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Estimation of the Impact of CAP Reform on the Structure of Farming in the Disadvantaged Areas of Ireland

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Abstract

In this paper the Johansen model was used to examine the impact of CAP Reform on the structure of farming in the Disadvantaged Areas of Ireland. The model is essentially a policy impact model using an elasticity set. Application of the model requires information on all relevant elasticities of outputs and inputs with respect to all output and input prices. These elasticities were estimated directly for a translog profit function from a combination of cross section and time series data. In order to test the usefulness of the model, a validation exercise was undertaken for the period 1992–1995. The model performed reasonably well in that the predicted direction of change in the volume of outputs and inputs was generally in the same direction as actual volume changes in outputs and inputs over the period tested.

Keywords: Johansen model, dual approach, elasticity, symmetry, linearly homogeneous, monotonicity, convexity.

JEL Classification: Q1

1 Introduction

The Common Agricultural Policy (CAP) underwent radical reform in 1992. This reform resulted in a movement away from price support towards what are being called "direct income payments". The direct income payments take a variety of forms. Some payment mechanisms have been designed to maintain farm incomes while reducing the incentive to expand production; e.g. the introduction of quotas for livestock premium payments and set-aside. Other payment mechanisms were intended to have more specific environmental objectives, with the express aim of encouraging environmentally friendly farming practices. The European Community has committed itself to making more radical changes in CAP post 1996.

Following the 1992 CAP Reform, and the commitment to implement more radical changes in the future, there was much concern in areas heavily dependent on agriculture as to what the impact of such changes might be. In autumn 1993, the European Union (EU) commissioned a three year research project to investigate the impact of the 1992 Reform on peripheral areas in Ireland, Scotland and Portugal.[1] Part of this research involved the development of models for the agricultural sectors in each of the study areas to forecast the impact of policy changes on agricultural output. The study area chosen for Ireland is the designated "Disadvantaged Areas" within the meaning of Directive 84/268/EEC. University College Galway developed the agricultural model for the Irish study area. The results of this research are presented in this working paper.

The paper consists of seven sections. The theoretical background is outlined in section 2. An outline of the data and the estimation method used in the study is presented in sections 3 and 4. The results and a validation of the results are presented in section 5 and 6. Section 7 concludes.

2 Theoretical Background

There exists a multiplicity of agricultural models that attempt to simulate the impact of policy changes on the agricultural sector. For our purposes, it was important to have a model with general equilibrium type features; that is to say, a model that recognised the interdependence of different sub-sectors within agriculture. The Johansen model satisfied this requirement.

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[1] AAIR Proposal AIR3–CT93 0083 'The Impact of CAP Reforms on Peripheral Regions in the Community'.

The Johansen model is essentially a policy impact model using an elasticity set. Its application involves a two stage approach. In order to apply the model one must have estimates of the elasticity set. One may either choose to estimate the elasticity set or, alternatively, use their judgement as to what seem like reasonable elasticities. We chose to estimate the elasticities. In order to do so we adopted the dual approach.

2.1 Johansen Model

An essential element of this model is the matrix of output supply and input demand elasticities for the farm system. Expression 1 shows all outputs and inputs as functions of all prices and fixed factors.

$$\begin{aligned} Y_i &= f(P, Z) \quad i = 1, \ldots, n \\ -X_j &= f(P, Z) \quad j = 1, \ldots, k \end{aligned} \tag{1}$$

where Y_i is output of product i, X_j is input of product j, P is a matrix of all output and input prices, and Z is a matrix of quasi-fixed factors.

The Johansen model proposes the estimation of the impact of policy changes by linearising the system of output supply and input demand relations in terms of percentage changes (Dixon et. al. 1982). Thus, percentage changes in the volumes of all outputs and inputs are related to percentage changes in all prices and fixed factors via the appropriate elasticities.

For example, let us assume that a production system consists of 2 outputs, 1 variable input and one quasi-fixed input. Linearising in terms of percentage changes, the output supply and input demand relations are written as follows:

$$\begin{aligned} \hat{Y}_1 &= e_{11}\hat{P}_1 + e_{12}\hat{P}_2 + e_{13}\hat{P}_3 + e_{14}\hat{Z} \\ \hat{Y}_2 &= e_{21}\hat{P}_1 + e_{22}\hat{P}_2 + e_{23}\hat{P}_3 + e_{24}\hat{Z} \\ \hat{X} &= e_{31}\hat{P}_1 + e_{32}\hat{P}_2 + e_{33}\hat{P}_3 + e_{34}\hat{Z} \end{aligned}$$

where, $\hat{Y}_1, \hat{Y}_2, \hat{X}$ are the percentage volume changes in both outputs and the input respectively,

$\hat{P}_1, \hat{P}_2, \hat{P}_3$ are the percentage changes in the prices of both outputs and the input respectively,

$\hat{Z}$ is the percentage change in the quasi-fixed factor,

e_{11}, e_{22}, and e_{33} are the own price elasticities,

e_{12}, e_{13}, e_{31}, and e_{32} are the cross price elasticities,

e_{14}, e_{24}, and e_{34} are the quasi-fixed factor elasticities.

This can also be expressed in the following way:

$$\begin{aligned}
\hat{Y}_1 & -e_{11}\hat{P}_1 - e_{12}\hat{P}_2 - e_{13}\hat{P}_3 - e_{14}\hat{Z} &= 0 \\
\hat{Y}_2 & -e_{21}\hat{P}_1 - e_{22}\hat{P}_2 - e_{23}\hat{P}_3 - e_{24}\hat{Z} &= 0 \\
\hat{X} & -e_{31}\hat{P}_1 - e_{32}\hat{P}_2 - e_{33}\hat{P}_3 - e_{34}\hat{Z} &= 0
\end{aligned}$$

It can also be expressed in matrix form as follows:

$$\begin{bmatrix} 1 & 0 & 0 & -e_{11} & -e_{12} & -e_{13} & -e_{14} \\ 0 & 1 & 0 & -e_{21} & -e_{22} & -e_{23} & -e_{24} \\ 0 & 0 & 1 & -e_{31} & -e_{32} & -e_{33} & -e_{34} \end{bmatrix} \begin{bmatrix} \hat{Y}_1 \\ \hat{Y}_2 \\ \hat{X} \\ \hat{P}_1 \\ \hat{P}_2 \\ \hat{P}_3 \\ \hat{Z} \end{bmatrix} = 0$$

or $\mathbf{AV} = 0$, where $\mathbf{A}$ is the 3×7 matrix shown above and $\mathbf{V}$ is the 7×1 vector of variables.

