ESSAYS ON THE TECHNICAL AND ECONOMIC EFFICIENCY OF BROILER PRODUCTION IN SAUDI ARABIA

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PREFACE

This thesis consists of three papers. In the first paper, two examples are used to explain the non-parametric and parametric approaches of estimating technical efficiency, using an Excel spreadsheet, DEAP Version 2.1, SHAZAM and FRONTIER Version 4.1. (Excel® is a registered trademark of Microsoft Corporation). In the second paper, technical, allocative, and economic efficiencies, for broiler farms in the central region of Saudi Arabia are estimated using the data envelopment analysis approach. The third paper includes estimates of technical efficiency for the same data set using the stochastic frontier approach.

My deep gratitude and sincere appreciation are expressed to my major advisor, Dr. Francis Epplin. I do not know how to thank him for his encouragement, tremendous support, academic guidance, friendship, helpfulness, and his patience. I also wish to express my deep gratitude and sincere appreciation to my other committee members Dr. Arthur Stoecker, Dr. R. Joe Schatzer, and Dr. Thomas Peeper, for their helpful suggestions and useful discussions.

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ABSTRACT

This paper presents two methods used to estimate technical efficiency. After having presented the concept of technical efficiency, the methods used to estimate the production frontier that is needed to estimate the technical efficiency scores are discussed using examples.

Different efficiency measurement approaches have been developed. The methods are classified into two types. The first method is the non-parametric approach, data envelopment analysis (DEA), with constant and variable returns to scale. This method is demonstrated using two techniques, the Microsoft Excel spreadsheet and the DEAP Version 2.1.

The second method is the parametric approach, the stochastic frontier approach (SFA), with constant and variable returns to scale. Two techniques, statistical SHAZAM software and FRONTIER Version 4.1, are used to illustrate the SFA.

Key words: technical efficiency, data envelopment analysis, stochastic frontier analysis, EXCEL, DEAP, SHAZAM, FRONTIER, constant returns to scale, variable returns to scale.

A GUIDE TO THE USE OF EXCEL SPREADSHEETS, DEAP VERSION 2.1, SHAZAM, AND FRONTIER VERSION 4.1 IN DETERMINING TECHNICAL EFFICIENCY

Introduction

The measurement of efficiency has been a popular field of research since Farrell published a seminal paper in 1957. Much research has focused on the economic efficiency of agricultural production, and the analysis has centered on the technical, allocative and scale efficiency of farm production (Chavas and Aliber). When a number of firms or farms produce a similar or identical product these concepts may be employed to differentiate among efficient and inefficient firms. Farrell developed the concept of technical efficiency based on the relationships between inputs and outputs (Parikh, Ali, and Shah). He proposed that the efficiency of a firm consists of two components, technical efficiency, that reflects the ability of firms or farms to maximize their output from a given set of inputs, and allocative efficiency, which reflects the ability of firms or farms to use the inputs in the optimal proportions, given their prices. If we combine those two measures the overall efficiency would be determined. In the efficiency literature, several methods have been used to estimate technical efficiency. The most important methods to estimate the score or the performance of technical efficiency are the

(i) mathematical programming method (e.g. Data Envelopment Analysis) and the (ii) econometric method (e.g. Stochastic Frontier Approach).

According to Lovell, the main differences between the two approaches in frontier calculation are that the econometric approach is stochastic (SFA). It attempts to distinguish the effects of the noise from the effects of inefficiency, while the Data Envelopment Analysis (DEA) method is not stochastic, and combines the noise and inefficiency effects. Moreover, the econometric method is parametric, and confounds the effects of misspecification of functional form with inefficiency effects. The mathematical programming approach is non-parametric and less sensitive to this kind of error (Reinhard).

The DEA method uses input and output data for a group of farms to construct a piece-wise linear surface over the data points. It defines the frontier with output levels held constant for each farm. Linear programming can be used to estimate the DEA frontier. The observed input and output quantities form a production possibility space, against which the individual farms are compared to determine their technical efficiency (Fraser and Cordina).

SFA and DEA provide the same technical efficiency scores when a constant returns to scale (CRS) technology applies, but are unequal when variable returns to scale (VRS) is assumed (Rao and Coelli). DEA optimizes individual observations with the objective of calculating a discrete piecewise frontier determined by the efficient decision-making units (Yin). However, it has been used in management science to evaluate ex post the efficiency of achieving an objective from a given level of inputs (Banker, Charnes, and Cooper).

Seiford and Thrall presented a comprehensive review of the methodology, and discuss the mathematical approach to efficient frontier of DEA. The nonparametric approach in which the term data envelopment analysis was first used was initiated by Charnes, Cooper, and Rhodes (1978). Since then there have been a large number of papers that have extended and applied the DEA approach (Coelli, Rao, and Battese). There are several reasons for using DEA analysis to assess technical efficiency. First, DEA is useful for identifying the areas that will be most interesting for extension efforts. Because DEA is based on linear programming, many agriculturists are already familiar with it and therefore less effort will be required for them to use this analytical technique than to learn new efficiency methodologies such as stochastic frontiers. Second, DEA generates detailed information related to input use and the optimal mix of factors, and identifies efficient farms within a sample and those that are most important for benchmarking. Third, the amount of computer software that supports DEA analysis has increased significantly in the last few years; this software is relatively easy to use and the results it generates are easy to understand. The final important reason for using DEA is that it is not necessary to use parametric specifications of functional form to establish the frontier. Therefore, DEA does not require restrictions to functional form that can affect the analysis or skew measures of efficiency (Fraser and Cordina). Frontier production functions can be estimated for both cross-sectional and panel data. Coelli, Rao and Battese, Kalirajan and Shand, and Bravo-Ureta and Pinheiro provide reviews of the application of frontier production functions to estimate the technical efficiency for both types of data. Aigner, Lovell, and Schmidt using cross sectional data proposed the stochastic frontier function.

The purpose of this tutorial is to explain both the DEA and SFA methods of estimating technical efficiency, assuming constant returns to scale (CRS) and variable returns to scale (VRS).

Methodology

Technical Efficiency

Efficiency in production can be defined in terms of the production function that relates the level of various inputs (Berte). Technical efficiency is a measure of a farm's success in producing maximum output from a given set of input; in other words, technical efficiency refers to the physical relationship between inputs used in the production process. Technical efficiency measures output relative to that of the efficient isoquant. Efficient farms produce on the production frontier or, alternatively stated, on the efficient isoquant. The concept of technical efficiency relates to the question of where a firm or farm uses the best available technology in its production process (Chavas and Aliber).

In general, the aim of measuring farm level efficiency is to estimate the frontier that envelops all the input/output data with those observations lying on the frontier being described as technically efficient. Observations lying below the frontier are considered to be technically inefficient (Fraser and Cordina).

Koopmans (p. 60) provided a formal definition of technical efficiency: "a producer is technically efficient if any output requires a reduction in at least one other output or an increase in at least one input, and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output. Thus a technically inefficient producer could produce the same outputs with less of at least one input, or could use the same inputs to produce more of at least one output."

Farrell Measures of efficiency

The basic ideas underlying the Farrell approach to efficiency measurement are illustrated in Figure 1. This diagram shows the efficient unit isoquant (*II'*) for a group of farms constructed from the input bundles of farms. The farms produce *y* output, by using two inputs (x_1, x_2). A constant returns to scale production function is assumed.

$$y = f(x_1, x_2) \tag{1}$$

The unit isoquant can characterize this function frontier (*II'*) if the farm is observed using (x_1, x_2) to produce *y*. An inefficient farm is at point *P*. The point *Q* is the intersection of the line segment *OQ* with the isoquant (*II'*). According to Farrell the technical efficiency of point *P* is represented by the ratio $\frac{OQ}{OP}$. It is the ratio of inputs needed to produce the output to the inputs actually used to produce the output, given the input mix used. (*AA'*) represents the ratio of input prices. The point *Q'* represents the minimum cost combination of x_1 and x_2 on the efficient isoquant. Farrell allocative efficiency is the ratio $\frac{OR}{OQ}$.

Technical efficiency (TE) will take a value between zero and one ($0 < \text{TE} \leq 1$). Where a value of one indicates the firm is fully technically efficient, and hence provides an indicator of the degree of technical inefficiency of the farm. That implies the farm is producing on the production frontier. For example, the point *Q* is technically efficient because it lies on the efficient isoquant. The distance *RQ* represents the reduction in production costs that would occur if production were to occur at the allocative (and technically) efficient point *Q'*. Total economic efficiency (*EE*) is defined to be the ratio

$\frac{OR}{OP}$, where the distance RP can be interpreted in terms of a cost reduction. The product of technical and allocative efficiency provides the overall economic efficiency $TE * AE = (\frac{OQ}{OP}) * (\frac{OR}{OQ}) = (\frac{OR}{OP}) = EE$. Zero and one bound all three measures (Coelli, Rao, and Battese). These efficiency measures assume the production function of the fully efficient farm is known. In practice this is not the case, and the efficient isoquant must be estimated from the sample data.

Data Envelopment Analysis

Farm technical efficiency with (CRS) DEA model

Following Coelli, Rao, and Battese consider the situation with K inputs, M outputs and N farms or decision-making units. For the *ith* farm we have x_i and y_i vectors. So we have $K{\times}N$ input matrix, X, and the $M{\times}N$ output matrix, Y, for the entire set of the data. Since the efficiency is defined as the ratio of weighted sum output over the weighted sum of inputs, then $\frac{\sum_{m=1}^{M} u_{im} y_{im}}{\sum_{k=1}^{K} v_{ik} x_{ik}}$ where u_i is an $M{\times}1$ vector of output weights and v_i is $K{\times}1$vector of input weights. A mathematical programming model can be formulated to determine the optimal weights as follows:

$$(2) \qquad Max_{\,u_i, v_i} \left(\frac{\sum_{m=1}^{M} u_{im}\, y_{im}}{\sum_{k=1}^{K} v_{ik}\, x_{ik}} \right)$$

$$\text{s.t.} \qquad \frac{\sum_{m=1}^{M} u_{im} y_{im}}{\sum_{k=1}^{K} v_{ik} x_{ik}} \leq 1 \qquad k=1,2,\ldots,K$$

$$u_{im}, v_{ik} \geq 0, \ \forall m, k$$

The linear programming problem finds the vectors of weights u_i, and v_i that maximize the efficiency score of the farm i. The above ratio form yields an infinite number of solutions so it is necessary to formulate the problem by imposing the constraint $v'x_k=1$, to equation (2) and change the notation from u and v to μ and v which is known as the multiplier form of the DEA constant returns to scale model.

(3)
$$Max_{\mu,v}(\mu' y_i)$$

$$\text{s.t.} \qquad v'x_k=1$$

$$\mu' y_m - v'x_k \leq 0, \qquad k=1,2,\ldots,K$$

$$\mu, v \geq 0$$

Alternatively, the dual of the DEA problem can be expressed as follows:

(4)
$$\text{Min}_{\theta,\lambda}\ \theta_i^{CRS}$$

$$\text{s.t.} \qquad Y\lambda - y \geq 0$$

$$\theta x_i - X\lambda \geq 0 \qquad i = 1,2,\ldots,N$$

$$\lambda \geq 0$$

where θ_i^{CRS} is a scalar that measures the TE of the ith farm and λ is an $N \times 1$ vector of constants or weights attached to each of the efficient farmers (Sharma, PingSun, and

Halina). The estimated value of θ is the efficiency score for the *ith* farm. This estimate will satisfy the restriction $\theta \leq 1$, with the value of $\theta = 1$ indicating a technically efficient farm, and the farm is on the frontier. If $\theta^{CRS} < 1$, then the farmer lies below the frontier and is technically inefficient. To derive a technical efficiency score for each farm, the problem needs to be solved once for each farm.

To estimate the overall economic efficiency (*EE*), we can solve for the cost-minimizing DEA model (Fare, Grosskopf, and Lovell) as follow:

$$\text{(5)} \qquad Min_{\theta_i^{CRS}\lambda} W_i' X_i^*$$

$$\text{s. t.} \quad Y\lambda - y \geq 0$$

$$X_i^* \geq X\lambda$$

$$\lambda \geq 0$$

where X_i^* is the cost minimizing vector for the *i*th farm, given its input price vector, W_i, and output level, Y_i. This equation accounts for input slacks not captured by equation (4), and attributes any input slacks to allocative inefficiency (Ferrier and Lovell). The (*EE*) can be determined as the ratio of the minimum cost to the observed cost

$$\text{(6)} \qquad EE_i = \frac{W_i' X_i^*}{W_i' X_i}$$

the allocative efficiency (*AE*) can be derived from equation (4) and equation (6) as follow

$$\text{(7)} \qquad AE_i = \frac{EE_i}{\theta_i^{CRS}}$$

Example

To illustrate CRS input orientation DEA involving six farms using two inputs (x_1, x_2) to produce a single output (y) the data are reported in Table 1. The input/output ratios for this example are plotted in Figure 2 along with the DEA frontier corresponding to the solution of the DEA model defined in equation (3).

From Figure 2 we can note that farms A, B, C, and D are located on the frontier. They are technically efficient. But, farms E and F are not on the frontier indicating that they are inefficient. Technical efficiency for farm E may be calculated from the graph by the ratio of $TE_E = \frac{0E'}{0E}$. From Figure 2 $0E'=3$, and $0E=4$, then $TE_E=3/4=0.75$. Similarly farm F has a technically efficiency score of 0.66. The DEA frontier is the result of running six linear programming problems-one for each of the six farms. For example, for farm E, we can rewrite equation (4) as

(8)

$$Min_{\theta,\lambda}\ \theta_E^{CRS},$$

$$\text{s.t.}\quad -y_E + (y_A\lambda_A + y_B\lambda_B + y_C\lambda_C + y_D\lambda_D + y_E\lambda_E + y_F\lambda_F) \geq 0,$$

$$\theta x_{1E} - (x_{1A}\lambda_A + x_{1B}\lambda_B + x_{1C}\lambda_C + x_{1D}\lambda_D + x_{1E}\lambda_E + x_{1F}\lambda_F) \geq 0,$$

$$\theta x_{2E} - (x_{2A}\lambda_A + x_{2B}\lambda_B + x_{2C}\lambda_C + x_{2D}\lambda_D + x_{2E}\lambda_E + x_{2F}\lambda_F) \geq 0,$$

$$\lambda \geq 0$$

where $\lambda=(\lambda_A, \lambda_B, \lambda_C, \lambda_D, \lambda_E, \lambda_F)$. The solution values of θ and λ derived from the linear programming model are listed in row five of Table 2. Note that the TE of farm E of 0.75 is the same as that derived from the graph in Figure 2. By this measure farm E could reduce the consumption of all inputs by 25% without reducing output. This implies production at the point E' in Figure 2. This point (E') lies on the line joining points B and C and halfway between the two points. Farms B and C are referred to as peers of farm E. They define where the relevant part of the frontier is, and hence define efficient production for farm E. Point E' is a linear combination of 0.5 of point B and 0.5 of point C where the weights in this linear combination are the lambdas (λs) in row 5 of Table 2. Hence, $\lambda_B = 0.5$ and $\lambda_C = 0.5$, all other lambdas are equal to zero.

The efficiency of farm F is 0.66. By this measure farm F could reduce the consumption of all inputs by 33% without reducing output. This implies production at the point F' in Figure 2. This point (F') lies on the line joining point C. Farm C is referred to as the peer of farm F. Since the ray from point F to the origin passes directly through point C, λ_C is equal to 1.0 and all other lambdas are equal to zero.

Price information is necessary to measure allocative efficiency. If the input price ratio is one, the only allocatively efficient farms are B and C. Alternatively, if the price of x_2 is half the price of x_1 then farm C is allocatively efficient and farm B is not.

DEA results may be calculated using any mathematical programming software. We obtained our result for this hypothetical example using the Excel solver and DEAP Version 2.1. (Excel® is a registered trademark of Microsoft Corporation).

CRS DEA Model Solution Using Microsoft's Excel Solver

Our objective for this example is to use Excel solver to estimate θ and λ that provide a minimum value of θ. The steps are as follows.

a) Create a new spreadsheet in Excel.

b) Set up an initial tableau (Table1) in an Excel spreadsheet as shown in Figure 3. The problem is defined in section A1 to K9 of the spreadsheet. Cells in Rows 7, 8 and 9 include the constraints, which represent the output y and two inputs x_1 and x_2 as in equation 8. The objective function value θ_E^{CRS} (technical efficiency) is presented in Row

6 Column C. The RHS of the constraint values are presented in Column D Rows 7, 8, and 9. The observations are placed in Column F and following. The model will be designed to solve for the minimization of theta and the model will enter this value in Row 6 Column C. Cells in Row 5, Columns E and following are left blank.

c) Equations are entered in Column C, Rows 6, 7, 8, and 9 as shown in Figure 4. The equations to calculate the value of the objective function are entered in Cell C6 where θ_E (since farm E is used as an example) is minimized as shown in equation 8. The SUMPRODUCT function as written will place the value of (E5*E6)in cell C6, where the objective function is minimized: θ_E^{CRS}. The constraint equations for this problem: $-y_E + (y_A\lambda_A + y_B\lambda_B + y_C\lambda_C + y_D\lambda_D + y_E\lambda_E + y_F\lambda_F) \geq 0$, $\theta x_{1E} - (x_{1A}\lambda_A + x_{1B}\lambda_B + x_{1C}\lambda_C + x_{1D}\lambda_D + x_{1E}\lambda_E + x_{1F}\lambda_F) \geq 0$, and $\theta x_{2E} - (x_{2A}\lambda_A + x_{2B}\lambda_B + x_{2C}\lambda_C + x_{2D}\lambda_D + x_{2E}\lambda_E + x_{2F}\lambda_F) \geq 0$, are defined in cells C7, C8, and C9. The equation in cell C6 is copied to cells C7, C8, and C9.

d) The solver option is used to solve for the technical efficiency for each farm as shown in Figure 5. The cell of the objective function is defined as the target cell (C6). The constraint equations are defined to limit the output to be greater than or equal to one, and inputs to be greater than or equal to zero.

e) Click on the options tab (Figure 6) and activate the appropriate options, such as "Assume Linear Model", and the option " Assume Non-Negative," to ensure that the activity levels ($\lambda \geq 0$) are more than or equal to zero. Then click ok to return to the solver dialogue box, then click solve.

