency to vary freely through time but also attempt to separate and remove any time-invariant unobserved heterogeneity from the inefficiency term.

Despite considerable differences in the underlying inefficiency assumptions, these models generally depict similar overall trends in TFP for the period. Technical change and scale efficiency change are also very similar across models. Although technical efficiency change contributes only slightly to overall TFP, considerable differences are evident across models in each sector. In an effort to uncover the most appropriate model, the theoretical consistency (violations of first and second-order conditions) of the production function in each is explored. In all but the Cereals sector, the True Random Effects model is the more theoretically consistent (all models perform well in the Sheep sector). In the Cereals sector, the True Fixed Effects model performs significantly better.

TFP growth was highest in the Cattle Rearing sector followed by the Dairy, Cattle Finishing, Sheep and Cereals sectors. Average annual TFP growth rates are 2 per cent, 1.4 per cent, 0.9 per cent, 0.4 per cent and -0.2 per cent respectively. The Cattle and Dairy sectors show broadly similar trends for the period. In general, 1998 and 2002 appear to show TFP declines in all sectors while improvements are evident in 2000 and 2004.

TFP fluctuations can largely be attributed to the weather, and in this regard, trends in individual sectors give a reasonable approximation of prevailing conditions in individual years. In an attempt to control for these weather conditions a model development is currently under way in which weather variables are being directly linked to the NFS data and included in the production function.

The determinants of technical efficiency were also explored. It was found that efficiency levels were positively correlated with extension use (although only significant in the dairy system), soil quality and the level of intensification (livestock systems). The use of artificial insemination was also explored in the dairy and cattle rearing systems but is only significant in the dairy system. The incidence of off-farm employment was not significant in any system and as such has no significant negative effect on farm efficiency levels.

This model also included a dummy variable for farms that are surveyed in either 2005 and/or 2006 alongside the usual efficiency inputs to further explore the effects of decoupling. In the cattle rearing, cattle finishing and sheep systems, the coefficient was of the hypothesised negative sign which would suggest that decoupling has lead to improvements in efficiency. In the dairy and cereals systems, the coefficient was positive which is contrary to the hypothesis (implying mean efficiency has in fact declined in these years). However, only in the dairy system was the effect significant. Although predominantly insignificant, these results are again suggestive. The production effects of decoupling are expected to be larger in the both cattle and sheep systems where the reliance on direct payments is considerably higher. Given that only these systems display the expected relationship (despite insignificance) may suggest a possible causal relationship. However, notwithstanding the above evidence, the overriding hypothesis has in general not been realised – it appears decoupling has not brought significant system-wide improvements in technical efficiency. The results may help highlight the underlying motives of farmers.

The importance of the scale of operations is of particular interest and the results highlight that larger farms are more efficient. This finding presents a serious challenge for policy makers and for those involved in planning the future of Irish agriculture, which at present is characterised by relatively small scale operations (internationally). The degree of specialisation will also be an important issue for the competitive future of Irish farming. It is evident that higher levels of specialisation are associated with higher efficiency levels in the dairy, cereals and cattle finishing systems but to lower efficiency levels in the cattle rearing and sheep systems (not significant in the cattle systems).

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Appendix A

Table A1: Correlation Matrices for Inefficiency Estimates

	PL	BC	TRE	TFE
---------------------------------*Dairy Sector*----------------------------------				
PL	1.000	-	-	-
BC	0.984	1.000	-	-
TRE	0.209	0.259	1.000	-
TFE	0.056	0.052	0.894	1.00
----------------------------*Cattle Rearing Sector*----------------------------				
PL	1.000	-	-	-
BC	0.655	1.000	-	-
TRE	0.243	0.263	1.000	-
TFE	0.050	0.032	0.920	1.00
----------------------------*Cattle Finishing Sector*--------------------------				
PL	1.000	-	-	-
BC	0.668	1.000	-	-
TRE	0.313	0.342	1.000	-
TFE	0.015	0.004	0.870	1.00
---------------------------------*Sheep Sector*----------------------------------				
PL	1.000	-	-	-
BC	0.800	1.000	-	-
TRE	0.309	0.331	1.000	-
TFE	0.073	0.079	0.939	1.00
---------------------------------*Cereals Sector*--------------------------------				
PL	1.000	-	-	-
BC	0.803	1.000	-	-
TRE	0.338	0.372	1.000	-
TFE	0.119	0.087	0.842	1.00