Alternatively, one can engage in a process known as model closure. This basically involves dividing the above matrices into two matrices as follows:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{Y}_1 \\ \hat{Y}_2 \\ \hat{X} \end{bmatrix} + \begin{bmatrix} -e_{11} & -e_{12} & -e_{13} & -e_{14} \\ -e_{21} & -e_{22} & -e_{23} & -e_{24} \\ -e_{31} & -e_{32} & -e_{33} & -e_{34} \end{bmatrix} \begin{bmatrix} \hat{P}_1 \\ \hat{P}_2 \\ \hat{P}_3 \\ \hat{Z} \end{bmatrix} = 0$$

or $\mathbf{A}_1\mathbf{V}_1 + \mathbf{A}_2\mathbf{V}_2 = 0$.

The criterion used for the splitting of the original matrix are those variables that are endogenous $\mathbf{V}_1$ and those that are exogenous $\mathbf{V}_2$ (Munk, 1985). Thus, in the example given here, $\hat{Y}_1, \hat{Y}_2$ and $\hat{X}$ are endogenous variables, which are contained in the vector $\mathbf{V}_1$, while $\hat{P}_1, \hat{P}_2, \hat{P}_3$ and $\hat{Z}$ are the exogenous variables, which are contained in the vector $\mathbf{V}_2$. $\mathbf{A}_1$ is the identity matrix, while $\mathbf{A}_2$ is the matrix of output supply and input demand elasticities, which, in this case, are estimated from the translog profit function. In other words, one set of variables (the endogenous set) are determined within the system, while the other set of variables are determined outside the system. Proceeding logically one can see that:

$$\mathbf{A}_1\mathbf{V}_1 = -\mathbf{A}_2\mathbf{V}_2$$

By matrix inversion, one can solve for $\mathbf{V}_1$ as follows:

$$\mathbf{V}_1 = -\mathbf{A}_1^{-1}\mathbf{A}_2\mathbf{V}_2$$

Writing out the matrices in full, the above expression is simply:

$$\begin{bmatrix} \hat{Y}_1 \\ \hat{Y}_2 \\ \hat{X} \end{bmatrix} = -\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} -e_{11} & -e_{12} & -e_{13} & -e_{14} \\ -e_{21} & -e_{22} & -e_{23} & -e_{24} \\ -e_{31} & -e_{32} & -e_{33} & -e_{34} \end{bmatrix} \begin{bmatrix} \hat{P}_1 \\ \hat{P}_2 \\ \hat{P}_3 \\ \hat{Z} \end{bmatrix}$$

The inverse of the identity matrix is simply the identity matrix, so the solution is the matrix of elasticities multiplied by the vector of price changes and fixed factor changes.

2.1.1 Estimating the impact of policy initiatives other than price changes

The great advantage of the Johansen model is that it is a very flexible tool for modelling the effects of different types of policy instruments. For example, the policy initiative could be a change in quota instead of a change in price. Let us assume that a quota is applied to output Y_1 and that the quota is reduced by a certain percentage. The quota change is now represented as an exogenous change, while the change in the shadow price (where the shadow price of a good is its true scarcity value) of good Y_1 is the endogenous variable. The procedure involved in modelling this policy initiative is to exchange the appropriate columns in the $\mathbf{A}_1$ and $\mathbf{A}_2$ matrices.

In this instance, since the manipulation is of the first equation, we swap the first column of matrix $\mathbf{A}_1$ with the first column of matrix $\mathbf{A}_1$ and solve for the system as follows:

$$\begin{bmatrix} \hat{Y}_1 \\ \hat{Y}_2 \\ \hat{X} \end{bmatrix} = -\begin{bmatrix} -e_{11} & 0 & 0 \\ -e_{21} & 1 & 0 \\ -e_{31} & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} 1 & -e_{12} & -e_{13} & -e_{14} \\ 0 & -e_{22} & -e_{23} & -e_{24} \\ 0 & -e_{32} & -e_{33} & -e_{34} \end{bmatrix} \begin{bmatrix} \hat{P}_1 \\ \hat{P}_2 \\ \hat{P}_3 \\ \hat{Z} \end{bmatrix}$$

This approach is, essentially, general equilibrium in that a change in quota of one good affects the outputs of other goods (just as a change in the price of one good affects the output of all other goods).

One could also model the effect of a quota on inputs. In the context of the example given above, this would involve switching the third columns in the two **A** matrices.

Policy initiatives such as taxation or subsidisation of outputs and inputs are easily incorporated into this model, since they can be modelled as a change in the prices that the producer faces.

Modelling direct income payments is more difficult, since direct payments are by definition production neutral. If one assumes that direct income payments have zero output effects, then one would not include them in the Johansen model. Alternatively, one could treat such payments as an addition to the producer's financial capital. If a producer's plans are constrained by his/her level of financial capital, then the latter acts as an exogenous constraint on the level of inputs and outputs and, as a consequence, profits. If such capital is included in the model as a quasi fixed factor, then one would show such payments as a change in this quasi fixed factor. Often in this type of model aggregation of different types of capital takes place. When one engages in aggregation, one is implicitly assuming perfect substitutability between the different forms of capital. In other words, if one shows an increase in direct income payments as an increase in the capital stock, one is assuming that the output effect of a change in financial capital is the same as the output effect of a change in any other type of physical capital also included in this category.

Set-aside of land is another popular policy tool that has been used in recent CAP initiatives. Farmers are compensated financially for setting land aside. If land is included as a fixed factor, then set-aside can be modelled as a reduction in this fixed factor. Financial compensation for set-aside can be either ignored (if we assume that it has no output effects) or it can be included as an increase in some other fixed factor category, as explained in the previous paragraph.

2.2 The Dual Approach

Profits are a function of outputs and inputs, given the market prices of these outputs and inputs and given the technology that changes inputs into outputs. The dual approach, which is widely discussed in the literature (see Diewert 1974 and Lau 1978), assumes that information about short run production functions can be summarised in a restricted profit function, that relates profits to all prices and fixed factors.

$$\Pi = \Pi(P, Z) \tag{2}$$

where Π represents profit, P is a vector of output and input prices and Z is the level of fixed factors. The nature of the relationship between inputs and outputs is the nature of the technological relationship between prices and profits, if the decision maker is a rational profit maximiser. The function that relates profit to prices is known as the *dual* of the primal relationship between inputs and outputs. It is valid to use the dual approach if one assumes that markets are perfectly competitive, in the sense that prices are given, and, if one assumes that rational profit maximisation describes accurately producer behaviour.