Since farm E is used in the example, the objective function value is determined to be 0.75 and is presented in cell C6 (Figure 7). By this measure farm E is 75% technically efficient. This is the same result obtain by visual analysis of the graph reported in Figure 2. The results in Figure 7 also show that λ_B and λ_C are both 0.5 with all other λs equal to zero. This confirms that farms B and C are peers of farm E. Further, as shown in Figure 2, a linear combination of 0.5 of farm B and 0.5 of farm C would define the point at which a ray from the origin to the input combination used on farm E intersects the efficient unit isoquant. To determine the technical efficiency of other farms, the value in cells E8 and E9 are changed (X_k).

The most obvious advantage for using a spreadsheet solver to solve for DEA are its availability and familiarity to most decision-making units. Another advantage is its flexibility since additional constraints can be incorporated to reflect special features of the solutions. But the use of standard linear programming software requires that this procedure be conducted for each farm. The DEAP Version 2.1[1] program can calculate the efficiency results for all farms with one program (Appendix A). To calculate results using DEAP the user should construct a data file (Table A.1.) and instruction file (Table A.2.). Results of DEAP Version 2.1 are presented in Table A.3. Note that farm E (number 5) has a technical efficiency score of 0.75.

Farm technical efficiency with (VRS) DEA model

Imposing constant returns to scale results in the maintained hypothesis that all farms in the set are operating at the minimum point on their long run average cost (LRAC) function. But, this may not be the case in practice. For example, a capital constraint may restrict farm size to less than that necessary to achieve minimum LRAC. The CRS model may be expanded to account for VRS (Banker, Charnes, and Cooper).

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[1] DEAP 2.1 can be downloaded from the internet by accessing the address for the Center for Efficiency and Productivity Analysis at the University of New England, Armidale, NSW, Australia: http://www.une.edu.au/econometrics/cepa.htm.

Imposing CRS when not all farms are operating at the optimal scale results in measures of technical efficiency (TE) that are confounded by scale efficiencies (SE). Alternatively, a VRS specification permits the measure of (TE) to be decomposed into pure TE and scale efficiency (Fraser and Cordina). The VRS mathematical programming formulation is as follows:

(9)

$$Min_{\theta,\lambda}\ \theta^{VRS}$$

$$\text{s.t.}\quad Y\lambda - y \geq 0$$

$$\theta x_i - X\lambda \geq 0 \qquad i = 1,2,\ldots,n$$

$$N'\lambda = 1$$

$$\lambda \geq 0$$

where N is an $N \times 1$ vector of ones. The inclusion of the convexity constraint means that the data are enveloped more closely than with the CRS model. This means that the technical efficiency scores derived under VRS will be greater than or equal to those obtained under CRS. The constraint $N'\lambda = 1$, ensures that a farm is only compared to other farms of similar size.

Example[2]

Data used to illustrate VRS input orientation DEA involving five farms using one input to produce a single output are presented in Table 3. The results of the VRS and

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[2] The example and discussion closely follows that presented in Coelli, T.J., D.S., Prasada Rao, and G.E., Battese. An Introduction to Efficiency and Productivity Analysis. London. UK:Kluwer Academic Publishers, 1998.

CRS DEA are shown in Figure 8. The solution for this linear programming problem is listed in Table 4.

The result indicates that farm C is the only efficient farm when CRS is assumed. Farms A, C, and E are efficient when VRS is assumed. For instance, farm B is 50% technically efficient under CRS but 62.5% technically efficient when the VRS is assumed.

The procedure of using the solver option of Excel to solve this linear programming problem will be the same as the steps used with CRS above, with the addition of a convexity constraint.

a) Set up an initial Tableau (Table 3) in an Excel spreadsheet as shown in Figure 9. The problem is defined in section A1 to J9 of the spreadsheet. Cells in Rows 7, 8 and 9 include the constraints, which represent the output *y*, input, and vector of once (equation 9). The objective function value θ_B^{CRS} (technical efficiency) is presented in Row 6 Column C. The RHS of the constraint values are presented in Column D Rows 7, 8, and 9. The observations are placed in Column F and following. Cells in Row 5, Columns E and following are left blank. The model will be designed to solve for the minimization of theta and the model will enter this value in Row 6 Column C. Equations are entered in Column C, Rows 6, 7, 8, and 9 as shown in Figure 9.

b) The equations to calculate the value of the objective function are entered in Cell C6 where θ_B (since farm B is uses as the example farm) is minimized as shown in equation 9. The SUMPRODUCT function as written will place the value of (E5*E6) in cell C6, where the objective function is minimized: θ_B^{VRS}. The constraint equations for this problem: $Y\lambda - y \geq 0$, $\theta x_i - X\lambda \geq 0$, and $N'\lambda = 1$, are defined in cells C7, C8, and C9 by copying the equation in cell C6 to cells C7, C8, and C9 (Figure 10).

c) The solver option is used to solve for the technical efficiency for each farm as in Figure 11. In this step we will define the cell of the objective function as the target cell (C6). Since the objective is to minimize θ, the "Equal to: • Min" is selected. The constraint equations are defined to limit the output be grater than or equal to 4, inputs to be greater than or equal to zero, and the vector of one to be equal to one. To find the feasible solution for this problem, the constraint equations in equation 9 should be met.

The objective function value of 0.625 is presented in cell C6, which means that farm B is 62.5% technically efficient. Values in cells D7 and E8 are changed to solve for the efficiency of other farms in the set. The DEAP Version 2.1 program can calculate the same result (Appendix B).

Scale Efficiencies

The nature of returns to scale for any farm may be determined by the scale efficiency measure (Fare, Grosskopf, and Lovell). The main reason for this method is that scale economies can be determined directly both for efficient as well as for inefficient farms (Lothgren and Magnus).

Scale efficiency could be calculated by conducting both CRS and VRS DEA. Then the technical efficiency scores obtained from the CRS DEA can be decomposed into two components, one due to scale inefficiency and one due to pure technical inefficiency. If there is a difference in the CRS and VRS technical efficiency scores for a particular farm, then this indicates that the farm has scale inefficiency, which equals the difference between the VRS and the CRS technical efficiency score. Thus, the input-oriented scale efficiency is defined as

$Se_i = \frac{TE_i^{CRS}}{TE_i^{VRS}}$ where $Se_i = 1$ indicates scale efficiency or CRS. $Se_i < 1$ indicates scale inefficiency resulting from either increasing or decreasing returns to scale. But the value of scale efficiency does not indicate whether the firm is operating in an area of increasing or decreasing returns to scale. A DEA specification with a non-increasing returns can be imposed as follows:

(10)

$$
\begin{aligned}
& Min_{\theta,\lambda}\ \theta, \\
& \text{s.t} \quad Y\lambda - y \geq 0 \\
& \theta x_i - X\lambda \geq 0 \qquad i = 1,2,\ldots,n \\
& N'\lambda \leq 1 \\
& \lambda \geq 0
\end{aligned}
$$

using the constraint $N'\lambda \leq 1$ to ensure that the i-th farm will not be compared against farms that are substantially larger, but may be compared with farms that are smaller.

The NIRS may be considered with CRS as follows. $Se_i = \frac{TE_i^{CRS}}{TE_i^{NIRS}} \begin{cases} =1 \Rightarrow IRS \\ <1 \Rightarrow DRS \end{cases}$ indicating whether the scale-inefficiency is due to a small output (IRS) or to a large output (DRS) (Lothgren and Magnus). Let θ^{NIRS} represent the TE measure assuming non-increasing returns to scale. By this measure, $\theta^{CRS} = \theta^{NIRS}$ indicates increasing returns to scale. Alternatively, $\theta^{CRS} < \theta^{NIRS}$, indicates decreasing returns to scale (Fare, Grosskopf, and Lovell).

Figure 8 illustrates a case with one-input, one-output and five observations. The CRS and VRS DEA frontiers are plotted. The efficient frontier based on CRS is represented by the line from the origin through C, while based on VRS the frontier goes through A, C, and E. Under CRS when farm B is operating at point B then the technical inefficiency is the distance BB_c. However, under VRS, the technical inefficiency is the distance BB_v. The difference between the two measures is due to scale inefficiency. This can be interpreted as the ratio of the average product of a farm operating at the point B_v to the average product of the farm operating at a point of constant returns to scale, point C. The point b^{CRS} shows the necessary input used if the farm was operating at the optimal scale and technically efficient. The point b^{VRS} shows that under conditions of increasing returns to scale, more input is necessary to produce the given level of output than is indicated if CRS is assumed.

From Figure 8 we note that farm C is the only one that produced at the CRS frontier and the only one that has the maximum output per input. Farm B would need to increase in scale to reduce scale inefficiency.

"The nature of the scale inefficiencies for a particular farm can be determined by seeing whether NIRS TE score is equal to the VRS TE score" (Coelli, Rao, and Battese, p. 152). If they are equal, as in the case of farm D, then the farm exhibits DRS. If they are unequal, as in the case of farm B, then the farm exhibits IRS.

Stochastic Frontier Analysis

Stochastic frontier production function

The main strengths of the stochastic frontier approach are that it deals with stochastic noise. Tests of hypotheses regarding production structure technology and the existence of inefficiency can be performed on a stochastic frontier. The main problems with the stochastic frontier production function are, that the selection of a distributional form for the inefficiency effects may be arbitrary, the production function must be specified by a particular functional form, and the stochastic frontier approach is only well-developed for single –output technology (Coelli, Rao and Battese).

A production function can be specified for cross-sectional data with an error term containing two components: one that accounts for technical inefficiency (v_i) and a second one that accounts for random effects (u_i). The frontier production function proposed by Aigner, Lovell and Schmidt is as follows:

$$y_i = f(x_i;\beta) + \varepsilon_i \qquad i=1, 2, ..., n \tag{11}$$

where y_i is the quantity of output of the *ith* farm; X_i is a ($kx1$) vector of quantities of input employed by the *ith* farm to produce y; β is a vector of unknown production function parameters to be estimated; and ε_i is an error term made up of two components,

$$\varepsilon_i = v_i - u_i \tag{12}$$

The v_i's are assumed to be independent and identically distributed random errors having a normal distribution with mean zero and variance σ_v^2. thus, v_i accounts for measurement error and other factors that are beyond the farmers control. The v_i's are assumed to be independent of the u_i's that are nonnegative random errors ($u_i \geq 0,\ \forall i$). The u_i's are assumed to account for technical inefficiency in production and assumed to be independent and identically distributed exponential or half-normal random variables.

If we combine equation (11) and (12), assuming a Cobb-Douglas specification, the stochastic frontier production function for this study could be rewritten as follows:

(13) $$\ln y_i = \beta_0 + \sum_{i=1}^{m} \beta_i \ln x_{ij} + v_i - u_i \qquad i=1,2,\ldots,n$$

where y_i is the output of farm *i*, x_{ij} is the amount of input *j* used by farm *i*, β_j are parameters to be estimated. The output values are bounded above by the stochastic variable, $\exp(X_i\beta + v_i)$. The random error, v_i, can be positive or negative and so the stochastic frontier. To illustrate the basic feature of the model following Coelli, Rao, and Battese, assume two farms, *i* and *j*, producing two outputs, y_i and y_j, using two inputs, x_i and x_j. The inputs are represented on the horizontal axis and the outputs on the vertical axis. Assuming diminishing returns to scale of the deterministic component of the frontier model, $y = exp\ (x\beta)$, the observed input-output are presented on Figure 14 by the point marked with × above the value of x_i, but the value of stochastic frontier output, $y_i^* \equiv exp\ (X_i\beta + v_i)$, is marked by the point⊗ above the production function because the random error v_i, is positive. Similarly, the *j*th farm has a negative random error v_j, so the frontier output will be below the production function (Coelli, Rao, and Battese).

Technical efficiency (TE) of farm *i* is the ratio of actual output for the *ith* farm (y_i), relative to the potential output, defined by the frontier function, given the input vector $exp\ (x_i\beta)$, is used to define the TE of the *i*th farm.

(14) $$TE_i = \frac{y_i}{\exp(x_i\beta)} = \frac{\exp(x_i\beta - u_i)}{\exp(x_i\beta)} = \exp(-u_i).$$

Where y_i is the observed output, and $\exp\ (x_i\beta)$ is the estimated value of the frontier output. The parameters β can be estimated where $\sum_{i=1}^{n} u_i$ is minimized, subject to the constraints that $u_i \geq 0$, $i=1,2\ldots n$ (Coelli, Rao, and Battese). This efficiency measure takes the values between 0 and 1 with smaller ratio indicating greater inefficiency.

Maximum- Likelihood Estimation:

Assuming independence between v_i and u_i, the parameters of the stochastic frontier function (β), defined by equation (13), can be estimated using the maximum-likelihood (ML) method. ML is computationally demanding. It requires numerical maximization of the likelihood function. The ML estimator is asymptotically efficient. According to Coelli, Rao and Battese, the basic elements of obtaining ML estimators for the parameters of the stochastic frontier model are consistent with the case of a half-normal distribution for the technical inefficiency effects.

Battese and Corra showed the log-likelihood function is equal to

$$\textbf{(15)}\ \ln L(y \mid \beta, \gamma, \sigma^2) = -\frac{N}{2}\ln(\frac{\pi}{2}) - \frac{N}{2}\log(\sigma_S^2) + \sum_{i=1}^{N}\ln[1-\phi(Z_i)] - \frac{1}{2\sigma_S^2}\sum_{i=1}^{N}(\ln y_i - x_i\beta)^2$$

where $\sigma^2 = \sigma_u{}^2 + \sigma_v{}^2$, $\gamma = \sigma_u/\sigma_v$, $Z_i = \frac{(\ln y_i - x_i\beta)}{\sigma_S}\sqrt{\frac{\gamma}{1-\gamma}}$; and ϕ (.) is the cumulative distribution function of the standard normal random variable. The ML estimates β, σ^2_s and γ are obtained by finding the maximum of the log-likelihood function defined in equation (15). The ML estimators are consistent and asymptotically efficient (Coelli, Rao, and Battese). The parameters of the stochastic frontier model can be estimated by using SAS, GAUSS, LIMDEP, SHAZAM, or FRONTIER Version 4.1.

Mean Technical Efficiency:

Assuming that the non-negative random variable associated with technical inefficiency in production, u'_is, are independently and identically distributed half-normal random variables, and the mathematical expectation of the technical efficiency, $TE_i = \exp(-u_i)$, then

$$E[\exp(-u_i)] = 2[1 - \Phi(\sigma_S \sqrt{\gamma})] \exp(-\gamma \sigma_S^2 / 2) \tag{16}$$

By substituting the maximum likelihood estimators for the relevant parameters in equation (16) the mean technical efficiency can be determined (Coelli, Rao, and Battese).

Testing Distributional Assumption:

A common criticism of the stochastic frontier model is the distributional assumption (Schmidt). If the distributional assumptions are incorrect, then the maximum likelihood estimates are incorrect (Carter and Cubbage).

The null hypothesis for the frontier model which is defined by equation (13), is that there are no technical inefficiency effects in the model, H_0: $\sigma^2 = 0$ and H_a: $\sigma^2 > 0$, where, σ^2 is the variance of the normal distribution that is truncated at zero to obtain the distribution of u_i. To test the above hypothesis, the Wald statistic involves the ratio of the maximum likelihood estimator for σ^2 to its estimated standard error (Aigner, Lovell, and Schmidt). Coelli, Rao, and Battese use the equivalent set of hypotheses such as H_0: $\gamma=0$ versus H_a: $\gamma>0$, using the Wald test, which is asymptotically distributed as a standard normal random variable, and the test should be perform as a one-sided test because γ cannot be negative. The one-sided generalized likelihood-ratio test is used when ML estimation is involved because it has the correct size, where the critical value for a test of size α is given by $\chi^2_{1,(2\alpha)}$ (Coelli, 1995).

$$LR = -2\ln\left[\frac{L(H_0)}{L(H_a)}\right] \tag{17}$$

where $L(H_0)$ is the value of the likelihood function for the frontier model, in which the parameter restrictions are specified by the null hypothesis; and $L(H_a)$ is the value of the likelihood function for the general frontier model. If the null hypothesis is true, then γ has approximately chi-square (or mixed chi-square) distribution $\frac{\chi_0^2}{2} + \frac{\chi_a^2}{2}$ with degrees of freedom equal to the difference between the parameters estimated under H_0 and H_a, respectively (Ajibefun, Battese and Kada).

Example

Farm technical efficiency with (CRS) SFA model

The reason for this simple example is to further explain how to estimate the stochastic frontier production function, and to show that when the data exhibit CRS the DEA results will be similar to SFA results. This example involved generating a single output (y), considering the two random errors (v_i and u_i), and two inputs (x_1, x_2) for twenty farms. Data are presented in Table 5. The first column in Table 5 contains an integer for farm number. The following two columns are the inputs followed by the original output when the two random errors are not included. The last three columns are the random errors v_i, u_i, and the output when the random errors are considered. These two random errors (v_i and u_i) were generated using the data analysis option in Excel tools. The random number generator option assuming a normal distribution with zero mean and standard deviation of 1,000 was used. Since u_i is a nonnegative random error, the absolute value for each generated random error was used. The last column is the stochastic output when the random errors are considered.