Table A2: Descriptive Statistics for Inefficiency Estimates (All Sectors)

	Mean	Standard Deviation	Skewness	Kurtosis	Minimum	Maximum
Dairy Sector						
PL [6]	0.237	0.141	0.530	2.972	0.008	0.800
BC	0.238	0.146	0.985	6.931	0.008	1.708
TRE	0.089	0.056	3.847	35.060	0.009	0.899
TFE	0.179	0.053	2.749	21.427	0.042	0.741
Cattle Rearing Sector						
PL	0.455	0.122	-0.351	2.891	0.058	0.927
BC	0.306	0.183	0.812	3.183	0.031	0.947
TRE	0.189	0.070	1.649	7.361	0.046	0.669
TFE	0.310	0.078	1.613	8.360	0.105	0.871
Cattle Finishing Sector						
PL	0.144	0.044	0.777	7.589	0.024	0.452
BC	0.098	0.061	1.533	7.324	0.015	0.507
TRE	0.062	0.024	2.506	14.673	0.015	0.275
TFE	0.072	0.013	1.745	10.552	0.032	0.154
Sheep Sector						
PL	0.377	0.102	-0.139	3.050	0.090	0.650
BC	0.277	0.176	1.229	4.611	0.042	1.023
TRE	0.230	0.111	1.650	7.041	0.055	0.957
TFE	0.335	0.103	1.639	8.308	0.112	1.121
Cereals Sector						
PL	0.371	0.126	0.571	4.251	0.045	0.858
BC	0.257	0.183	1.716	8.290	0.011	1.725
TRE	0.158	0.093	2.689	15.745	0.030	1.045
TFE	0.261	0.096	1.939	8.426	0.076	0.765

[6] Where PL, BC, TRE and TFE stand for Pit and Lee (1981), Battese and Coelli (1992), True Random Effects and True Fixed Effects respectively.

Table A.3: Theoretical Testing for Dairy Sector – Concavity and Monotonicity

	PL	BC	TRE	TFE
Mean of First-Order Conditions				
HERD	0.635	0.635	0.588	0.704
DIRECT	0.254	0.254	0.232	0.323
CAPITAL	0.080	0.080	0.075	0.069
LABOUR	0.111	0.111	0.126	0.060
LAND	0.009	0.009	0.039	-0.047
Percentage of First-Order Violations				
HERD	0%	0%	0%	0%
DIRECT	0%	0%	0%	0%
CAPITAL	.06%	0.09%	.03%	0.60%
LABOUR	9.02%	9.22%	3.15%	17.95%
LAND	37.88%	37.88%	15.69%	90.84%
Mean of Second-Order Conditions				
HERD	-0.130	-0.123	-0.303	0.236
DIRECT	-0.168	-0.167	-0.146	-0.125
CAPITAL	-0.054	-0.053	-0.049	-0.039
LABOUR	-0.311	-0.312	-0.344	-0.107
LAND	-0.060	-0.058	-0.100	0.023
Percentage of Second-Order Violations				
HERD	0.46%	0.52%	0%	100%
DIRECT	0%	0%	0%	0.03%
CAPITAL	0.29%	0.29%	0.31%	3.61%
LABOUR	0.03%	0.23%	0.06%	3.75%
LAND	6.33%	6.56%	1.75%	71.97%

Table A.4: Theoretical Testing for Cattle Rearing Sector – Concavity and Monotonicity

	PL	BC	TRE	TFE
Mean of First-Order Conditions				
DIRECT	0.194	0.193	0.188	0.195
CAPITAL	0.314	0.315	0.316	0.304
LABOUR	0.403	0.401	0.400	0.456
LAND	0.096	0.097	0.089	0.067
Percentage of First-Order Violations				
DIRECT	0.140%	0.140%	0.050%	0.240%
CAPITAL	0.000%	0.000%	0.000%	0.000%
LABOUR	0.050%	0.050%	0.000%	0.000%
LAND	2.130%	2.180%	1.000%	9.060%
Mean of Second-Order Conditions				
DIRECT	-0.046	-0.047	-0.077	-0.007
CAPITAL	-0.178	-0.178	-0.193	-0.141
LABOUR	-0.056	-0.057	-0.075	-0.140
LAND	-0.125	-0.124	-0.112	-0.074
Percentage of Second-Order Violations				
DIRECT	15.27%	14.98%	5.550%	40.640%
CAPITAL	0.050%	0.050%	0.050%	0.240%
LABOUR	0.470%	0.430%	0.190%	0.000%
LAND	0.380%	0.430%	0.430%	4.550%