The profit function is the dual of the production function if it satisfies certain regularity conditions. The profit function must be (i) non-negative, (ii) continuous, (iii) linearly homogeneous in prices and fixed inputs, (iv) convex in prices, (v) concave in fixed inputs, (vi) increasing in output prices and decreasing in input prices and (vii) non-decreasing in fixed inputs.

If the profit function satisfies these conditions for rational profit maximising behaviour, then it is very straightforward to solve for output supply and input demand functions. A proposition known as Hotelling's Lemma states that the first derivative of a profit function with respect to the output/input price of a good will give us the optimal output/input of that good (Varian, 1992).

$$\frac{\partial \Pi(P,Z)}{\partial P_i} = Y_i \quad \text{or} \quad \frac{\partial \Pi(P,Z)}{\partial P_j} = -X_j \tag{3}$$

where P_i denotes the output price of good i, P_j stands for the price of input j, Y_i denotes the quantity of output of good i and X_j represents the input j. The first derivative is positive with respect to output prices and negative with respect to input prices.

The first derivative of the profit function with respect to the fixed factor gives us the shadow price of that factor; in other words it shows us the effect on profits of a marginal change in the level of the fixed factor. When the fixed factor is at its optimal level (the level that the profit maximising producer would choose in the long run), the shadow price of the fixed factor should equal its market price.

$$\frac{\delta \Pi}{\delta Z^*} = P_z \tag{4}$$

where Z^* is the optimal level of the fixed factor and P_z is the market price of the fixed factor.

In this study we assume that certain inputs are fixed and proceed to estimate the relationship between the restricted profit function and both prices and the level of fixed factors. We justify this approach by appealing to common sense. There are also precedents in using restricted profit functions in agricultural modelling (see Cox and Higgins 1985, Higgins 1986, Guyomard 1988 and Boyle and O'Neill 1990).

2.2.1 The Translog Profit Function

In order to estimate the relevant technological parameters, we need to have a more precise idea of the nature of the functional relationship between inputs and outputs. Some of the more popular functional forms used to describe technology, such as Cobb-Douglas and CES (constant elasticity of substitution), we deemed too restrictive. The former constrains the elasticity of substitution between inputs to equal one, while the latter constrains the elasticity of substitution between inputs to be constant. We adopt a more flexible functional form known as the Translog function. The Translog function is flexible enough to allow the elasticities of substitution between inputs, outputs and inputs and outputs to vary.

The log of this profit function is shown in expression 5:

$$\begin{aligned} \ln \Pi(P, Z) &= a_0 + \sum_{i=1}^{n} a_i \ln P_i + \sum_{k=1}^{m} b_k \ln Z_k + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} \ln P_i \ln P_j \\ & \sum_{i=1}^{n} \sum_{k=1}^{m} b_{ik} \ln P_i \ln Z_k + \frac{1}{2} \sum_{h=1}^{m} \sum_{k=1}^{m} c_{hk} \ln Z_h \ln Z_k \qquad (5) \\ & i, j = 1, \ldots, n \qquad h, k = 1, \ldots, m \end{aligned}$$

where Π in this instance is the difference between gross revenue and the cost of all variable inputs and P represents the vector of prices of all outputs *and* all inputs.

We apply Hotelling's Lemma to get the output supply and input demand equations. However, the derivative of the *log* of profit with respect to the *log* of output/input prices gives us the *share* (as opposed to the absolute quantity) of that output/input in total profit. (Sidhu, Baanante, 1981; Christensen, Jorgensen, Lau 1973).

$$\frac{\partial \ln \Pi}{\partial P_i} = \frac{\partial \Pi}{\partial P_i} \frac{P_i}{\Pi} = Y_i \frac{P_i}{\Pi} = S_i \qquad (6)$$

where S_i is the share of output/input i in variable profit. It is positive for outputs and negative for inputs. Hence, expression 7 simply shows the relationship between the share of an output or input and the logs of all prices and fixed factors.

$$S_i = a_i + \sum_{i=1}^{n} \ln P_j + \sum_{k=1}^{m} b_{ik} \ln Z_k \qquad (7)$$

The beauty of this expression is its simplicity, shares are simply expressed as a linear expression of all prices and fixed inputs. This facilitates estimation since we can use a linear estimation method. Of course we cannot be sure that the model is correct in the sense that it is an accurate representation of the behaviour that we are trying to capture or the technology constraining that behaviour. As mentioned in section 2.2, the profit function is the dual of the production function and an appropriate way of representing technology, when prices are given and producers behave in a profit maximising manner. For the translog specification, linear homogeneity of degree one in prices (one of the regularity conditions for the profit function to be the dual of the production function) is satisfied when expression 8 holds.

$$\sum_{i=1}^{n} a_i = 1, \sum_{j=1}^{n} a_{ij} = 0, \quad \text{for all } i \qquad \text{and} \quad \sum_{i=1}^{n} b_{ik} = 0 \text{ for all } k \tag{8}$$

Symmetry (which is a consequence of profit maximisation and which requires that the compensated cross price effects between any pair of inputs and/or outputs be the same) is satisfied when equation 9 holds.

$$a_{ij} \quad = a_{ji} \quad \text{for all } i \text{ and } j \tag{9}$$

We can test for homogeneity and symmetry or we can arbitrarily impose homogeneity and symmetry restrictions. We adopt the latter approach.

It is not possible to impose monotonicity and convexity and so these properties have to be tested for statistically. Monotonicity (the condition that output is increasing in output prices and decreasing in input prices) is satisfied if predicted output and input shares are positive and negative respectively. Convexity is satisfied if the bordered Hessian matrix of second order partial derivatives of the profit function is positive semi-definite (Higgins, 1981). Failure to satisfy convexity throws into question profit maximisation as the driving force behind the producer's decisions.

The set of share equations contain all the information necessary to estimate own and cross price elasticities of output supply and input demand. These elasticities are calculated using the following formulae (Binswanger, 1974):

$$e_{ii} = \frac{a_{ii}}{S_i} + S_i - 1 \qquad\qquad e_{ij} = \frac{a_{ij}}{S_i} + S_j \tag{10}$$

where e_{ii} and e_{ij} are the own and cross price elasticities of output supply and input demand and S_i and S_i are the share of input/output i and j respectively for the average of all farms used in the estimation.