The statistical software SHAZAM, computer program DEAP Version 2.1 and the computer program FRONTIER Version 4.1 are used to estimate technical efficiency for this sample of data.

To estimate the CRS Cobb-Douglas stochastic frontier production function assuming CRS using SHAZAM (Appendix C.1.) software, we have to create the following command file[3] (White).

```
⌊SAMPLE 1 20
```

Since we have 20 observations, SAMPLE is used to specify the sample size. The sample size is the number of observations in the data, where 1 is the first observation, and 20 is the last observation.

```
⌊READ N Y X1 X2
```

To enter the data, the output and inputs should follow the command read, where N=number of observation, Y=output, and X's=are the input variables.

```
⌊GENR LY=LOG (Y)
⌊GENR LX1=LOG (X1)
⌊GENR LX2=LOG (X2)
```

The GENR command will create new variables for old ones and do a variety of data transformation. Since the Cobb-Douglas production function is used, the original data are transformed by the logarithm option.

```
⌊OLS LY LX1 LX2 /COEF=BOLS
```

OLS command will run an ordinary least squares regression. This command will run a regression of the output (LY) on input variables LX1 and LX2. The constant is

---

[3] The command and its explanation are from White, Kenneth J. "Shazam User's Reference Manual Version 8.0." Canada:McGraw-Hill Book Company, 1997.

automatically included in the regression. The option COEF =BOLS enables the user to use the estimated regression coefficient in further commands.

```
|_GENR SIG=SQRT ($SIG2)
```

The estimate of the standard error is the square root of the variance. The likelihood function may be evaluated for a number of values of gamma, by adjusting the intercept and σ_s^2 using corrected OLS. The best estimate that corresponds to the largest log likelihood estimation is used as a starting value to obtain the maximum likelihood estimate.

```
|_DIM BETA 5
```

The DIM command will reserve enough space for all the observations.

```
|_GEN1 BETA: 2=BOLS: 3
|_GEN1 BETA: 3=BOLS: 1
|_GEN1 BETA: 4=BOLS: 2
|_GEN1 BETA: 1=SIG
|_GEN1 BETA: 5=1
|_GENR CONSTANT=0.5*LOG (2/$PI)
```

The GEN1 command is used to generate a scalar variable or constant. It is equivalent to using both a SAMPLE 11 command and GENR command to generate a variable with only one observation.

Define the regression function in a character string.

```
|_ERROR: (LY- (B0+BX1*LX1+BX2*LX2))
```

Specify the density function for the "Half-Normal" model (equation 15).

Use the LOGDEN option on the NL command, to specify that the equation command is the LOG-DENSITY for a single observation rather than a regression equation. SHAZAM will compute the likelihood function assuming the log-densities. This option allows maximum likelihood estimation of a large variety of functions.

```
⌊NL 1/ NCOEF=5 LOGDEN START=BETA COEF=BNEW
```

The NL command provides general features for the estimation of nonlinear models. The option NCOEF is used to specify the number of coefficients. The starting values of the parameters are provided via the START option. Because of the asymmetric distribution, we thus have a regression model with a nonnormal distribution specified for the disturbance (Green).

```
⌊EQ CONSTANT-0.5*LOG (SIGMA**2)- 0.5*([ERROR]/SIGMA)**2+LOG
NCDF (-[ERROR]*GAMMA/SIGMA))
```

EQ is required for every equation in the model. NCDF=standard normal cumulative distribution function.

```
⌊END
```

The command the follows may be used to recover an estimate for σ_v (reported as test value).

```
⌊TEST (SIGMA*SIGMA/(1+GAMMA*GAMMA))**0.5
```

Recover an estimate for σ_u.

```
⌊TEST (SIGMA*SIGMA*GAMMA*GAMMA/(1+GAMMA*GAMMA))**0.5

⌊GEN1 SIGMA=BNEW: 1
⌊GEN1 GAMMA=BNEW: 5
⌊GENR Z=(LY- (BNEW: 2+BNEW: 3*LX1+BNEW: 4*LX2))*GAMMA/SIGMA
⌊? DISTRIB Z/PDF=PDFZ
```

Calculation of the estimated inefficiencies. PDF=the probability density function.

```
⌊GENR U=SIGMA*GAMMA/(1+GAMMA*GAMMA)*(PDFZ/(1-NCDF (Z))-Z)
⌊PRINT U
```

```
└STOP
```

The maximum likelihood (ML) estimates of the parameters of the Cobb-Douglas stochastic frontier production function are presented in Table C.1. of appendix C. The signs of the slope coefficients of the stochastic frontier production function are positive. The first estimated coefficient x_1 is highly significant, but the second is not. The empirical results in Table C.1. of appendix C indicate that the elasticity of output with respect to x_1 and x_2 was estimated to be 0.55 and 0.084 This indicates that, if x_1 and x_2 quantities increased by one percent, then the total output production would increase by 0.55 and 0.084 percent respectively.

The technical efficiency of the *ith* farm is defined by TE_i=exp ($-u_i$). The estimated technical efficiencies are listed in the bottom of Table C.1. For example, u_5 for farm 5 is equal to 0.3556377, thus the TE_5=exp(-0.3556377) = 0.70.

To estimate the Cobb-Douglas stochastic frontier production function for the above example assuming CRS using FRONTIER Version 4.1 program we have to construct three files, two for the data and one for the instruction (Table C.2 and C.3.). The result is shown in Table C.4. This program uses a three-step procedure to estimate the maximum likelihood estimates[4]:

1. Ordinary Least Squares (OLS) to estimate all β-parameters and σ_S^2. These parameters are unbiased with the exception of the intercept, β_0 ;
2. Grid search is used to estimate γ, where the likelihood function is evaluated for a number of values of γ between zero and one, with the β parameters obtained from

---

[4] FRONTIER 4.1 can be downloaded from the internet by accessing the address for the Center for Efficiency and Productivity Analysis at the University of New England, Armidale, NSW, Australia: http://www.une.edu.au/econometrics/cepa.htm.

the first step, and adjusting for the intercept β_o and σ_S^2 using corrected ordinary least square formula.

3. Use the best estimate from the second step as starting values in an iterative procedure, to obtain the maximum likelihood estimates.

In Table C.2 the first two columns contain an integer for farm number and year number. Since we assuming cross-sectional data, the year number will be equal to one. The last three columns is the log of output and inputs respectively.

The first results listed in Table C.3 are the OLS estimates for the parameters of the model. The estimated of γ is 0.9375, and the estimated standard error is 0.1037. This indicates that the majority of residual variation is due to the inefficiency effect, u_i. The estimated technical efficiencies are listed in the bottom of Table C.5. The mean technical efficiency is 59%. According to Coelli, Rao, and Battese, when the data reflect CRS the technical efficiency under the stochastic frontier will be equal to those estimated under data envelopment analysis. The results of running the DEAP Version 2.1 for the same data set are essentially the same as (Table C.5.) those obtained with SFA.

Farm technical efficiency with (VRS) SFA model

The reason for this example is to explain how we can estimate the stochastic frontier production function assuming variable returns to scale. This example is a statewide set of observations used by Zellner and Revankar (1970) to study production in the transportation equipment manufacturing industry (Greene). The data were used to estimate the stochastic frontier production function leading us to estimate the technical efficiency for each state. The data involved a single output (y) and two inputs x_1 capital and x_2 labor. DATA for twenty-five states are presented in Table 6.

As we mentioned above, stochastic frontiers can be estimated using many computer programs, such as SAS, GAUSS, SHAZAM, Fortran, LIMDEP, and FRONTIER. For this example the statistical software SHAZAM and the computer program FRONTIER Version 4.1 are used to estimate the technical efficiency for this sample of data.

To estimate the VRS Cobb-Douglas stochastic frontier production function using SHAZAM, the same command file was used. The estimated parameters of the function, β_0, β_1, and β_2 are presented in Table 7.

The technical efficiency of the *ith* state is defined by $TE_i = \exp(-u_i)$. The estimated technical efficiencies are listed in the bottom of Table D.1 of Appendix D. The mean technical efficiency is 84%.

To estimate the Cobb-Douglas stochastic frontier production function for the above example assuming VRS using the FRONTIER Version 4.1 program, we have to construct three files, two for the data and one for the instruction. The results are presented in Table D.2. The first result listed in Table D.2 is the OLS estimates of the parameters, assuming no technical inefficiency.

The estimated parameters for β_1 and β_2 are unbiased, but the OLS estimate for β_0 and σ^2_s, are biased. These OLS estimates are used as starting values in the iterative process to obtain the ML estimate by conducting the grid search over values of γ between 0 and 1 and choosing the value corresponding to the largest log likelihood function as starting values in an iterative maximization routine (Coelli, Rao, and Battese).

The ML results of estimated parameters are similar to the SHAZAM estimates reported in Table 9. The maximum likelihood (ML) estimates of the Cobb-Douglas stochastic frontier production function parameters are presented in Tables 7 and D.2. The signs of the slope coefficients of the stochastic frontier production function are positive and significant. The empirical results in Table 7 indicate that the elasticity of production with respect to capital was estimated to be 0.258. This indicates that, if the capital quantity increased by one percent, then the total production would increase by 0.258 percent. Moreover, the elasticity of labor is 0.780. Thus, if the quantity of labor increased by one percent, then total production is expected to increase by 0.78 percent.

The estimate of the γ parameter associated with the variance in the stochastic frontier was 0.6152. It is statistically significant for an alpha level of 5%. This indicates that the stochastic frontier model may be significantly different from the deterministic frontier.

Also the one-sided generalized likelihood ratio test of $\gamma=0$ provides a statistic of 0.43161which less than the 5% critical value of 2.71 indicating that the average response function is an adequate representation of the data.

A summary of technical efficiency indexes calculated from the estimated production frontiers is listed in Table D.2. These values range from 0.60 to 0.94, with mean technical efficiency estimated to be 0.84. This implies that the transportation equipment manufacturing industry is producing to about 84 percent of the potential frontier production levels, implying that the production is about 16% below the frontier. This also means that a significant proportion of production in transportation equipment manufacturing industry is lost due to technical inefficiency. Given the levels of their inputs and the technology currently being used, 80% of the transportation equipment manufacturing industry had technical efficiencies less than 90%. About 68% of the transportation equipment manufacturing industry had technical efficiencies between 80-90%.

TABLE 1.

EXAMPLE DATA FOR CRS DEA TE MODEL

Farm	y	x_1	x_2	x_1/y	x_2/y
A	1	1	8	1	8
B	1	2	4	2	4
C	1	4	2	4	2
D	1	6	1	6	1
E	1	4	4	4	4
F	1	6	3	6	3

TABLE 2

CRS INPUT-ORIENTATION DEA TE MODEL RESULTS

Farm	θ	λ_A	λ_B	λ_C	λ_D	λ_E	λ_F
A	1.0	1.0	-	-	-	-	-
B	1.0	-	1.0	-	-	-	-
C	1.0	-	-	1.0	-	-	-
D	1.0	-	-	-	1.0	-	-
E	0.75	-	0.5	0.5	-	-	-
F	0.66	-	-	1.0	-	-	-

TABLE 3

EXAMPLE DATA FOR VRS DEA TE MODEL

Farm	Y	X
A	2	4
B	4	8
C	6	6
D	8	10
E	10	12

TABLE 4

VRS INPUT-ORIENTATION DEA TE MODEL RESULTS

Farm	CRS TE	VRS TE	Scale	
A	0.500	1.000	0.500	irs
B	0.500	0.625	0.800	irs
C	1.000	1.000	1.000	-
D	0.800	0.900	0.889	drs
E	0.833	1.000	0.833	drs
Mean	0.727	0.905	0.804	

TABLE 5

EXAMPLE DATA FOR STOCHASTIC FRONTIER PRODUCTION FUNCTION ASSUMING CRS TE MODEL

N	X_1	X_2	Y[5]	V	U	Y+V-U
1	270	2440	4058.32	-300.23	1277.68	2480.409
2	170	3250	3716.52	244.26	1276.47	2684.300
3	380	3800	6008.33	1198.35	1733.13	5473.544
4	200	2840	3768.29	-2183.59	234.18	1350.519
5	85	2340	2229.91	1095.02	1086.70	2238.232
6	265	3780	5004.25	-690.20	1690.43	2623.611
7	95	4500	3269.17	-1846.91	977.63	444.6338
8	320	2460	4436.21	-773.51	2117.93	1544.776
9	190	2130	3180.80	-567.92	404.05	2208.829
10	50	2565	1790.60	134.85	365.49	1559.960
11	440	4000	6633.25	-326.99	370.24	5936.018
12	370	4420	6394.14	1342.64	85.28	7651.495
13	240	2650	3987.48	-186.16	513.21	3288.115
14	160	2080	2884.44	1972.21	865.67	3990.980
15	380	2600	4969.91	2375.65	654.91	6690.657
16	250	3000	4330.13	1661.46	1612.40	4379.185
17	320	2955	4862.09	538.95	902.19	4498.855
18	105	2800	2711.08	1918.92	84.52	4545.486
19	350	2545	4718.97	-523.80	675.14	3520.044
20	90	2640	2437.21	-381.32	757.61	1298.276

---

[5] $Y= 5*(X_1^{0.5})*(X_2^{0.5})$

TABLE 6

EXAMPLE DATA FOR STOCHASTIC FRONTIER PRODUCTION FUNCTION ASSUMING VRS TE MODEL

State	T	Output	Capital	Labor
Alabama	1	126.148	3.804	31.551
California	1	3201.486	185.446	452.844
Connecticut	1	690.67	39.712	124.074
Florida	1	56.296	6.547	19.181
Georgia	1	304.531	11.53	45.534
Illinois	1	723.028	58.987	88.391
Indiana	1	992.169	112.884	148.53
Iowa	1	35.796	2.698	8.017
Kansas	1	494.515	10.36	86.189
Kentucky	1	124.948	5.213	12
Louisiana	1	73.328	3.763	15.9
Maine	1	29.467	1.967	6.47
Wisconsin	1	415.262	17.546	69.342
Maryland	1	241.53	15.347	39.416
Massachusetts	1	4079.554	435.105	490.384
Michigan	1	652.085	32.84	84.831
Missouri	1	667.113	33.292	83.033
New Jersey	1	940.43	72.974	190.094
New York	1	1611.899	157.978	259.916
Ohio	1	617.579	34.324	98.152
Pennsylvania	1	527.413	22.736	109.728
Texas	1	174.394	7.173	31.301
Virginia	1	636.948	30.807	87.963
Washington	1	22.7	1.543	4.063
West Virginia	1	349.711	22.001	52.818

Source: Greene, W.H. *Econometric Analysis*. New York: Prentice Hall, 2000.

TABLE 7

ESTIMATED STOCHASTIC FRONTIER PRODUCTION FUNCTION WITH SHAZAM AND FRONTIER VERSION 4.1 ASSUMING VRS

Variables	SHAZAM Least Squares Model Coefficient	SHAZAM ML or Half-Normal Model Coefficient	FRONTIER 4.1 Least Squares Model Coefficient	FRONTIER 4.1 ML Model Coefficient
Intercept	1.844 (0.233)	2.081 (0.281)	1.844 (0.233)	2.081 (0.282)
X_1	0.245 (0.107)	0.258 (0.097)	0.245 (0.106)	0.258 (0.099)
X_2	0.805 (0.126)	0.780 (0.119)	0.805 (0.126)	0.780 (0.120)
σ	0.235	0.282 (0.075)	0.076	0.079 (0.042)
σ_u		0.221 (0.123)		
σ_v		0.175 (0.053)		
γ		1.264 (1.025)		0.615 (0.385)
Log L	2.25371	2.46952	2.25371	2.46952