Table A.5: Theoretical Testing for Cattle Finishing Sector – Concavity and Monotonicity

	PL	BC	TRE	TFE
----------*Mean of First-Order Conditions*----------				
HERD	0.701	0.701	0.710	0.726
DIRECT	0.123	0.123	0.120	0.125
CAPITAL	0.012	0.012	0.012	0.011
LABOUR	0.119	0.119	0.117	0.116
LAND	0.041	0.041	0.039	0.021
----------*Percentage of First-Order Violations*----------				
HERD	0.00%	0.00%	0.00%	0.00%
DIRECT	1.77%	1.77%	1.31%	1.12%
CAPITAL	8.62%	8.62%	7.55%	13.85%
LABOUR	0.05%	0.05%	0.05%	0.05%
LAND	4.71%	4.76%	6.25%	17.72%
----------*Mean of Second-Order Conditions*----------				
HERD	-0.044	-0.044	-0.041	-0.025
DIRECT	-0.040	-0.040	-0.044	-0.052
CAPITAL	-0.003	-0.003	-0.004	-0.005
LABOUR	-0.082	-0.082	-0.075	-0.067
LAND	0.011	0.011	0.000	0.022
----------*Percentage of Second-Order Violations*----------				
HERD	18.18%	18.18%	20.61%	28.30%
DIRECT	10.91%	10.91%	9.18%	9.00%
CAPITAL	31.19%	31.05%	25.50%	27.27%
LABOUR	0.19%	0.19%	0.51%	1.21%
LAND	66.53%	66.53%	47.51%	83.64%

Table A.6: Theoretical Testing for Sheep Sector – Concavity and Monotonicity

	PL	BC	TRE	TFE
	Mean of First-Order Conditions			
DIRECT	0.389	0.387	0.387	0.395
CAPITAL	0.195	0.196	0.201	0.206
LABOUR	0.403	0.400	0.396	0.393
	Percentage of First-Order Violations			
DIRECT	0.460%	0.700%	0.580%	0.580%
CAPITAL	0.000%	0.000%	0.000%	0.000%
LABOUR	0.000%	0.000%	0.000%	0.120%
	Mean of Second-Order Conditions			
DIRECT	-0.083	-0.069	-0.082	-0.079
CAPITAL	-0.252	-0.258	-0.248	-0.236
LABOUR	-0.113	-0.134	-0.095	-0.120
	Percentage of Second-Order Violations			
DIRECT	3.250%	4.870%	3.250%	4.290%
CAPITAL	0.000%	0.000%	0.000%	0.000%
LABOUR	0.350%	0.120%	0.580%	0.230%

Table A.7: Theoretical Testing for Cereals Sector – Concavity and Monotonicity

	PL	BC	TRE	TFE
---*Mean of First-Order Conditions*--------------------------------------				
LAND	0.202	0.200	0.253	0.075
DIRECT	0.406	0.412	0.366	0.573
CAPITAL	0.027	0.027	0.031	0.015
LABOUR	0.444	0.442	0.443	0.424
--*Percentage of First-Order Violations*--------------------------------				
LAND	6.50%	6.69%	4.53%	29.53%
DIRECT	0.89%	0.89%	1.48%	0.20%
CAPITAL	22.34%	22.15%	16.63%	29.63%
LABOUR	0.10%	0.10%	0.10%	0.00%
---*Mean of Second-Order Conditions*-----------------------------------				
LAND	-0.101	-0.115	-0.138	-0.205
DIRECT	-0.681	-0.694	-0.705	-0.617
CAPITAL	0.010	0.009	-0.005	-0.014
LABOUR	-0.002	-0.021	0.017	-0.087
---*Percentage of Second-Order Violations*-------------------------------				
LAND	10.83%	8.76%	5.71%	6.30%
DIRECT	0.00%	0.00%	0.00%	0.00%
CAPITAL	55.12%	52.95%	42.22%	29.53%
LABOUR	25.10%	11.81%	51.08%	0.20%