The netput quasi-fixed factor elasticity is estimated using the following formula:

$$e_{ik} \quad = \quad b_k + \sum_{h=1}^{m} c_{hk} \ln Z_h + \sum_{i=1}^{n} b_{ik} \ln P_i + \frac{b_{ik}}{S_i} \tag{11}$$

3 Data

The data used are from the Farm Management Survey conducted by Teagasc, the Agricultural and Food Development Authority. The data set consisted of individual farm records for the designated "Disadvantaged Areas" within the meaning of Directive 84/268/EEC. The Disadvantaged Areas covered approximately 58% of the land area of the Republic in the period 1989 to 1991, which is the time span covered by our data set.

Estimates were derived for the aggregate farm. We did not disaggregate by farm size or by system of farming. It was not feasible to do so, due to the small number of observations in certain size and system categories.

The estimates were derived from a data set of 1,491 observations. This did not include all the farm records in the original data set. Some records were excluded on the grounds that their inclusion would have introduced a major distortion into the estimates. Farms not yielding a positive return to their fixed factors were excluded. Long term losses are not consistent with rational profit maximising behaviour and, as such, had to be excluded from a behavioural model whose basic premise is the rational pursuit of profit. Pig and poultry producers were also excluded. On the vast majority of farms in the Disadvantaged Areas, pig and poultry production either does not exist or, if it does, it is a very marginal activity. There are, however, a small number of very large producers who are all concentrated in a relatively small geographical area. Running a separate regression to model the behaviour of a small number of pig and poultry producers was not feasible due to lack of observations. Including them in the representative farm model was also inappropriate for standard methodological reasons.

In order to derive the estimates it was necessary to undertake a lot of work with the available data. The model consisted of 4 outputs, 4 variable inputs and 3 quasi-fixed inputs. The outputs included were: (i) milk; (ii) cattle; (iii) sheep and; (iv) crops, while the variable inputs included were: (i) purchased concentrates; (ii) bulky feed; (iii) fertiliser and; (iv) hired labour. The fixed inputs included were: (i) the utilised agricultural area of land; (ii) family labour defined in terms of labour units and; (iii) value of buildings, machinery and livestock (aggregated together to represent the farm's working capital). For more details see Appendix A.

4 Estimation

The parameters of the share equations were estimated from the following system (equation 7, earlier):

$$S_i \;=\; a_i + \sum_{i=1}^{n} a_{ij} \ln P_j + \sum_{k=1}^{m} b_{ik} \ln Z_k$$

The system consisted of 8 share equations. Each equation included 8 price variables and three quasi-fixed factors as exogenous variables. The linear homogeneity and symmetry restrictions outlined in section 2.2.1 were imposed on the system. They were imposed by dropping one share equation, and using SAS/ETS software. The hired labour share equation was dropped. The parameters of this equation were then indirectly calculated from the other 7 estimated equations.

The choice of estimation method was governed by two factors:

1. The fact that error terms across equations are correlated. This correlation arises because of the restriction that the share equations sum to 1. The sum of the error terms must equal zero for every observation, since all share equations for each farm must add up to 1.
2. The need to impose symmetry restrictions (cross equation restrictions) on the estimating system.

Given the combination of these two factors, a systems method of estimation was deemed appropriate. The systems method chosen was the Zellner or Seemingly Unrelated Regression Estimation method. For efficient estimation (by which we mean the estimator that yields the minimum variance), one must take into account the correlation between equation errors. Zellner estimation achieves an improvement in efficiency by taking into explicit account the fact that cross-equation error correlations may not be zero (Pindyck and Rubinfeld 1991). The improvement in efficiency is gained by treating the system of seemingly unrelated equations as a single large equation and applying generalised least squares estimation. The Zellner method also allows for the imposition of cross equation restrictions (Griffiths, Hill and Judge, 1993). For a definition of the variables included in the Generalised Translog Profit Function see Appendix B.

As stated above we dropped the hired labour share equation from the estimating system. The choice of which of the eight share equations to drop was an arbitrary one. The seemingly unrelated regression estimates are not invariant to the choice of equation to drop. However, iteration of the seemingly unrelated regression technique produces parameter estimates that converge to maximum likelihood parameter estimates, which are unique and independent of the equation omitted (Johnston, 1991). Therefore we adopted the Iterative Zellner Method.

5 Results

The estimated equations are outlined in Table 1. The degree of observed variance explained, as measured by the R^2, is disappointingly low and quite a number of the coefficients are not statistically significant. However, it was not possible to improve on these results.

If profit-maximising behaviour is satisfied, then the conditions of monotonicity and convexity must be satisfied. Monotonicity is satisfied if the predicted output shares are positive and predicted input shares are negative. This condition was checked at the average level of prices and fixed factors and was found to hold. Convexity is satisfied if the bordered Hessian matrix of second partial derivatives of the profit function with respect to netput prices is positive semi-definite. This was checked using Cholesky factorisation but was found not to hold (Fuss and Mc Fadden 1978). This rejection of convexity may have been due to data problems or because of variables left out of the system.

Using the estimated parameters of the share equations, the own and cross price elasticities of output supply and input demand were estimated. All of these elasticities were estimated at the average level of prices and fixed inputs and are outlined in Table 2.

- The own price elasticities for all four outputs; milk, cattle, sheep and crops have the correct sign. The own price elasticities for inputs have the correct sign except for bulky feed. The positive own-price elasticity for bulky feed is consistent with the rejection of convexity reported earlier.
- Milk and cattle are substitutes. Milk is more responsive to a change in cattle prices than cattle output is to a change in milk price. This is probably due to the fact that it is easier to adjust milk output than cattle output, as the former can be adjusted by changing concentrate feed levels or by drying off animals earlier or by feeding milk to calves. Milk and sheep are complements. Sheep output is more responsive to a change in the price of milk than milk output is to a change in the price of sheep. Milk and crops are substitutes. An increase in the price of milk leads to a predicted increase in all inputs, which is what one would expect.

- Cattle and sheep are substitutes and cattle and crops are complements. An increase in the price of cattle leads to a decrease in the quantity of purchased concentrates and bulky feed and to an increase in fertiliser and hired labour. One would expect an increase in the price of cattle to lead to an increase in the demand for purchased concentrates and bulky feed. However, milk and sheep output decrease as a result of an increase in the price of cattle. This may explain why the quantity of purchased concentrates and bulky feed decreases. Also, cattle rearing practices in disadvantaged areas are fairly extensive. Animals would be mainly grass fed, which may also explain why feed input decreases as cattle prices increase.

- Sheep and crops are substitutes. Crops are more responsive to a change in the price of sheep than sheep are to a change in the price of crops. An increase in the price of sheep leads to an increase in all inputs as one would expect.