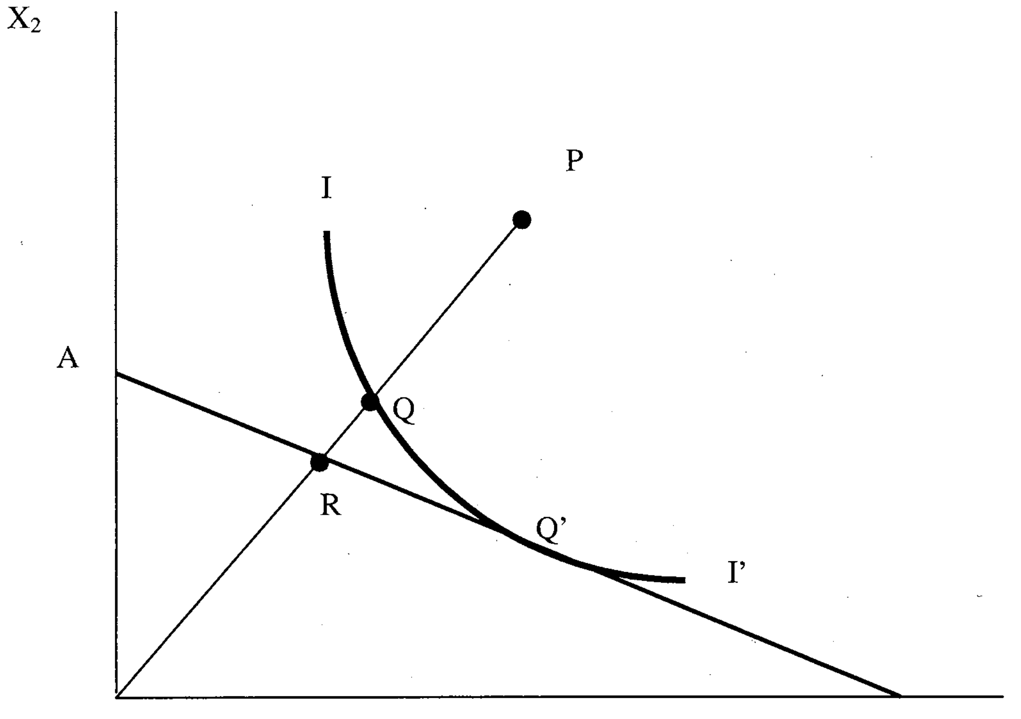


Figure 1. Farrell's measure of efficiency

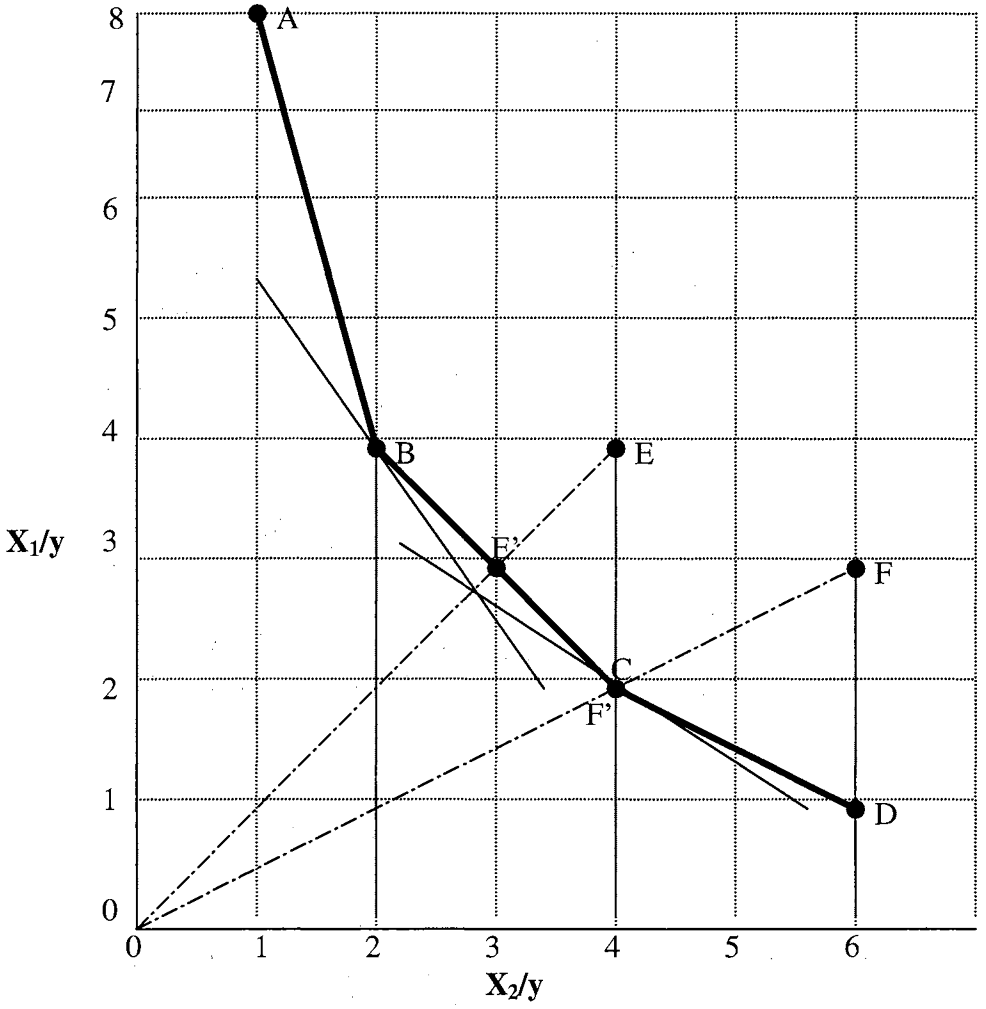
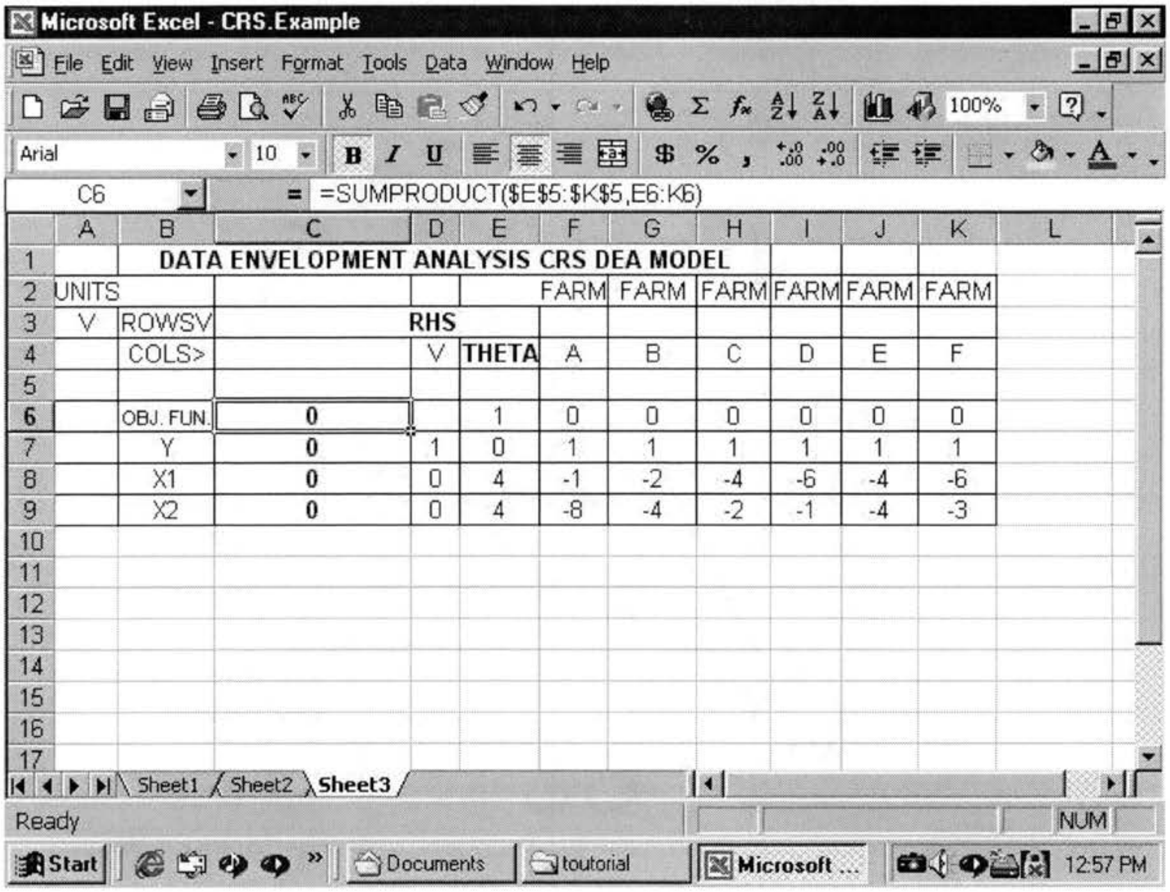


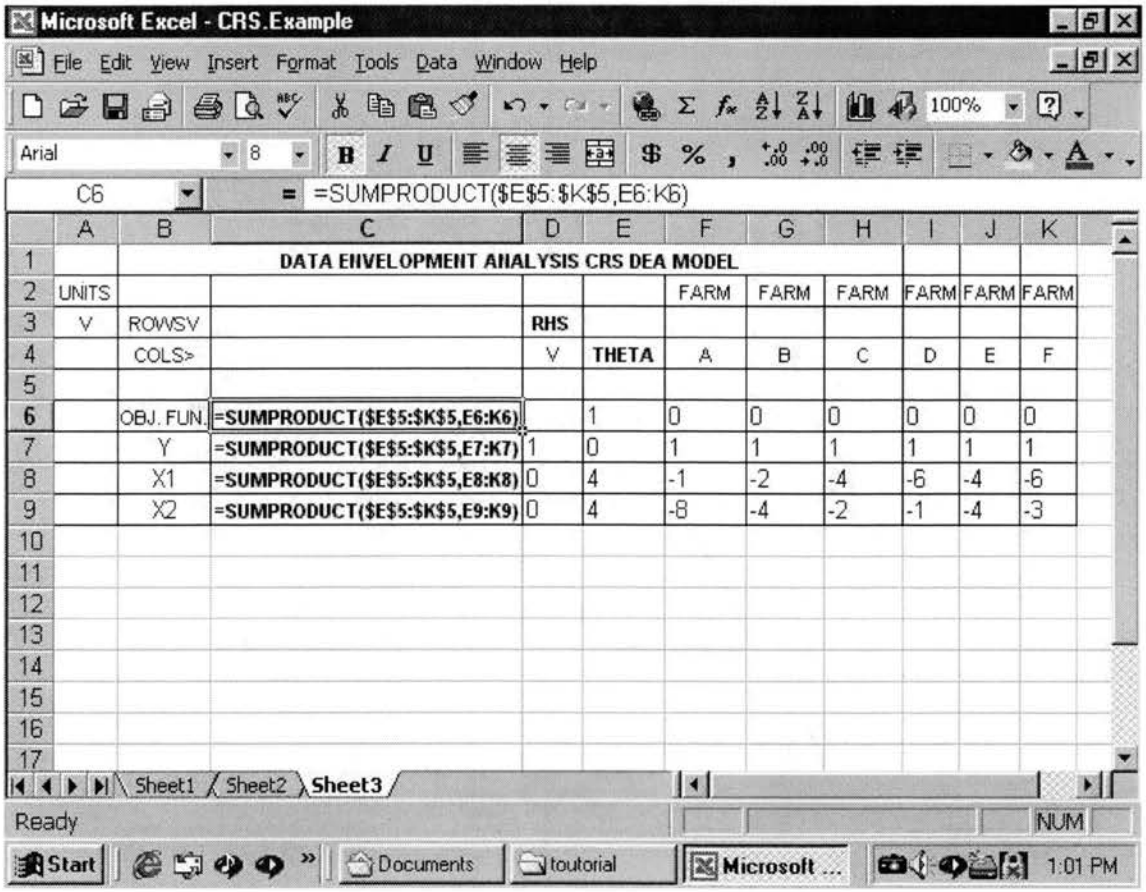
Figure 2. Constant returns to scale input-orientated DEA example



C6 = =SUMPRODUCT($E$5:$K$5,E6:K6)

	A	B	C	D	E	F	G	H	I	J	K	L
1		**DATA ENVELOPMENT ANALYSIS CRS DEA MODEL**										
2	UNITS					FARM	FARM	FARM	FARM	FARM	FARM	
3	V	ROWSV		**RHS**								
4		COLS>		V	**THETA**	A	B	C	D	E	F	
5												
6		OBJ. FUN.	**0**		1	0	0	0	0	0	0	
7		Y	**0**	1	0	1	1	1	1	1	1	
8		X1	**0**	0	4	-1	-2	-4	-6	-4	-6	
9		X2	**0**	0	4	-8	-4	-2	-1	-4	-3	

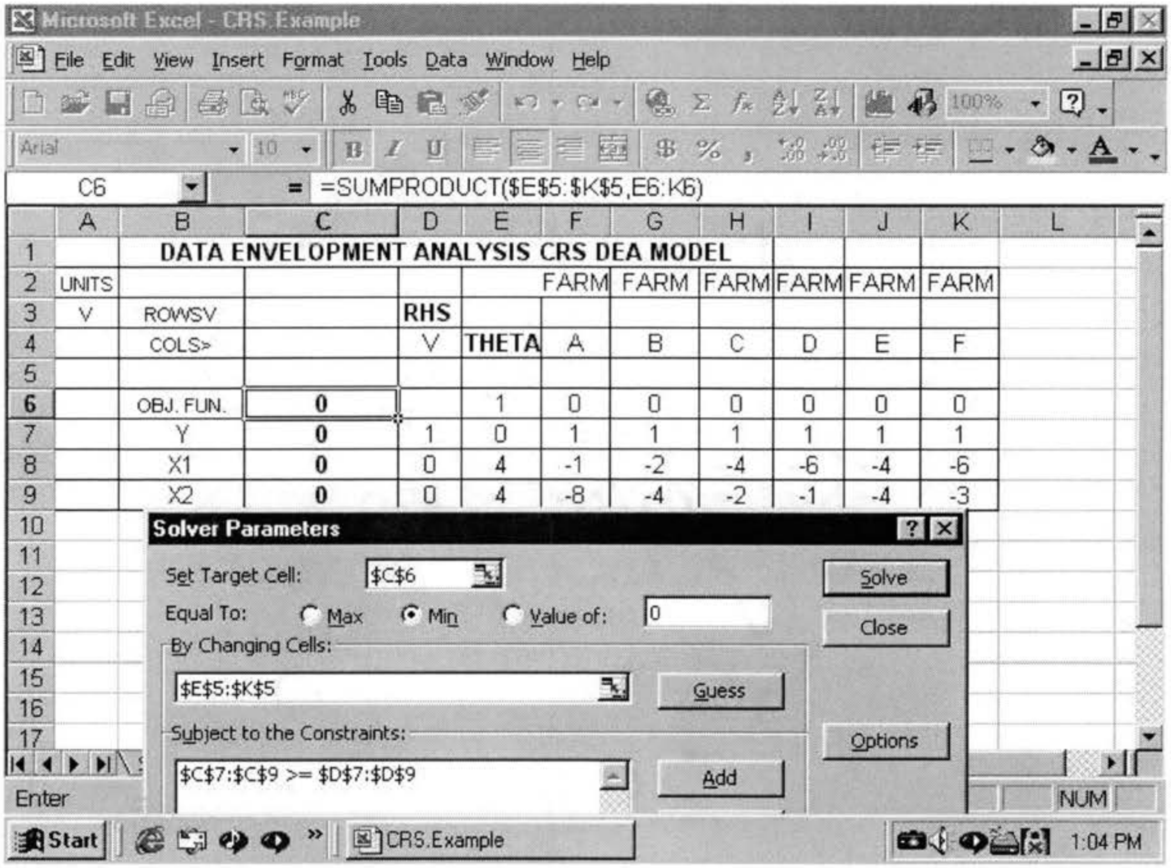
Figure 3. The initial Tableau for the CRS DEA TE model



C6 = =SUMPRODUCT($E$5:$K$5,E6:K6)

	A	B	C	D	E	F	G	H	I	J	K
1		DATA ENVELOPMENT ANALYSIS CRS DEA MODEL									
2	UNITS					FARM	FARM	FARM	FARM	FARM	FARM
3	V	ROWSV		RHS							
4		COLS>		V	THETA	A	B	C	D	E	F
5											
6		OBJ. FUN.	=SUMPRODUCT($E$5:$K$5,E6:K6)		1	0	0	0	0	0	0
7		Y	=SUMPRODUCT($E$5:$K$5,E7:K7)	1	0	1	1	1	1	1	1
8		X1	=SUMPRODUCT($E$5:$K$5,E8:K8)	0	4	-1	-2	-4	-6	-4	-6
9		X2	=SUMPRODUCT($E$5:$K$5,E9:K9)	0	4	-8	-4	-2	-1	-4	-3

Figure 4. The equations used to calculate the CRS DEA TE model using Excel



C6 = =SUMPRODUCT($E$5:$K$5,E6:K6)

	A	B	C	D	E	F	G	H	I	J	K	L
1		DATA ENVELOPMENT ANALYSIS CRS DEA MODEL										
2	UNITS					FARM	FARM	FARM	FARM	FARM	FARM	
3	V	ROWSV		RHS								
4		COLS>		V	THETA	A	B	C	D	E	F	
5												
6		OBJ. FUN.	0		1	0	0	0	0	0	0	
7		Y	0	1	0	1	1	1	1	1	1	
8		X1	0	0	4	-1	-2	-4	-6	-4	-6	
9		X2	0	0	4	-8	-4	-2	-1	-4	-3	

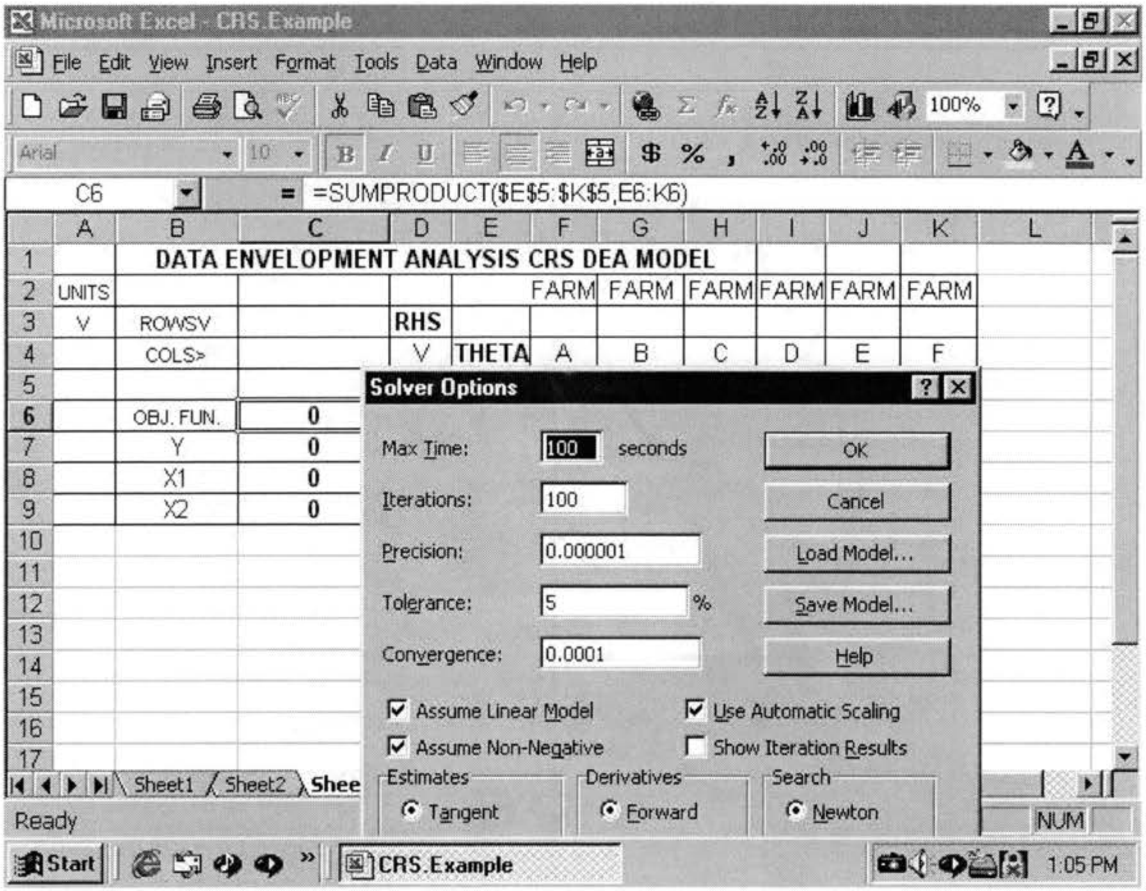
Set Target Cell: $C$6

Equal To: ○ Max ● Min ○ Value of: 0

By Changing Cells: $E$5:$K$5

Subject to the Constraints: $C$7:$C$9 >= $D$7:$D$9

Figure 5. Using Solver option in Excel to determine CRS DEA TE model



C6 = =SUMPRODUCT($E$5:$K$5,E6:K6)