- An increase in the price of crops leads to a decrease in the quantity of purchased concentrates and fertiliser use and an increase in bulky feed and hired labour.

- An increase in the price of purchased concentrates leads to a decrease in milk and sheep output and an increase in cattle and crop output which is what one would expect, since purchased concentrates are an important input in dairying. They are also more important as an input in sheep production than in cattle production. An increase in the price of purchased concentrates leads to a decrease in the quantity of all other inputs in the typical farm. This means that they are complementary.

- An increase in the price of fertiliser leads to a decrease in milk, cattle and sheep output and an increase in crop output. This is consistent with common sense, since fertiliser is an important input in all enterprises. An increase in the price of fertiliser leads to a decrease in the quantities of purchased concentrates and bulky feed and an increase in hired labour.

- An increase in the price of bulky feed leads to a decrease in the output of milk, sheep and crops and an increase in the output of cattle.

- An increase in the price of hired labour leads to a decrease in the quantity of all outputs and inputs except fertiliser.

The own and cross price elasticities outlined in Table 2 seem reasonable in general and were accepted as the elasticity figures to be employed in the Johansen model (Appendix C).

6 Validation of the model

In order to ensure that the estimated elasticities are reasonable and are, in fact, an acceptable approximation of the representative farmer's response to policy changes, it was necessary to validate the model. This was done by considering historical policy changes and changes in market conditions that affected the profitability of production and, using the Johansen model, predicting the changes in the volume of all outputs and inputs as a result of these changes. The predicted changes were then compared to actual changes for the time periods in question. There are two ways of measuring actual changes in the volumes of outputs and inputs. One is to conduct a survey in the study area and the second is to obtain information from published sources. In our case it would have been more accurate to conduct a survey, as published information is not available for our study area. However, due to the time constraint and the high cost involved it was not feasible to do so.

Data on the percentage changes in the price and volume of agricultural outputs and inputs is published in the Annual Review and Outlook for Agriculture, the Food Industry and Forestry on an annual basis. The percentage change in the volume of agricultural outputs and inputs relates to the whole country. Although this is not truly representative of our study area, the actual changes for the country as a whole are used as a guideline to check that our results are reasonable. This is reasonable if we assume that developments nationally are positively correlated with developments in the Disadvantaged Areas.

The aim of this research was to estimate farmers responses to policy changes which have occurred following the 1992 CAP Reforms. Therefore, three historical price scenarios were run for 1992–93, 1993–94 and 1994–95. Irish farmers are constrained in the production of milk output by the milk quota, which was introduced in 1984. There was no change in the milk quota over the 1992–95 period. Therefore, all three policy scenarios were run with no change in the quota for milk.

6.1 Scenario 1: 1992–93

The CAP policy reforms which affected the main agricultural outputs in our study area i.e. cattle and sheep, did not come into effect until 1 January 1993. Therefore, the policy scenario run for 1992–93 was simply the percentage change in output and input prices over the period. The percentage price changes were expressed in real terms and are outlined in Table 3. Using these price changes, the predicted changes in the volume of outputs and inputs were estimated using the Johansen model.

The actual and predicted changes in the volume of agricultural outputs (excluding milk) and inputs are all in the same direction except for fertiliser. The magnitude differs, but this is not surprising. We did not expect the actual and predicted changes to be equal as the predicted changes relate to the disadvantaged area of the country, while the actual changes relate to the whole country. The predicted changes in the volume of cattle and sheep output are positive and less than the actual changes, while the predicted change in the volume of crop output is negative and greater than the actual change. The predicted and actual changes in the volume of purchased concentrates are fairly close in magnitude. There is no information available on the volume of bulky feed and hired labour and, therefore, it is not possible to compare actual and predicted changes. The predicted change in fertiliser use is slightly negative with a reduction of 0.8%, while the actual change was an increase of 4.6%. The price of fertiliser increased over the period in question. The predicted negative change in fertiliser use may indicate that farmers in the disadvantaged region of the country are more responsive to a change in the price of fertiliser than farmers in the country as a whole.

6.2 Scenario 2: 1993–94

The CAP reform measures, which became effective on 1 January 1993, switched the emphasis in the market support system, in the case of the beef sector, somewhat away from intervention purchasing towards direct payments to farmers under the Livestock Premium Schemes. For the policy scenarios for 1993–94 and 1994–95, we assumed that increases in the value of premium payments and the introduction of the deseasonalisation and extensification premiums were reflected in the market price of cattle. This is not an unreasonable assumption. If farmers receive increased premium payments, this increases the value of the animal and will be reflected in market prices.

Under the CAP reform measures quotas were introduced for the suckler cow, special beef premium and ewe premium schemes. In running the policy scenarios for 1993–94 and 1994–95 it was necessary to take account of the operation of such schemes.

In a perfectly competitive world, market prices are identical to shadow prices. The shadow price of an output/input to a producer is the change in the profitability associated with a marginal change in that output/input. The imposition of a quota, to the extent that it acts as a constraint on producer behaviour, reduces profit. This results in a divergence between the market price and the shadow model of a complex reality, is utopian.

7 Conclusions

In this study a simple policy model (Johansen) was used to examine the impact of changes in CAP on the structure of farming in the Disadvantaged Areas of Ireland. The Johansen model is flexible enough to incorporate a variety of policy initiatives ranging from price changes, taxation/subsidisation of inputs and/or outputs, quotas on inputs and/or outputs, set aside and production neutral payments to farmers. To be operational, the model requires information on all relevant elasticities of outputs and inputs with respect to all output and input prices. These elasticities were estimated directly using a combination of cross section and time series data. The translog profit function was the behavioural model chosen to model the farm sector.

Results were disappointing insofar as the diagnostics were poor. This is not surprising as R^2s are usually quite low where cross section data is used. The rejection of convexity could be seen as an invalidation of the model, however, it may, more optimistically, be considered as arising from inadequate data.

An alternative test of the usefulness of the model as a guide to policy is to see how well it predicted the consequences of CAP Reform for the period 1992–1995. Validation was approximate, insofar as figures on the movement of outputs and inputs are only available from published sources for the country as a whole. Therefore, by comparing the models predictions to national developments in agriculture, we are implicitly assuming a positive relationship between agriculture nationally and agriculture in the Disadvantaged Areas.

According to the latter criteria, the model performed reasonably well, in that the predicted direction of change in outputs and inputs was generally in the same direction as actual changes in outputs and inputs over the period tested. Differences existed between the actual magnitude of change and the predicted magnitude of change. That is to be expected given that we are comparing national developments to what our model predicts should have happened in the Disadvantaged Areas.