	A	B	C	D	E	F	G	H	I	J	K	L
1		DATA ENVELOPMENT ANALYSIS CRS DEA MODEL										
2	UNITS					FARM	FARM	FARM	FARM	FARM	FARM	
3	V	ROWSV		RHS								
4		COLS>		V	THETA	A	B	C	D	E	F	
5												
6		OBJ. FUN.	0									
7		Y	0									
8		X1	0									
9		X2	0									

Max Time: 100 seconds

Iterations: 100

Precision: 0.000001

Tolerance: 5 %

Convergence: 0.0001

☑ Assume Linear Model

☑ Use Automatic Scaling

☑ Assume Non-Negative

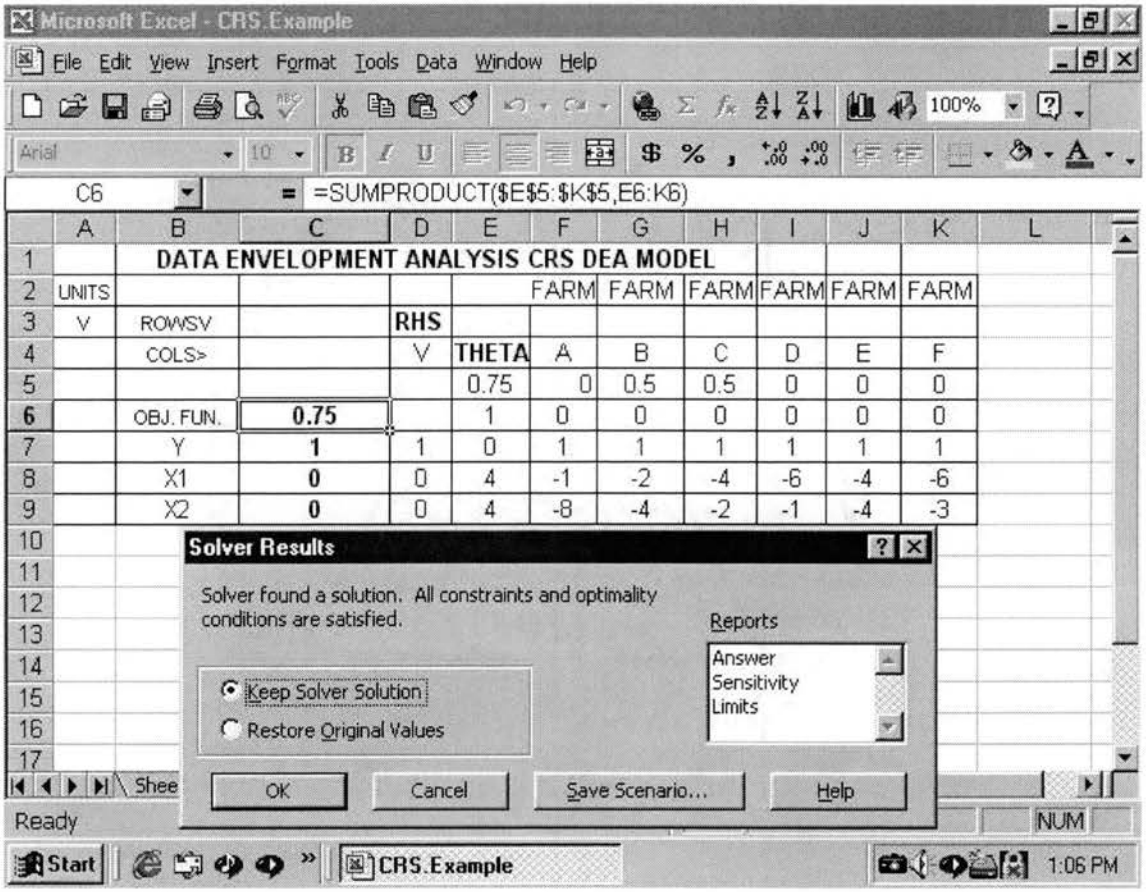
☐ Show Iteration Results

Estimates: ● Tangent

Derivatives: ● Forward

Search: ● Newton

Figure 6. Using option tab in solver to calculate the CRS DEA TE model



C6 = =SUMPRODUCT($E$5:$K$5,E6:K6)

	A	B	C	D	E	F	G	H	I	J	K
1		DATA ENVELOPMENT ANALYSIS CRS DEA MODEL									
2	UNITS					FARM	FARM	FARM	FARM	FARM	FARM
3	V	ROWSV		RHS							
4		COLS>		V	THETA	A	B	C	D	E	F
5					0.75	0	0.5	0.5	0	0	0
6		OBJ. FUN.	0.75		1	0	0	0	0	0	0
7		Y	1	1	0	1	1	1	1	1	1
8		X1	0	0	4	-1	-2	-4	-6	-4	-6
9		X2	0	0	4	-8	-4	-2	-1	-4	-3

Solver Results

Solver found a solution. All constraints and optimality conditions are satisfied.

● Keep Solver Solution

○ Restore Original Values

Reports

Answer
Sensitivity
Limits

Figure 7. The result of using solver to calculate the CRS DEA TE model for farm D

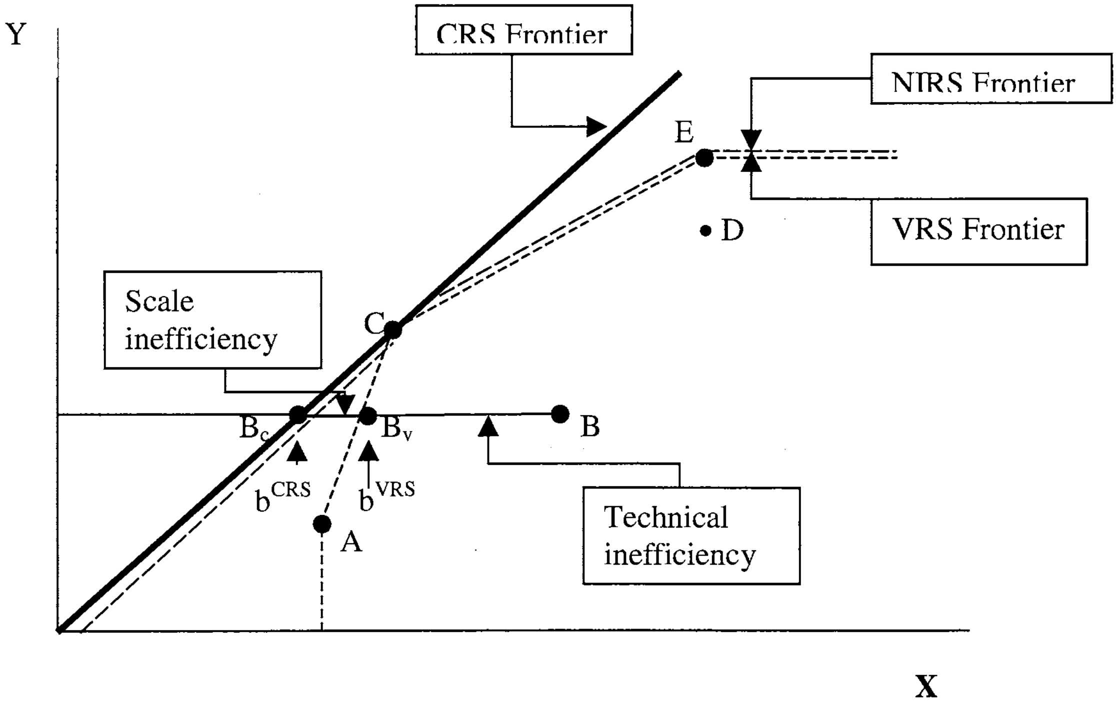
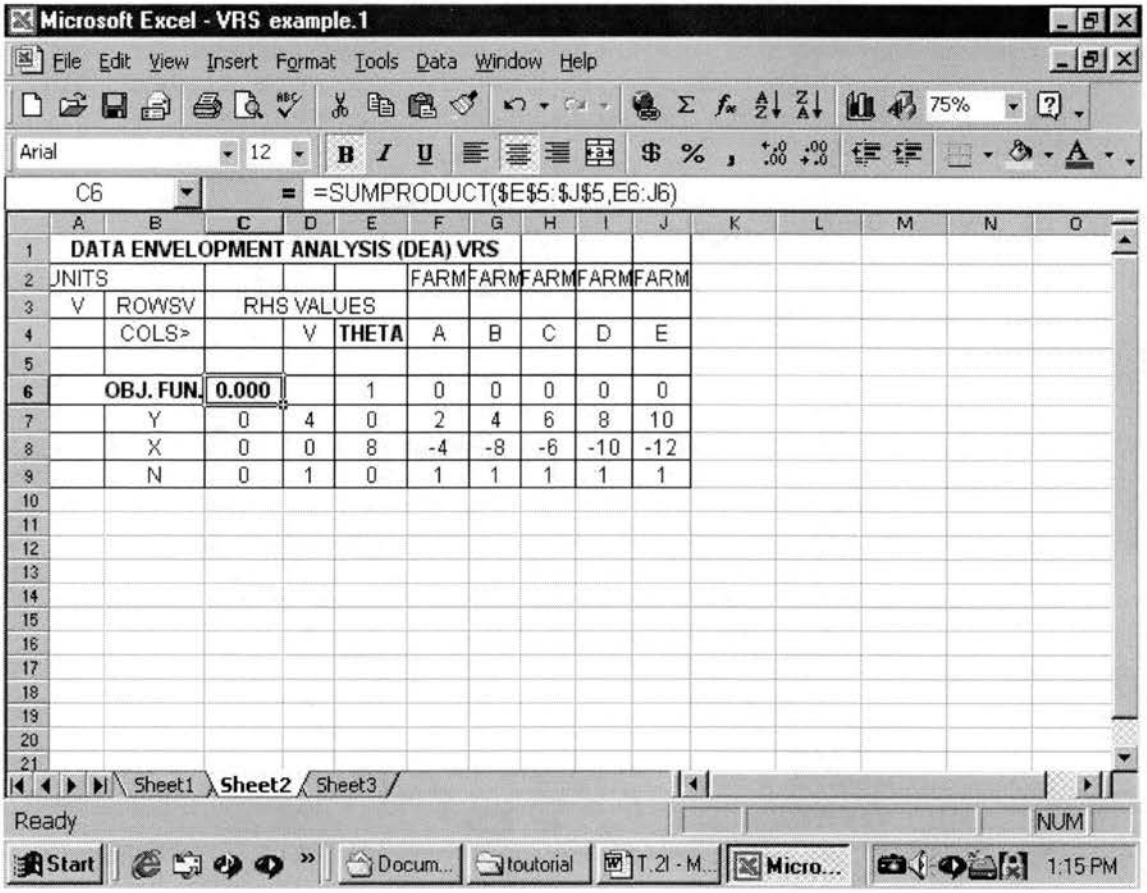


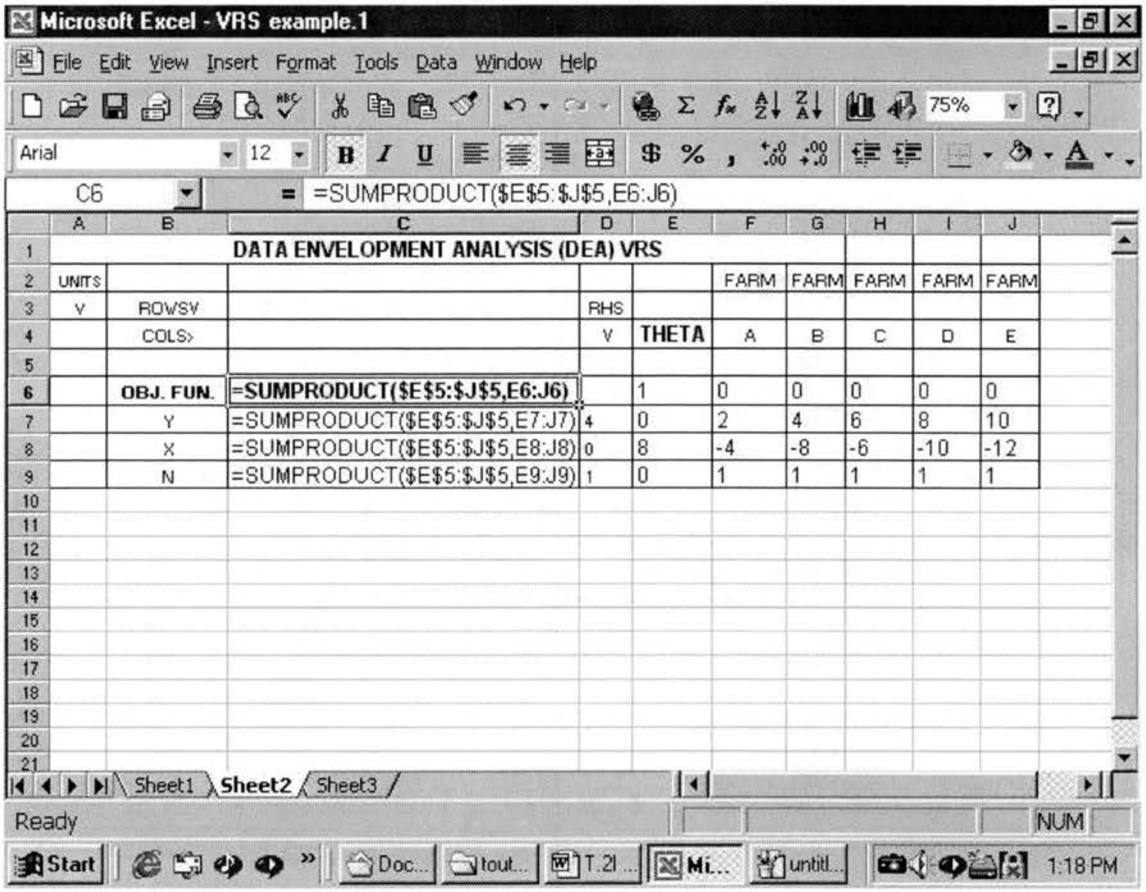
Figure 8. VRS input – oriented DEA TE example and calculation of scale economics



C6 = =SUMPRODUCT($E$5:$J$5,E6:J6)

	A	B	C	D	E	F	G	H	I	J
1	**DATA ENVELOPMENT ANALYSIS (DEA) VRS**									
2	UNITS					FARM	FARM	FARM	FARM	FARM
3	V	ROWSV	RHS VALUES							
4		COLS>		V	**THETA**	A	B	C	D	E
5										
6		**OBJ. FUN.**	**0.000**		1	0	0	0	0	0
7		Y	0	4	0	2	4	6	8	10
8		X	0	0	8	-4	-8	-6	-10	-12
9		N	0	1	0	1	1	1	1	1

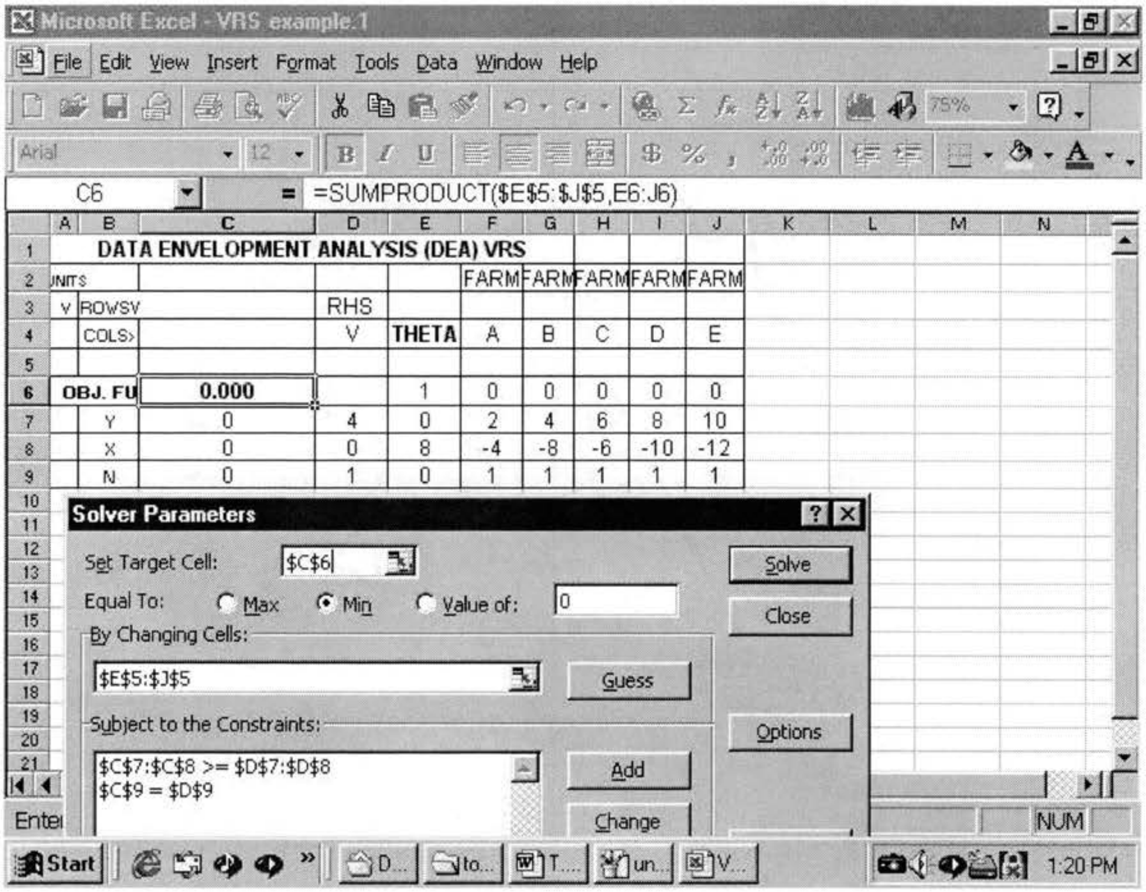
Figure 9. The initial Tableau for the VRS DEA TE model