Table 1 Parameter Estimates of share equations

.	Milk	Cattle	Sheep	Crops	Pur. Con	Bulky Feed	Fertiliser	Hired Labour
Intercept	0.330 (30.822)	0.656 (63.132)	0.199 (20.472)	0.017 (11.529)	-0.103 (32.343)	-0.018 (11.073)	-0.070 (35.417)	-0.012 ----------
Milk	0.675 (5.204)	-0.650 (9.432)	0.143 (1.835)	-0.038 (2.183)	-0.081 (1.657)	-0.002 (0.132)	-0.030 (1.189)	-0.018 (1.433)
Cattle	-0.650 (9.432)	0.809 (5.020)	-0.336 (1.635)	0.005 (0.444)	0.104 (4.733)	0.049 (4.386)	0.012 (0.873)	0.007 (0.855)
Sheep	0.143 (1.835)	-0.336 (1.635)	0.299 (1.556)	-0.018 (1.259)	-0.017 (0.582)	-0.040 (2.694)	-0.026 (1.362)	-0.006 (0.555)
Crops	-0.038 (2.183)	0.005 (0.444)	-0.018 (0.582)	0.037 (3.493)	0.032 (2.834)	-0.008 (1.234)	0.004 (0.463)	-0.014 (2.543)
Pur. Con	-0.081 (1.657)	0.104 (4.738)	-0.017 (0.582)	0.032 (2.834)	-0.070 (3.360)	0.009 (0.843)	0.012 (0.856)	0.009 (1.077)
Bulky Feed	-0.002 (0.132)	0.049 (4.386)	-0.040 (2.694)	-0.008 (1.234)	0.009 (0.843)	-0.021 (2.579)	0.012 (1.464)	0.002 (0.317)
Fertiliser	-0.030 (1.189)	0.012 (0.873)	-0.025 (1.362)	0.004 (0.463)	0.012 (0.856)	0.012 (1.464)	0.018 (2.435)	-0.003 (0.419)
Hired Labour	-0.018 (1.433)	0.007 (0.855)	-0.006 (0.555)	-0.014 (2.543)	0.009 (1.077)	0.002 (0.317)	-0.030 (0.419)	0.024 ----------
Family Labour	0.218 (10.365)	-0.167 (8.159)	-0.036 (1.863)	0.005 (1.611)	-0.028 (4.459)	0.010 (3.346)	-0.013 (3.37)	0.010 ----------
Land	-0.008 (0.565)	-0.086 (5.881)	0.107 (7.756)	-0.001 (0.700)	-0.002 (0.431)	-0.006 (2.468)	0.001 (0.058)	-0.003 ----------
Capital	0.028 (2.056)	0.045 (3.433)	-0.068 (5.608)	0.004 (2.010)	-0.001 (0.290)	0.006 (3.243)	-0.005 (2.153)	-0.007 ----------
R2	0.17	0.12	0.06	0.02	0.04	0.05	0.03	----------

t statistics are in parentheses

Table 2 Estimated Price Elasticities

Price Quantity	Milk	Cattle	Sheep	Crops	Purchased Concentrate	Bulky Feed	Fertiliser	Hired Labour
Milk	1.37*	-1.31*	0.63	-0.09*	-0.35	-0.02	-0.16	-0.07
Cattle	-0.66*	0.89*	-0.31	0.02	0.06*	0.06*	-0.05	-0.002
Sheep	1.05	-1.03	0.70	-0.07	-0.19	-0.22*	-0.20	-0.04
Crops	-1.84*	0.93	-0.86	1.15*	1.76*	-0.47	0.18	-0.84
Purchased Concentrate	1.11	-0.35*	0.36	-0.29*	-0.43*	-0.10	-0.19	-0.10
Bulky Feed	0.46	-2.11*	2.45*	0.47	-0.61	0.17*	-0.73	-0.10
Fertiliser	0.76	0.48	0.56	-0.04	-0.28	-0.18	-1.32	0.03
Hired Labour	1.81	0.11	0.68	1.21	-0.85	-0.14	0.17	-2.99

Table 3 Scenario 1 - Historical Price Changes 1992-93 (Real Price Change)

Commodity	Price change	Predicted change in volume	Actual change in volume
Milk	-1.96%*	0	-1.0%
Cattle	2.10%	0.05%	0.5%
Sheep	8.70%	1.55%	5.3%
Crops	-10.50%	-16.20%	-9.8%
Purchased Concentrate	0.10%	2.01%	2.8%
Bulky Feed	0.10%**	7.48%	-------
Fertiliser	4.30%	-0.80%	4.6%
Hired Labour	3.75%**	-20.00%	-------

*The price change for milk is not the actual price change but the change in the shadow price.

** There is no information available on the percentage price change for bulky feed. We assume that the percentage price change is the same as that for purchased concentrates. Also there is no information available on the actual change in the volume of bulky feed and hired labour.

Table 4 Scenario 2 - Adjusted Historical Real Price Changes 1993-94

Commodity	Price change	Predicted change in volume (except for milk)	Actual change in volume
Milk	-3.54%*	0	0.4%
Cattle	-5.88%**	-1.45%	-3.7%
Sheep	-4.16%**	-0.45%	-7.1%
Crops	6.64%	7.98%	9.3%
Purchased Concentrates	-0.70%	-4.85%	10.7%
Bulky Feed	-0.70%***	5.25%	-------
Fertiliser	-2.20%	-4.78%	-1.8%
Hired Labour	3.50%***	-8.60%	-------

*The price change for milk is not the actual price change but the change in the shadow price.

**The historical real price changes for cattle and sheep were adjusted by changes in their shadow prices due to the introduction of effective quotas on these outputs.

*** There is no information available on the percentage price change for bulky feed. We assume that the percentage price change is the same as that for purchased concentrates. Also there is no information available on the actual change in the volume of bulky feed and hired labour.

Table 5 Scenario 3 Adjusted Historical Real Price Changes 1994-95

Commodity	Price Change	Predicted Change	Actual Change
Milk	-0.43%*	0	0.4%
Cattle	-4.78%	-1.95%	5.6%
Sheep	-8.87%	-1.96%	-3.4%
Crops	0.80%	1.75%	14.7%
Purchased Concentrates	-3.20%	-1.96%	-1.3%
Bulky Feed	-3.20%**	-15.42%	-------
Fertiliser	7.30%	-15.77%	5.5%
Hired Labour	0.40%***	-3.16%	-------

* The predicted change in milk is the predicted change in the shadow price of milk and not the change in the volume of milk output.