C6 = =SUMPRODUCT($E$5:$J$5,E6:J6)

	A	B	C	D	E	F	G	H	I	J
1			**DATA ENVELOPMENT ANALYSIS (DEA) VRS**							
2	UNITS					FARM	FARM	FARM	FARM	FARM
3	V	ROWSV		RHS						
4		COLS>		V	**THETA**	A	B	C	D	E
5										
6		**OBJ. FUN.**	**=SUMPRODUCT($E$5:$J$5,E6:J6)**		1	0	0	0	0	0
7		Y	=SUMPRODUCT($E$5:$J$5,E7:J7)	4	0	2	4	6	8	10
8		X	=SUMPRODUCT($E$5:$J$5,E8:J8)	0	8	-4	-8	-6	-10	-12
9		N	=SUMPRODUCT($E$5:$J$5,E9:J9)	1	0	1	1	1	1	1

Figure 10. The equations used to calculate the VRS DEA TE model using Excel



C6 = =SUMPRODUCT($E$5:$J$5,E6:J6)

	A	B	C	D	E	F	G	H	I	J
1		DATA ENVELOPMENT ANALYSIS (DEA) VRS								
2	UNITS					FARM	FARM	FARM	FARM	FARM
3	V	ROWSV		RHS						
4		COLS>		V	**THETA**	A	B	C	D	E
5										
6	**OBJ. FU**		**0.000**		1	0	0	0	0	0
7		Y	0	4	0	2	4	6	8	10
8		X	0	0	8	-4	-8	-6	-10	-12
9		N	0	1	0	1	1	1	1	1

Solver Parameters

Set Target Cell: $C$6

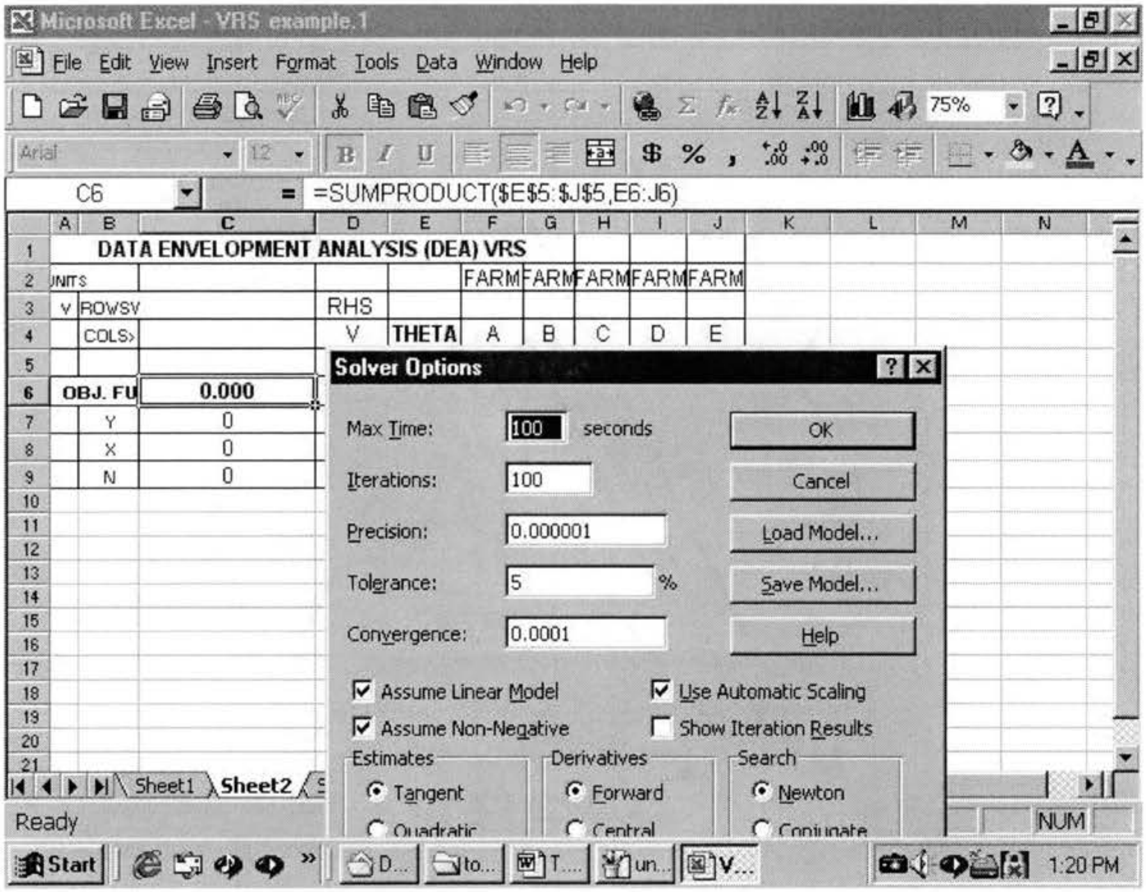
Equal To: ○ Max ● Min ○ Value of: 0

By Changing Cells: $E$5:$J$5

Subject to the Constraints:

$C$7:$C$8 >= $D$7:$D$8
$C$9 = $D$9

Figure 11. Using Solver option in Excel to determine VRS DEA TE model



C6 =SUMPRODUCT($E$5:$J$5,E6:J6)

	A	B	C	D	E	F	G	H	I	J
1		DATA ENVELOPMENT ANALYSIS (DEA) VRS								
2	NITS					FARM	FARM	FARM	FARM	FARM
3	V	ROWSV		RHS						
4		COLS>		V	THETA	A	B	C	D	E
5										
6		OBJ. FU	0.000							
7		Y	0							
8		X	0							
9		N	0							

Max Time: 100 seconds

Iterations: 100

Precision: 0.000001

Tolerance: 5 %

Convergence: 0.0001

☑ Assume Linear Model

☑ Use Automatic Scaling

☑ Assume Non-Negative

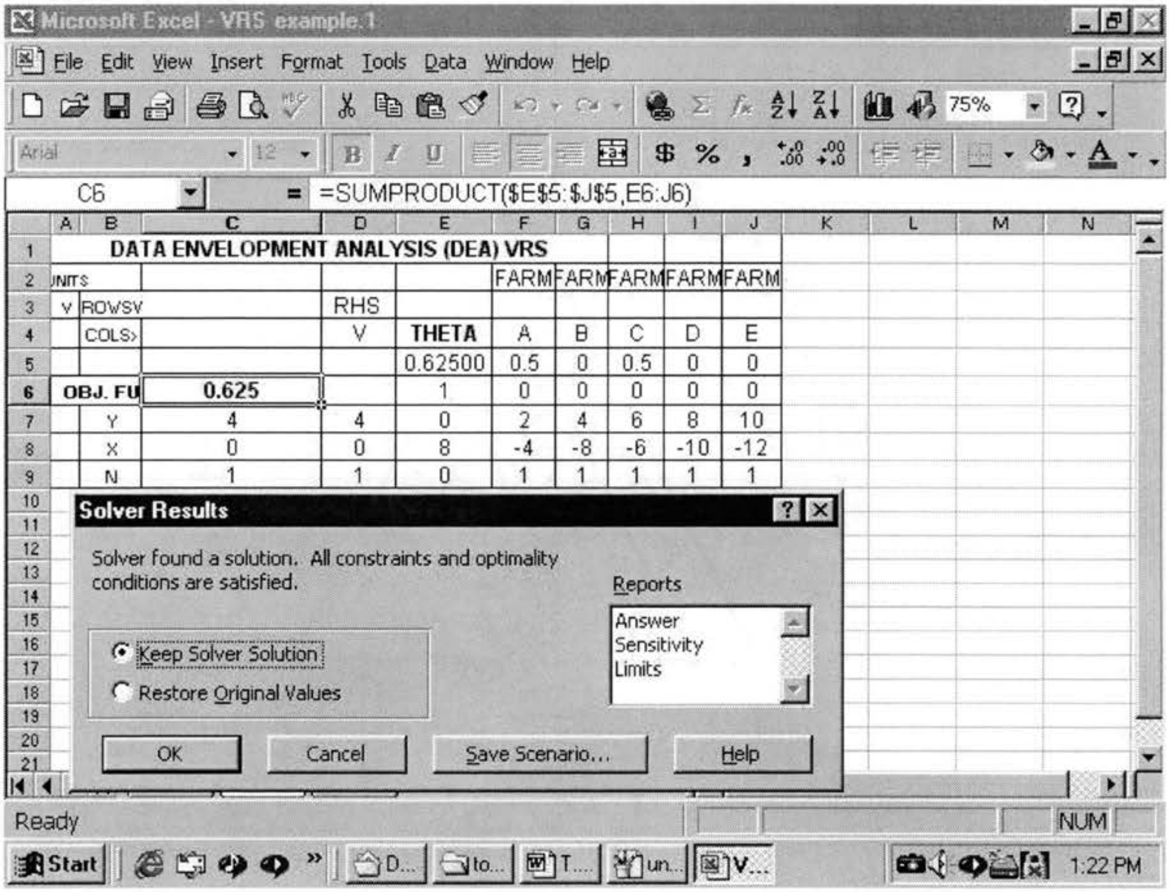
☐ Show Iteration Results

Estimates: ● Tangent ○ Quadratic

Derivatives: ● Forward ○ Central

Search: ● Newton ○ Conjugate

Figure 12. Using option tab in solver to calculate the VRS DEA TE model



C6 = =SUMPRODUCT($E$5:$J$5,E6:J6)

	A	B	C	D	E	F	G	H	I	J
1		DATA ENVELOPMENT ANALYSIS (DEA) VRS								
2	NITS					FARM	FARM	FARM	FARM	FARM
3	V	ROWSV		RHS						
4		COLS>		V	**THETA**	A	B	C	D	E
5					0.62500	0.5	0	0.5	0	0
6	**OBJ. FU**		**0.625**		1	0	0	0	0	0
7		Y	4	4	0	2	4	6	8	10
8		X	0	0	8	-4	-8	-6	-10	-12
9		N	1	1	0	1	1	1	1	1

Solver Results

Solver found a solution. All constraints and optimality conditions are satisfied.

● Keep Solver Solution

○ Restore Original Values

Reports

Answer
Sensitivity
Limits

Figure 13. The result of using solver to calculate the VRS DEA TE model for farm B

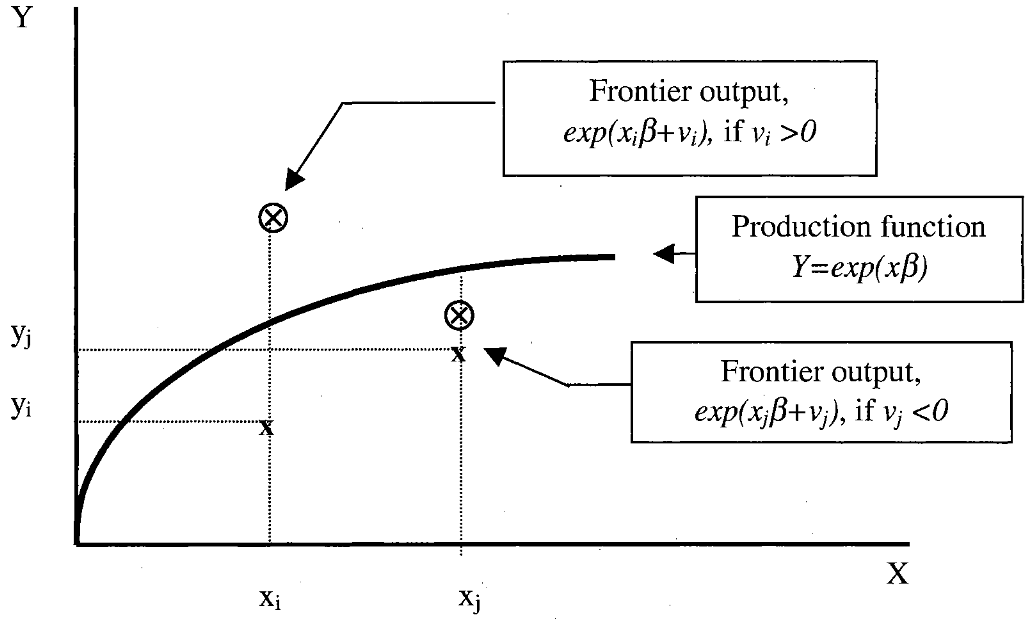


Figure 14. The Stochastic frontier production function

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Appendix A.

Table A.1

LISTING OF DATA FILE FOR CRS EXAMPLE USING DEAP VERSION 2.1

```
1     1     8
1     2     4
1     4     2
1     6     1
1     4     4
1     6     3
```

TABLE A.2

THE INSTRUCTION FILE FOR CRS EXAMPLE USING DEAP VERSION 2.1

```
eg1.dta                    DATA FILE NAME
eg1.out                    OUTPUT FILE NAME
6                          NUMBER OF FIRMS
1                          NUMBER OF TIME PERIODS
1                          NUMBER OF OUTPUTS
2                          NUMBER OF INPUTS
0                          0=INPUT AND 1=OUTPUT ORIENTATED
0                          0=CRS AND 1=VRS
0                          0=DEA (MULTI-STAGE), 1=COST-DEA,
                           2=MALMQUIST-DEA, 3=DEA (1-STAGE),
                           4=DEA (2-STAGE)
```

TABLE A.3

OUTPUT FILE FOR CRS EXAMPLE USING DEAP VERSION 2.1

```
Results from DEAP Version 2.1
Instruction file = eg1.ins
Data file        = eg1.dta
Input orientated DEA
Scale assumption: CRS
Slacks calculated using multi-stage method
EFFICIENCY SUMMARY:
 firm     te
    1  1.000
    2  1.000
    3  1.000
    4  1.000
    5  0.750
    6  0.667
 mean  0.903
SUMMARY OF OUTPUT SLACKS:
 firm  output:            1
    1                 0.000
    2                 0.000
    3                 0.000
    4                 0.000
    5                 0.000
    6                 0.000
 mean              0.000
SUMMARY OF INPUT SLACKS:
 firm  input:             1            2
    1                 0.000        0.000
    2                 0.000        0.000
    3                 0.000        0.000
    4                 0.000        0.000
    5                 0.000        0.000
    6                 0.000        0.000
    mean             0.000        0.000
SUMMARY OF PEERS:
 firm  peers:
    1      1
    2      2
    3      3
    4      4
    5      3    2
    6      3
SUMMARY OF PEER WEIGHTS:
  (in same order as above)
 firm  peer weights:
    1   1.000
    2   1.000
    3   1.000
```

TABLE A.3 (Continued)

```
      4   1.000
      5   0.500 0.500
      6   1.000
  PEER COUNT SUMMARY:
    (i.e., no. times each firm is a peer for another)
   firm  peer count:
      1       0
      2       1
      3       2
      4       0
      5       0
      6       0

  SUMMARY OF OUTPUT TARGETS:
   firm  output:           1
      1                1.000
      2                1.000
      3                1.000
      4                1.000
      5                1.000
      6                1.000
  SUMMARY OF INPUT TARGETS:
   firm  input:            1           2
      1                1.000       8.000
      2                2.000       4.000
      3                4.000       2.000
      4                6.000       1.000
      5                3.000       3.000
      6                4.000       2.000
  FIRM BY FIRM RESULTS:
  Results for firm:     1
  Technical efficiency = 1.000
  PROJECTION SUMMARY:
variable   original   radial        slack           projected
            value      movement      movement         value
   output  1  1.000        0.000         0.000          1.000
  input   1  1.000        0.000         0.000          1.000
   input   2  8.000        0.000         0.000          8.000
  LISTING OF PEERS:
   peer    lambda weight
      1      1.000
  Results for firm:     2
  Technical efficiency = 1.000
  PROJECTION SUMMARY:
  variable   original        radial         slack     projected
                value      movement      movement         value
   output  1     1.000         0.000         0.000         1.000
  input   1     2.000         0.000         0.000         2.000
   input   2     4.000         0.000         0.000         4.000
```