** There is no information available on the percentage price change for bulky feed. We assume that the percentage price change is the same as that for purchased concentrates. Also there is no information available on the actual change in the volume of bulky feed.

*** There is no information available on the actual change in hired labour.

A Data

A.1 Data Preparation

The multi-product profit function requires data on the value of all outputs and inputs as a share of profit, as well as the price of all outputs and inputs. Econometrics requires variation of prices (which are the exogenous variables) in order to establish the statistical relationship between prices and shares. This rules out the possibility of using published data on prices. Hence, proxies for the prices of all outputs and inputs necessitated volume, as well as, value data. There were four major steps involved in the initial data preparation: (i) deciding what outputs and inputs to include and exclude in our analysis (ii) expressing all values at 1989 prices; (iii) aggregating in a meaningful and consistent way the various sub-components of a given commodity category and; (iv) addressing the inconsistencies in the way data is reported across different commodity types.

A.2 Variables included in the Estimation

Table A1 gives a breakdown of product shares in gross output for the average farm in the Disadvantaged Areas for the three years under review.

The most important outputs and inputs were included in our model. Output and input variables were only excluded when they were relatively unimportant and as such their inclusion was not worthwhile and/or where it was not possible to calculate a unit value/price for the output or input.

Table A1 Product Shares (%) included in the Estimation

Year	Dairying	Cattle	Sheep	Crops	Other	Total
1989	45	30	15	5	5	100
1990	39	33	17	7	4	100
1991	36	33	16	11	4	100

Source: Farm Management Survey

Our model consisted of 4 outputs, 4 variable inputs and 3 quasi-fixed inputs. The outputs included were: (i) milk; (ii) cattle; (iii) sheep and; (iv) crops, while the variable inputs included were: (i) purchased concentrates; (ii) bulky feed; (iii) fertiliser and; (iv) hired labour. The fixed inputs included were: (i) the utilised agricultural area of land; (ii) family labour defined in terms of labour units and; (iii) value of buildings, machinery and livestock (aggregated together to represent the farm's working capital).

The outputs excluded were pigs, poultry, horses and revenue from hired machinery. The output of pigs and poultry was negligible for the farms included in our sample. Volume figures were not available in the Farm Managment Survey (Teagasc, various years) for poultry and horses, thus making it impossible to calculate unit value/price figures for the output of these birds and animals. Finally, revenue from hired machinery was excluded, as a meaningful measure of unit price could not be calculated. The inputs excluded were indirect overhead costs and some direct costs, such as crop protection, purchased seed, hire of machinery and veterinary fees. Again, the reason for their exclusion was the inability to calculate a unit price. However, as pointed out by Higgins (1986), if prices or quantities of these excluded inputs vary in fixed proportion to the prices (Hicks aggregation) or quantities (Leontief aggregation) in the model, then their exclusion does not lead to any bias in the parameter estimates.

Profit was defined as the value of outputs less the cost of variable inputs; that is to say it is the return to fixed factors.

A.3 Price Deflators used to express all values in Common Prices

All values were expressed in 1989 prices. The price deflators used were the following:

- Livestock Output Index, which was used to deflate the value of cattle and sheep output and the value of cattle and sheep as a fixed livestock input.
- Total Agricultural Output Index, which was used to deflate the value of all other outputs.
- Capital Goods Price Index for Buildings and Construction which was used to deflate the value of buildings as a fixed input.
- Capital Goods Price Index for Transportable Capital for use in Agriculture which was used to deflate the value of machinery as a fixed input.

- Total Agricultural Input Price Index which was used to deflate the value of all other variable inputs.

The precise deflation indices are given in Table A2.

Table A2 Agricultural Price Indices

	Liverstock Output	Total Agr. Output	Building and Construction	Transportable Capital	Total Agr. Inputs
1989	100.00	100.00	100.00	100.00	100.00
1990	89.05	88.70	104.30	103.30	100.20
1991	85.50	85.80	107.09	106.90	100.50

Source: Economic Series 1993, CSO.

A.3.1 Aggregation Index

Our outputs and inputs are not unique homogenous products. Each output and input category consists of many different goods, each with a separate value and price. In order to derive a unit value/price for a good, we need to be able to aggregate together the prices of the goods that are sub-components of the broader product classification. For example, sheep output consists of, inter-alia, fat lambs, store lambs, fat hoggets, breeding ewes, to mention but a few. Yet we need a single figure for the unit value/price of sheep as an output. The index used to aggregate sub-components of the different output and input categories was the Divisia Price Index. This index was chosen over other methods of aggregation as it is considered to be particularly appropriate when the functional form of the model being estimated is translog. The index is exact for the linear homogeneous translog function (Caves, Christensen and Diewert, 1982). An index which is derived from a particular aggregator function is termed exact for that function.

The Divisia Price Index is expressed as follows:

$$\ln P_j^k = \frac{1}{2}\sum_i^g (r_{ij}^k + \bar{r}_{ij})(\ln P_{ij}^k - \ln \bar{P}_{ij})$$

where, $\ln P_j^k$ is the price index for the jth aggregate on the kth farm,

r_{ij}^k is the share of the ith item in the value of the jth aggregate on the kth farm (e.g. the share of wheat in total crop output on the kth farm),

$\bar{r_{ij}}$ is the average value of the share of the ith item in the jth aggregate on all farms,

$\ln P_{ij}^k$ is the natural log of the price of the ith item in the jth aggregate on the kth farm,

$\ln \bar{P}_{ij}$ is the average of the natural log of the price of the ith item in the jth aggregate on all farms,

g is the number of items in the jth aggregate.

Essentially, the Divisia Price Index creates an index of price variation across farms for each product sub-component and then weights each sub-component price index by the arithmetic mean of the share of that sub-component in the output category for each farm and, on average, for all farms. In this way an index of price variation for an aggregate product category is derived.

A.3.2 A Detailed Description of Output and Input Variables

There is much inconsistency in the reporting of products that go into making up a general output and input product category. To some extent, this inconsistency in the classification of goods is understandable and arises because of the heterogeneity of outputs and inputs. For example, some outputs are more perishable than others, while other outputs are more divisible than others. Sub-commodities within an output category can be defined by generic type or by use. Also, reporting of outputs is more complicated than inputs, since the former has to deal with stocks and sales, while the latter usually simply reports use. The following is a description of the stages involved in arriving at meaningful figures for the values and prices of our 4 outputs and 4 variable inputs. We also include information on data used to represent our 3 quasi-fixed inputs.

Milk Output

The detail contained in a typical farm record for milk output consisted of value and volume figures for three sub-categories of milk. We felt that the appropriate price at which to value milk is at its sale price, since this is the opportunity cost of using milk on the farm. All milk was valued at sale price and a unit price was derived by dividing the total value of milk by the total volume of milk. A simple price index was then constructed using the average price as the numeraire.

Cattle Output

The typical farm record for cattle contains a breakdown of the opening and closing stocks of different types of cattle and sales. The volume as well as the value of total beasts sold are included. Subsidies on cattle are also included but no breakdown of subsidies according to type of animal is given. The total value of cattle output was calculated as the value of cattle sold plus the value of positive changes in inventory plus subsidies on cattle. A unit price for each type of cattle output was calculated by dividing the total value of each type by the volume of each type. An aggregate price index was then constructed using the Divisia price index.

Sheep Output

The typical farm record for sheep contains a breakdown of the opening and closing stocks of different types of sheep and sales. The volume, as well as the value, of total animals sold are included. Subsidies on sheep are also included but no breakdown of subsidies according to type of animal is given. The unit prices and the aggregate price index for sheep were calculated in a similar manner to those for cattle.

Crops Output

The typical farm record for crops contains information on the acreage devoted to, the yield per hectare and the value of output of each crop. The total value of crop output was the value of all crops produced on the farm. The volume of each type of crop output was obtained by multiplying the yield per hectare by the number of hectares. A unit price for each type of crop output was calculated by dividing the value of each type of crop by the volume. An aggregate price index for crops was constructed using the Divisia price index.

Purchased Concentrate Input

Each farm record contained a total value and a total volume figure for purchased concentrate usage on the farm. Figures for unit values for purchased concentrates were obtained by dividing total value figure by total volume figure. A simple price index was constructed using the average price as the numeraire.

Bulky Feed Input

The typical farm record for bulky feed contains information on the value and volume of each type of feed. The total value of bulky feed was the total value of all inputs used on the farm. A unit price for each type of bulky feed was obtained by dividing the value of each type by the volume of each type. An aggregate price index was constructed using a Divisia price index.

Fertiliser Input

Farm records for fertiliser use contain volume figures for the different types of fertiliser and a value figure for total fertiliser use. In order to estimate a unit value for each type of fertiliser we supplemented our information with published data obtained from the Statistical Bulletin. Using this data we calculated the relative price of phosphorus and potassium in terms of nitrogen. We then expressed the total volume of fertiliser in terms of the volume of nitrogen. Dividing the total value of fertiliser by this figure a unit value for nitrogen was obtained. Using the relative prices of phosphorus and potassium, unit values for phosphorus and potassium were calculated. An aggregate price index was constructed using the Divisia Price Index.

Hired Labour Input

Farm records for hired labour contain information on the cost of both casual and current hired labour, and on the total number of labour units. The total cost of hired labour was the cost of casual plus current hired labour. A unit value for hired labour was obtained by dividing this total value by the total number of labour units. A simple price index was then estimated using the average as the base.

Land

This was expressed in terms of utilised agricultural area. A simple index for utilised agricultural area was constructed using the average area as the base.

Family Labour

This was expressed in terms of labour units. A simple index for family labour was constructed using the average number of labour units as the base.

Capital

This was expressed in value/financial terms. The values included the value of buildings, machinery and livestock. Livestock value was calculated as the value of opening stock plus purchases less negative changes in inventory. The value of buildings in a given year is the average of beginning and end of year stock values. The value of machinery is end of year value based on the cost of replacement. The reason for including purchases of livestock as a quasi-fixed input is because such purchases add to the farmers stock and are not usually sold off in the year of purchase. A simple index for capital was constructed using the average value as the base.

B

Table A2 Definition of Variables in the Generalised Translog Profit Function

Π	Farm net profit
S_1	Share of milk in profit
S_2	Share of cattle in profit
S_3	Share of sheep in profit
S_4	Share of crops in profit
S_5	Share of purchased concentrates in profit
S_6	Share of bulky feed in profit
S_7	Share of fertiliser in profit
S_8	Share of hired labour in profit
$\ln P_1$	Natural log of index of milk prices as defined in Appendix A
$\ln P_2$	Divisia index for cattle as defined in Appendix A
$\ln P_3$	Divisia index for sheep as defined in Appendix A
$\ln P_4$	Divisia index for crops as defined in Appendix A
$\ln P_5$	Natural log of index of purchased concentrate prices as defined in Appendix A
$\ln P_6$	Divisia index for bulky feed as defined in Appendix A
$\ln P_7$	Divisia index for fertiliser as defined in Appendix A
$\ln P_8$	Natural log of index of hired labour prices as defined in Appendix A
$\ln Z_1$	Natural log of index of utilised agricultural area as defined in Appendix A
$\ln Z_2$	Natural log of index of family labour units as defined in Appendix A
$\ln Z_3$	Natural log of value of capital as defined in Appendix A

C

Johansen-type model of the agricultural sector in the selected study area

$$
\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ Y_6 \\ Y_7 \\ Y_8 \end{bmatrix}
= -[I]^{-1}
\begin{bmatrix}
-1.37 & 1.31 & -0.63 & 0.09 & 0.35 & 0.02 & 0.16 & 0.07 \\
0.66 & -0.89 & 0.31 & -0.02 & -0.06 & -0.06 & 0.05 & 0.00 \\
-1.05 & 1.03 & -0.70 & 0.07 & 0.19 & 0.22 & 0.20 & 0.04 \\
1.84 & -0.93 & 0.86 & -1.15 & -1.76 & 0.47 & -0.18 & 0.84 \\
-1.11 & 0.35 & -0.36 & 0.29 & 0.43 & 0.10 & 0.19 & 0.10 \\
-0.46 & 2.11 & -2.45 & -0.47 & 0.61 & -0.17 & 0.73 & 0.10 \\
-0.76 & -0.48 & -0.56 & 0.04 & 0.28 & 0.18 & 1.32 & -0.03 \\
-1.81 & -0.11 & -0.68 & -1.21 & 0.85 & 0.14 & -0.17 & 2.99
\end{bmatrix}
\begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \end{bmatrix}
$$

where Y_1 to Y_4 denote the percentage changes in the volume of milk, cattle, sheep and crops outputs;
Y_5 to Y_8 denote the percentage changes in the volume of purchased concentrates, bulky feed, fertiliser and hired labour inputs;
P_1 to P_8 denote the percentage changes in the respective prices;
I is an identity matrix.

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