TABLE A.3 (Continued)

```
LISTING OF PEERS:
 peer   lambda weight
   2      1.000
Results for firm:     3
Technical efficiency = 1.000
PROJECTION SUMMARY:
variable  original      radial        slack     projected
             value    movement     movement         value
 output  1   1.000       0.000        0.000         1.000
 input   1   4.000       0.000        0.000         4.000
 input   2   2.000       0.000        0.000         2.000
LISTING OF PEERS:
 peer   lambda weight
   3      1.000
Results for firm:     4
Technical efficiency = 1.000
PROJECTION SUMMARY:
variable   original      radial        slack     projected
              value    movement     movement         value
 output  1    1.000       0.000        0.000         1.000
 input   1    6.000       0.000        0.000         6.000
 input   2    1.000       0.000        0.000         1.000
LISTING OF PEERS:
 peer   lambda weight
   4      1.000
Results for firm:     5
Technical efficiency = 0.750
PROJECTION SUMMARY:
variable   original      radial        slack     projected
              value    movement     movement         value
 output  1    1.000       0.000        0.000         1.000
 input   1    4.000      -1.000        0.000         3.000
 input   2    4.000      -1.000        0.000         3.000
LISTING OF PEERS:
 peer   lambda weight
   3      0.500
   2      0.500
Results for firm:     6
Technical efficiency = 0.667
PROJECTION SUMMARY:
variable   original      radial        slack     projected
              value    movement     movement         value
 output  1    1.000       0.000        0.000         1.000
 input   1    6.000      -2.000        0.000         4.000
 input   2    3.000      -1.000        0.000         2.000
LISTING OF PEERS:
 peer   lambda weight
   3      1.000
```

Appendix B

Table B.1

LISTING OF DATA FILE FOR VRS EXAMPLE USING DEAP VERSION 2.1

```
2     4
4     8
6     6
8     10
10    12
```

Table B.2

THE INSTRUCTION FILE FOR VRS EXAMPLE USING DEAP VERSION 2.1

```
eg1.dta                     DATA FILE NAME
eg1.out                     OUTPUT FILE NAME
5                           NUMBER OF FIRMS
1                           NUMBER OF TIME PERIODS
1                           NUMBER OF OUTPUTS
1                           NUMBER OF INPUTS
0                           0=INPUT AND 1=OUTPUT ORIENTATED
1                      0=CRS AND 1=VRS
0                           0=DEA(MULTI-STAGE), 1=COST-DEA,
                            2=MALMQUIST-DEA, 3=DEA(1-STAGE),
                            4=DEA(2-STAGE)
```

TABLE B.3

Output File for VRS Example Using DEAP Version 2.1

```
Results from DEAP Version 2.1
Instruction file = eg2.ins
Data file        = eg2.dta
Input orientated DEA
Scale assumption: VRS
Slacks calculated using multi-stage method
EFFICIENCY SUMMARY:
 firm     crste    vrste  scale
    1     0.500  1.000  0.500 irs
    2     0.500  0.625  0.800 irs
    3     1.000  1.000  1.000  -
    4     0.800  0.900  0.889 drs
    5     0.833  1.000  0.833 drs
 mean     0.727  0.905  0.804
Note: crste = technical efficiency from CRS DEA
         vrste = technical efficiency from VRS DEA
         scale = scale efficiency = crste/vrste
Note also that all subsequent Tables refer to VRS results
SUMMARY OF OUTPUT SLACKS:
 firm  output:          1
    1              0.000
    2              0.000
    3              0.000
    4              0.000
    5              0.000
 mean          0.000
SUMMARY OF INPUT SLACKS:
 firm  input:           1
    1              0.000
    2              0.000
    3              0.000
    4              0.000
    5              0.000
 mean              0.000
SUMMARY OF PEERS:
```

TABLE B.3 (Continued)

```
 firm  peers:
    1      1
    2      1    3
    3      3
    4      3    5
    5      5
SUMMARY OF PEER WEIGHTS:
  (in same order as above)
 firm  peer weights:
    1   1.000
```

TABLE B.3 (Continued)

```
    2   0.500 0.500
    3   1.000
    4   0.500 0.500
    5   1.000
 PEER COUNT SUMMARY:
   (i.e., no. times each firm is a peer for another)
  firm  peer count:
    1       1
    2       0
    3       2
    4       0
    5       1
 SUMMARY OF OUTPUT TARGETS:
  firm  output:          1
    1               2.000
    2               4.000
    3               6.000
    4               8.000
    5              10.000
 SUMMARY OF INPUT TARGETS:
  firm  input:           1
    1               4.000
    2               5.000
    3               6.000
    4               9.000
    5              12.000
 FIRM BY FIRM RESULTS:
 Results for firm:     1
 Technical efficiency = 1.000
 Scale efficiency     = 0.500  (irs)
 PROJECTION SUMMARY:
 variable   original      radial        slack     projected
               value      movement     movement        value
 output  1    2.000        0.000        0.000        2.000
 input   1    4.000        0.000        0.000        4.000
 LISTING OF PEERS:
  peer   GAMMA weight
    1      1.000
 Results for firm:     2
 Technical efficiency = 0.625
 Scale efficiency     = 0.800  (irs)
 PROJECTION SUMMARY:
 variable   original      radial        slack     projected
               value     movement      movement       value
 output  1    4.000       0.000         0.000        4.000
 input   1    8.000      -3.000         0.000        5.000
 LISTING OF PEERS:
  peer   GAMMA weight
    1      0.500
```

TABLE B.3 (Continued)

```
    3      0.500
 Results for firm:      3
 Technical efficiency = 1.000
 Scale efficiency     = 1.000  (crs)
 PROJECTION SUMMARY:
 variable   original       radial          slack  projected
               value     movement       movement      value
 output   1    6.000        0.000          0.000      6.000
 input    1    6.000        0.000          0.000      6.000
 LISTING OF PEERS:
  peer   GAMMA weight
    3      1.000
 Results for firm:      4
 Technical efficiency = 0.900
 Scale efficiency     = 0.889  (drs)
 PROJECTION SUMMARY:
 variable   original       radial          slack  projected
               value     movement       movement      value
 output   1    8.000        0.000          0.000      8.000
 input    1   10.000       -1.000          0.000      9.000
 LISTING OF PEERS:
  peer   GAMMA weight
    3      0.500
    5      0.500
 Results for firm:      5
 Technical efficiency = 1.000
 Scale efficiency     = 0.833  (drs)
 PROJECTION SUMMARY:
 variable   original       radial          slack  projected
               value     movement       movement      value
 output   1   10.000        0.000          0.000     10.000
 input    1   12.000        0.000          0.000     12.000
 LISTING OF PEERS:
  peer   GAMMA weight
  5   1.000
```

Appendix C

TABLE C.1

THE SHAZAM OUTPUT FOR CRS SFA EXAMPLE

```
 |_Sample 1 20
 |_READ N T Y X1 X2
    5 VARIABLES AND       20 OBSERVATIONS STARTING AT OBS       1
 |_Sample 1 20
 |_GENR LY=LOG (Y)
 |_GENR LX1=LOG (X1)
 |_GENR LX2=LOG (X2)
 |_OLS LY LX1 LX2 /COEF=BOLS
 REQUIRED MEMORY IS PAR= 3 CURRENT PAR= 500
  OLS ESTIMATION
       20 OBSERVATIONS     DEPENDENT VARIABLE = LY
 ...NOTE.SAMPLE RANGE SET TO: 1, 20
  R-SQUARE = 0.3932     R-SQUARE ADJUSTED = 0.3218
 VARIANCE OF THE ESTIMATE-SIGMA**2 = 0.32036
 STANDARD ERROR OF THE ESTIMATE-SIGMA = 0.56601
 SUM OF SQUARED ERRORS-SSE= 5.4462
 MEAN OF DEPENDENT VARIABLE = 7.9494
 LOG OF THE LIKELIHOOD FUNCTION = -15.3706


VARIABLE   ESTIMATED STANDARD   T-RATIO        PARTIAL
STANDARDIZED ELASTICITY
   NAME    COEFFICIENT   ERROR      17 DF   P-VALUE CORR.
COEFFICIENT AT MEANS
 LX1        0.72293     0.2186       3.306     0.004 0.626
0.6460     0.4832
 LX2       -0.32887     0.5845     -0.5626     0.581-0.135    -
0.1099    -0.3300
 CONSTANT   6.7314      4.511        1.492     0.154 0.340
0.0000     0.8468
 |_GENR SIG=SQRT ($SIG2)
 . NOTE.CURRENT VALUE OF $SIG2= 0.32036
 |_DIM BETA 5
 |_GEN1 BETA: 2=BOLS: 3
 |_GEN1 BETA: 3=BOLS: 1
 |_GEN1 BETA: 4=BOLS: 2
 |_GEN1 BETA: 1=SIG
 |_GEN1 BETA: 5=1
 |_GENR CONSTANT=0.5*LOG (2/$PI)
 . NOTE.CURRENT VALUE OF $PI  = 3.1416
 |_*DEFINE THE REGRISSION FUNCTION IN A CHARACTER STRING
 |_ERROR: (LY- (B0+BX1*LX1+BX2*LX2))
 |_NL 1/ NCOEF=5 LOGDEN START=BETA COEF=BNEW
 ...NOTE.SAMPLE RANGE SET TO: 1, 20
```

TABLE C.1 (Continued)

```
|_EQ CONSTANT-0.5*LOG (SIGMA**2)- 0.5*((LY-
(B0+BX1*LX1+BX2*LX2))/SIGMA)**2+LOG (NCDF (- (LY-
(B0+BX1*LX1+BX2*LX2))*GAMMA/SIGMA))
 |_END
   4 VARIABLES IN 1 EQUATION WITH   5 COEFFICIENTS
 . ALGORITHM USES NUMERIC DERIVATIVES
        20 OBSERVATIONS

 REQUIRED MEMORY IS PAR= 20 CURRENT PAR= 500

 COEFFICIENT STARTING VALUES
 SIGMA      0.56601      B0          6.7314      BX1        0.72293
 BX2       -0.32887      GAMMA       1.0000
      100 MAXIMUM ITERATIONS, CONVERGENCE = 0.100000E-04

 INITIAL STATISTICS:
 TIME = 0.110 SEC.   ITER. NO.     0   FUNCT. EVALUATIONS     6
 LOG-LIKELIHOOD FUNCTION=   -20.42273
 COEFFICIENTS
0.5660069       6.731358      0.7229296     -0.3288703
1.000000
 GRADIENT
11.08871       31.57091       167.2617       252.3106      -
9.279521
 INTERMEDIATE STATISTICS:
 TIME = 0.160 SEC.   ITER. NO.    15   FUNCT. EVALUATIONS   139
 LOG-LIKELIHOOD FUNCTION=   -14.17774
COEFFICIENTS
0.8237517      4.944078      0.5578923    0.8366038E-01
3.880066
 GRADIENT
-0.1187661E-03 0.2885890E-02 0.1601276E-01 0.2855567E-01 -
0.9939784E-03
 FINAL STATISTICS:
 TIME = 0.160 SEC.   ITER. NO.    21   FUNCT. EVALUATIONS   201
 LOG-LIKELIHOOD FUNCTION=   -14.17773
 COEFFICIENTS
0.8235147       4.937677      0.5579488      0.8439801E-01
3.873751
 GRADIENT
0.3955114E-04 -0.2644080E-04 -0.1219848E-03 -0.2116833E-03
0.7316814E-07
 GTRANSPOSE*INVERSE (H)*G STATISTIC  -  = 0.38227E-10
      COEFFICIENT    ST. ERROR   T-RATIO
 SIGMA    0.82351     0.18659      4.4136
 B0        4.9377      3.3961      1.4539
 BX1      0.55795     0.22653      2.4630
 BX2      0.84398E-01 0.50547      0.16697
 GAMMA     3.8738      3.3108      1.1700
```

TABLE C.1 (Continued)

```
 |_END
 |_TEST (SIGMA*SIGMA/(1+GAMMA*GAMMA))**0.5
 TEST VALUE = 0.20584      STD. ERROR OF TEST VALUE 0.13667
 ASYMPTOTIC NORMAL STATISTIC = 1.5061242      P-VALUE= 0.13204
 WALD CHI-SQUARE STATISTIC = 2.2684102     WITH    1 D.F. P-
VALUE= 0.13204
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.44084
 |_*RECOVER AN ESTIMATE FOR SIGMA _U.
 |_TEST (SIGMA*SIGMA*GAMMA*GAMMA/(1+GAMMA*GAMMA))**0.5
 TEST VALUE = 0.79737      STD. ERROR OF TEST VALUE 0.21249
 ASYMPTOTIC NORMAL STATISTIC = 3.7525111      P-VALUE= 0.00018
 WALD CHI-SQUARE STATISTIC = 14.081339     WITH    1 D.F. P-
VALUE= 0.00018
 UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.07102
 |_*CALCULATION THE ESTIMATED INEFFICIENCIES
 |_GEN1 SIGMA=BNEW: 1
 |_GEN1 GAMMA=BNEW: 5
 |_GENR Z=(LY- (BNEW: 2+BNEW: 3*LX1+BNEW: 4*LX2))*GAMMA/SIGMA
 |_? DISTRIB Z/PDF=PDFZ
 |_GENR U=SIGMA*GAMMA/(1+GAMMA*GAMMA)*(PDFZ/(1-NCDF (Z))-Z)
 |_PRINT U
    U
0.8469816      0.5552827      0.3421578       1.271954
0.3556377
0.8192250       1.960547       1.380449      0.7611784
0.4140346
0.3459243      0.1600090      0.5300156      0.2086216
0.2015297
0.3198585      0.4044839      0.1037260      0.6582162
0.8854762
 |_STOP
 TYPE COMMAND
```

TABLE C.2

LISTING OF DATA FILE FOR CRS SFA EXAMPLE USING FRONTIER VERSION 4. 1

N	T	LY	LX1	LX2
1.000000	1.000000	7.816719	5.598422	7.799753
2.000000	1.000000	7.895176	5.135798	8.086410
3.000000	1.000000	8.607682	5.940171	8.242756
4.000000	1.000000	7.208245	5.298317	7.951559
5.000000	1.000000	7.713442	4.442651	7.757906
6.000000	1.000000	7.872307	5.579730	8.237479
7.000000	1.000000	6.097251	4.553877	8.411833
8.000000	1.000000	7.342634	5.768321	7.807917
9.000000	1.000000	7.700218	5.247024	7.663877
10.00000	1.000000	7.352416	3.912023	7.849714
11.00000	1.000000	8.688794	6.086775	8.294050
12.00000	1.000000	8.942656	5.913503	8.393895
13.00000	1.000000	8.098070	5.480639	7.882315
14.00000	1.000000	8.291792	5.075174	7.640123
15.00000	1.000000	8.808467	5.940171	7.863267
16.00000	1.000000	8.384618	5.521461	8.006368
17.00000	1.000000	8.411578	5.768321	7.991254
18.00000	1.000000	8.421890	4.653960	7.937375
19.00000	1.000000	8.166229	5.857933	7.841886
20.00000	1.000000	7.168793	4.499810	7.878534

TABLE C.3

THE INSTRUCTION FILE FOR CRS SFA EXAMPLE USING FRONTIER

VERSION 4.1

```
1               1=ERROR COMPONENTS MODEL, 2=TE EFFECTS MODEL
eg1.dta         DATA FILE NAME
eg1.out         OUTPUT FILE NAME
1               1=PRODUCTION FUNCTION, 2=COST FUNCTION
y               LOGGED DEPENDENT VARIABLE (Y/N)
20              NUMBER OF CROSS-SECTIONS
1               NUMBER OF TIME PERIODS
20              NUMBER OF OBSERVATIONS IN TOTAL
2               NUMBER OF REGRESSOR VARIABLES (Xs)
n               MU (Y/N) [OR DELTA0 (Y/N) IF USING TE EFFECTS
                 MODEL]
n               ETA (Y/N) [OR NUMBER OF TE EFFECTS REGRESSORS
                 (Zs)]
n               STARTING VALUES (Y/N)IF YES THEN BETA0 BETA1 TO
                BETAK
                SIGMA SQUARED GAMMA MU [OR DELTA0 ETA DELTA1 TO
                DELTAP]

NOTE: IF YOU ARE SUPPLYING STARTING VALUES AND YOU HAVE
RESTRICTED MU [OR DELTA0] TO BE ZERO THEN YOU SHOULD NOT SUPPLY A
STARTING VALUE FOR THIS PARAMETER.
```

TABLE C.4

THE OUTPUT FILE FOR CRS SFA EXAMPLE USING FRONTIER VERSION 4.1

```
Output from the program FRONTIER (Version 4.1c)
instruction file = EG1.INS
data file =       eg1.dta
Error Components Frontier (see B&C 1992)
The model is a production function
The dependent variable is logged
the ols estimates are :
                 coefficient     standard-error    t-ratio
  beta 0         0.67313584E+01  0.45107027E+01  0.14923082E+01
  beta 1         0.72292956E+00  0.21864579E+00  0.33063959E+01
  beta 2        -0.32887035E+00  0.58452288E+00 -0.56263041E+00
  sigma-squared  0.32036385E+00
log likelihood function =  -0.15370602E+02
the estimates after the grid search were :
  beta 0         0.72980339E+01
  beta 1         0.72292956E+00
  beta 2        -0.32887035E+00
  sigma-squared  0.59343036E+00
  gamma          0.85000000E+00
  mu is restricted to be zero
  eta is restricted to be zero
 iteration =     0  func evals =     19  llf = -0.14600178E+02
0.72980339E+01 0.72292956E+00-0.32887035E+00 0.59343036E+00
0.85000000E+00
 gradient step
 iteration =     5  func evals =     48  llf = -0.14344082E+02
0.68018040E+01 0.61457798E+00-0.18494485E+00 0.69930742E+00
0.92630115E+00
 iteration =    10  func evals =    152  llf = -0.14177731E+02
0.49377914E+01 0.55794693E+00 0.84385658E-01 0.67821461E+00
0.93754131E+00
 iteration =    12  func evals =    177  llf = -0.14177731E+02
0.49374303E+01 0.55794487E+00 0.84431654E-01 0.67817963E+00
0.93752513E+00
the final mle estimates are :
                 coefficient     standard-error    t-ratio
  beta 0         0.49374303E+01  0.36473681E+01  0.13536967E+01
  beta 1         0.55794487E+00  0.23214319E+00  0.24034514E+01
  beta 2         0.84431654E-01  0.54479241E+00  0.15497950E+00
  sigma-squared  0.67817963E+00  0.30751813E+00  0.22053322E+01
  gamma          0.93752513E+00  0.10378780E+00  0.90330956E+01
  mu is restricted to be zero
  eta is restricted to be zero
log likelihood function =  -0.14177731E+02
```

TABLE C.4 (Continued)

```
LR test of the one-sided error =    0.23857419E+01
with number of restrictions = 1
[note that this statistic has a mixed chi-square distribution]
number of iterations =     12
(maximum number of iterations set at :   100)
number of cross-sections =     20
number of time periods =     1
total number of observations =     20
thus there are:      0  obsns not in the panel
covariance matrix :
0.13303294E+02  0.34563655E+00 -0.19082590E+01 -0.16520122E+00 -
0.11333696E+00
0.34563655E+00  0.53890462E-01 -0.81546870E-01 -0.29999081E-01 -
0.15440955E-01
-0.19082590E+01 -0.81546870E-01  0.29679878E+00  0.45169473E-01
0.26111654E-01
-0.16520122E+00 -0.29999081E-01  0.45169473E-01  0.94567398E-01
0.21925311E-01
-0.11333696E+00 -0.15440955E-01  0.26111654E-01  0.21925311E-01
0.10771908E-01
technical efficiency estimates :
     firm             eff.-est.
       1           0.43730615E+00
       2           0.58509663E+00
       3           0.72133628E+00
       4           0.28590494E+00
       5           0.71198560E+00
       6           0.44960637E+00
       7           0.14360240E+00
       8           0.25651068E+00
       9           0.47647671E+00
      10           0.67260987E+00
      11           0.71871125E+00
      12           0.85811485E+00
      13           0.59995822E+00
      14           0.81962540E+00
      15           0.82514218E+00
      16           0.73703929E+00
      17           0.67892224E+00
      18           0.90486281E+00
      19           0.52808956E+00
      20           0.42079053E+00
 mean efficiency = 0.59158460E+00
```

TABLE C. 5

DEAP VERSION 2.1, FRONTIER VERSION 4.1, AND SHAZAM RESULTS OF SFA CRS TECHNICAL EFFICIENCY

Farm	FRONTIER Version 4.1	DEAP Version 2.1	SHAZAM
1	0.44	0.44	0.42870699
2	0.58	0.47	0.57390999
3	0.72	0.67	0.71023612
4	0.28	0.25	0.28028341
5	0.71	0.61	0.70072644
6	0.44	0.36	0.44077312
7	0.14	0.11	0.14078139
8	0.25	0.25	0.25146562
9	0.47	0.50	0.46711565
10	0.67	0.72	0.66097808
11	0.71	0.66	0.70756604
12	0.85	0.85	0.85213612
13	0.59	0.59	0.58859578
14	0.81	0.97	0.81170232
15	0.82	1.00	0.81747929
16	0.73	0.72	0.72625179
17	0.67	0.67	0.66732112
18	0.9	1.00	0.90147226
19	0.52	0.55	0.51777411
20	0.42	0.34	0.41251768
MEAN	0.59	0.59	0.58

APPENDIX D

TABLE D.1

THE SHAZAM OUTPUT FOR VRS SFA TE EXAMPLE

```
|_Sample 1 25
|_READ N T Y X1 X2
5 VARIABLES AND       25 OBSERVATIONS STARTING AT OBS       1
|_GENR LY=LOG (Y)
|_GENR LX1=LOG (X1)
|_GENR LX2=LOG (X2)
|_OLS LY LX1 LX2 /COEF=BOLS
REQUIRED MEMORY IS PAR= 4 CURRENT PAR= 500
OLS ESTIMATION
25 OBSERVATIONS     DEPENDENT VARIABLE = LY
NOTE.SAMPLE RANGE SET TO: 1, 25
R-SQUARE = 0.9731     R-SQUARE ADJUSTED = 0.9706
VARIANCE OF THE ESTIMATE-SIGMA**2 = 0.55557E-01
STANDARD ERROR OF THE ESTIMATE-SIGMA = 0.23571
SUM OF SQUARED ERRORS-SSE= 1.2223
MEAN OF DEPENDENT VARIABLE = 5.8121
LOG OF THE LIKELIHOOD FUNCTION = 2.25371
VARIABLE   ESTIMATED STANDARD T-RATIO PARTIAL STANDARDIZED
ELASTICITY
NAME COEFFICIENT ERROR 22 DF  P-VALUE CORR. COEFFICIENT AT MEANS
LX1       0.24543  0.1069  2.297  0.032 0.440   0.2638    0.1249
LX2       0.80518  0.1263  6.373  0.000 0.805   0.7319    0.5577
CONSTANT 1.8444   0.2336  7.896  0.000 0.860   0.0000    0.3173
|_GENR SIG=SQRT ($SIG2)
NOTE.CURRENT VALUE OF $SIG2= 0.55557E-01
|_DIM BETA 5
|_GEN1 BETA: 2=BOLS: 3
|_GEN1 BETA: 3=BOLS: 1
|_GEN1 BETA: 4=BOLS: 2
|_GEN1 BETA: 1=SIG
|_GEN1 BETA: 5=1
|_GENR CONSTANT=0.5*LOG (2/$PI)
NOTE.CURRENT VALUE OF $PI   = 3.1416
|_ERROR: (LY- (B0+BX1*LX1+BX2*LX2))
|_NL 1/ NCOEF=5 LOGDEN START=BETA COEF=BNEW
NOTE.SAMPLE RANGE SET TO: 1, 25
|_EQ CONSTANT-0.5*LOG (SIGMA**2)- 0.5*((LY-
(B0+BX1*LX1+BX2*LX2))/SIGMA)**2+LOG (NCDF (- (LY-
(B0+BX1*LX1+BX2*LX2))*GAMMA/SIGMA))
|_END
4 VARIABLES IN 1 EQUATION WITH   5 COEFFICIENTS
ALGORITHM USES NUMERIC DERIVATIVES
25 OBSERVATIONS
REQUIRED MEMORY IS PAR= 21 CURRENT PAR= 500
```

TABLE D.1 (Continued)

```
COEFFICIENT STARTING VALUES
SIGMA      0.23571      B0          1.8444      BX1         0.24543
BX2        0.80518      GAMMA       1.0000
100 MAXIMUM ITERATIONS, CONVERGENCE = 0.100000E-04
INITIAL STATISTICS:
TIME = 0.002 SEC.   ITER. NO.     0   FUNCT. EVALUATIONS     6
LOG-LIKELIHOOD FUNCTION=   -4.284729
COEFFICIENTS
0.2357059      1.844416      0.2454281      0.8051830
1.000000
GRADIENT
39.19681      94.29468      273.1348      373.1776       -
12.24326
INTERMEDIATE STATISTICS:
TIME = 0.062 SEC.   ITER. NO.    15   FUNCT. EVALUATIONS   149
LOG-LIKELIHOOD FUNCTION= 2.469521
COEFFICIENTS
0.2823997      2.081134      0.2585474      0.7802457
1.264535
GRADIENT
0.5455453E-06 0.5924178E-05 0.1260186E-04 0.2074479E-04 -
0.3192646E-06
FINAL STATISTICS:
TIME = 0.062 SEC.   ITER. NO.    16   FUNCT. EVALUATIONS   150
LOG-LIKELIHOOD FUNCTION= 2.469521
COEFFICIENTS
0.2823997      2.081134      0.2585474      0.7802457
1.264535
GRADIENT
0.5455453E-06 0.5924178E-05 0.1260186E-04 0.2074479E-04 -
0.3192646E-06
GTRANSPOSE*INVERSE (H)*G STATISTIC  -  = 0.18612E-12
           COEFFICIENT  ST. ERROR    T-RATIO
SIGMA      0.28240      0.75456E-01  3.7426
B0         2.0811       0.28101      7.4059
BX1        0.25855      0.97944E-01  2.6398
BX2        0.78025      0.11934      6.5379
GAMMA      1.2645       1.0255       1.2330
|_END
|_TEST (SIGMA*SIGMA/(1+GAMMA*GAMMA))**0.5
TEST VALUE = 0.17517     STD. ERROR OF TEST VALUE 0.53979E-01
ASYMPTOTIC NORMAL STATISTIC = 3.2451006      P-VALUE= 0.00117
WALD CHI-SQUARE STATISTIC = 10.530678     WITH    1 D.F. P-VALUE=
0.00117
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.09496
|_TEST (SIGMA*SIGMA*GAMMA*GAMMA/(1+GAMMA*GAMMA))**0.5
TEST VALUE = 0.22151     STD. ERROR OF TEST VALUE 0.12327
ASYMPTOTIC NORMAL STATISTIC = 1.7968689      P-VALUE= 0.07236
```

TABLE D.1 (Continued)

```
WALD CHI-SQUARE STATISTIC = 3.2287379      WITH    1 D.F. P-VALUE=
0.07236
UPPER BOUND ON P-VALUE BY CHEBYCHEV INEQUALITY = 0.30972
|_GEN1 SIGMA=BNEW: 1
|_GEN1 GAMMA=BNEW: 5
|_GENR Z=(LY- (BNEW: 2+BNEW: 3*LX1+BNEW: 4*LX2))*GAMMA/SIGMA
|_? DISTRIB Z/PDF=PDFZ
|_GENR U=SIGMA*GAMMA/(1+GAMMA*GAMMA)*(PDFZ/(1-NCDF (Z))-Z)
|_PRINT U
U
0.2011338     0.1448097     0.1903484  0.5175309      0.1039791
0.1212669     0.2112819     0.2493312  0.1009953      0.5626918E-
01
0.2033272     0.2226314     0.1353406  0.1563699      0.1580955
0.1028805     0.9584335E-01 0.2778777  0.2291421      0.1500666
0.2029788     0.1400013     0.1104758  0.1556137      0.1406706
|_STOP
 TYPE COMMAND
```

TABLE D. 2

THE OUTPUT FILE FOR VRS SFA TE EXAMPLE USING FRONTIER VERSION 4.1

```
Output from the program FRONTIER (Version 4.1c)
Instruction file = eg1.ins
Data file =        eg1.dta
Error Components Frontier (see B&C 1992)
The model is a production function
The dependent variable is logged
the ols estimates are :
                 Coefficient     standard-error    t-ratio
beta 0         0.18444157E+01  0.23359285E+00  0.78958569E+01
beta 1         0.24542807E+00  0.10685743E+00  0.22967805E+01
beta 2         0.80518296E+00  0.12633361E+00  0.63734660E+01
sigma-squared  0.55557271E-01
log likelihood function =   0.22537155E+01
the estimates after the grid search were :
beta 0         0.20112850E+01
beta 1         0.24542807E+00
beta 2         0.80518296E+00
sigma-squared  0.76735753E-01
gamma          0.57000000E+00
mu is restricted to be zero
eta is restricted to be zero
Iteration = 0 func evals = 19 llf = 0.24282478E+01
0.20112850E+01 0.24542807E+00 0.80518296E+00 0.76735753E-01
0.57000000E+00
Gradient step
Iteration = 5 func evals = 44 llf = 0.24692073E+01
0.20761046E+01 0.25804345E+00 0.78131004E+00 0.78708638E-01
0.60699319E+00
Iteration = 9 func evals = 105 llf = 0.24695218E+01
0.20811349E+01 0.25854785E+00 0.78024505E+00 0.79749628E-01
0.61524444E+00
The final mle estimates are:
                Coefficient      standard-error        t-ratio
beta 0          0.20811349E+01  0.28237172E+00  0.73701959E+01
beta 1          0.25854785E+00  0.99264027E-01   0.26046480E+01
beta 2          0.78024505E+00  0.12073719E+00  0.64623425E+01
sigma-squared 0.79749628E-01   0.42715782E-01   0.18669827E+01
gamma           0.61524444E+00  0.38571565E+00  0.15950725E+01
mu is restricted to be zero
eta is restricted to be zero
Log likelihood function = 0.24695218E+01
LR test of the one-sided error = 0.43161250E+00
With number of restrictions = 1
[Note that this statistic has a mixed chi-square distribution]
```

TABLE D. 2 (Continued)

```
Number of iterations = 9
(Maximum number of iterations set at: 100)
Number of cross-sections = 25
Number of time periods = 1
Total number of observations = 25
Thus there are: 0 obsns not in the panel
Covariance matrix:
0.79733789E-01 0.18126424E-01 -0.28478314E-01 0.68915944E-02
0.70207872E-01
0.18126424E-01 0.98533470E-02 -0.11323606E-01 0.64396790E-03
0.71994176E-02
-0.28478314E-01 -0.11323606E-01 0.14577468E-01 -0.12645404E-02 -
0.14068682E-01
0.68915944E-02 0.64396790E-03 -0.12645404E-02 0.18246381E-02
0.13940347E-01
0.70207872E-01 0.71994176E-02 -0.14068682E-01 0.13940347E-01
0.14877657E+00
Technical efficiency estimates:
     Firm             eff.-est.
       1           0.82317543E+00
       2           0.86926546E+00
       3           0.83184061E+00
       4           0.60163382E+00
       5           0.90405094E+00
       6           0.88917122E+00
       7           0.81508975E+00
       8           0.78535194E+00
       9           0.90664308E+00
      10           0.94644812E+00
      11           0.82142217E+00
      12           0.80612414E+00
      13           0.87722392E+00
      14           0.85963367E+00
      15           0.85820372E+00
      16           0.90500449E+00
      17           0.91113561E+00
      18           0.76363758E+00
      19           0.80101770E+00
      20           0.86487407E+00
      21           0.82170060E+00
      22           0.87329883E+00
      23           0.89843197E+00
      24           0.86026077E+00
      25           0.87273640E+00
Mean efficiency =  0.84669504E+00
```

Paper II

TECHNICAL, ALLOCATIVE, AND ECONOMIC EFFICIENCIES OF BROILER FARMS IN THE CENTRAL REGION OF SAUDI ARABIA: DATA ENVELOPMENT ANALYSIS APPROACH

TECHNICAL, ALLOCATIVE, AND ECONOMIC EFFICIENCIES OF BROILER FARMS IN THE CENTRAL REGION OF SAUDI ARABIA: DATA ENVELOPMENT ANALYSIS APPROACH

ABSTRACT

The agricultural sector of Saudi Arabia is one of the fastest growing sectors in the country. During the last thirty years the Saudi government has paid more attention to this sector, increasing expenditure and offering interest-free loans to farmers; an estimated 40 billion dollars has been spent on agriculture infrastructure, subsidized farm inputs, and output, and distribution of free land. These incentives led to an increase in the average growth rate of this sector from 5.2% in the 1970's to 7% in 1999. Broiler farms are considered one of the highest priority areas that have gained major support and incentives in the government policy. Broiler farms in Central Saudi Arabia require substantial high investment costs and competent management. Some of the farms have experienced a wide range of technical and managerial problems. Some farms are operated at less than full capacity while others have ceased operations. The aim here is to determine the performance of the farms that remain, to measure their technical, allocative, and economic efficiencies, and to determine if the mean technical efficiency differs between small and large farms. The Data Envelopment Analysis approach (DEA) is used to estimate the technical, allocative, and economic efficiencies of broiler farms in the central region of Saudi Arabia by determining which farms are located on the production frontier and which are not. The mean technical efficiency of small farms will be compared with that of large farms to determine if policy instruments should be targeted toward small or large farms.

Key words: technical efficiency, allocative efficiency, economic efficiency, scale efficiency, constant returns to scale, and variable returns to scale, Saudi Arabia, broilers

TECHNICAL, ALLOCATIVE, AND ECONOMIC EFFICIENCIES OF BROILER FARMS IN THE CENTRAL REGION OF SAUDI ARABIA: DATA ENVELOPMENT ANALYSIS APPROACH

Introduction

Measurement of the efficiency of agricultural production is an important issue in developing countries. A measure of producer performance is often useful for policy purposes, and the concept of economic efficiency provides a theoretical basis for such a measure (Russell and Young).

Broiler farms are among the important agricultural industries in Saudi Arabia. The government gave free land, long-term loans without interest, and subsidies such as 50% of feed costs and 30% of the equipment costs (drinking troughs, automatic feed troughs, incubators, hatchers including related electrical equipment, animal feed mixers, automatic cages with all its accessories, slaughtering, freezing and cooling equipment, egg handling and cleaning equipment, cartons for packing chicks, bags for packing feed and cages for transporting). Additional incentives included free tariffs for some broiler farm machinery, free inoculations, transportation services and communication facilities.

These subsidies were implemented to encourage the private sector to invest in the industry. As a result, the number of broiler farms increased from 239 farms, producing 124,000 tons in 1983 to 318 in 1999 producing 460,000 tons (Table 1). Ten new farms are under construction, and 412 potential new farms are under study. The broiler farms are considered one of the highest priority areas and have received substantial support and incentives from the Saudi Arabian government. Total loans to broiler farms from the agricultural bank reached 1,462 million SR by 1996 ($390 million). This accounted for

23% of all loans provided for specialized agricultural projects in the country during 1996 (SAAB). Many (32%) of the farms are located in the Central Region that includes Riyadh, Kharj, and Qassim (Table 2). This region includes 50 % of the total production capacity of broiler farms Kingdomwide (Figure 1).

In spite of the sizable investment in these farms, most are not operating at full production capacity. More than 40% of the current broiler farms are unable to meet their debt obligations (Ministry of Agriculture and Water).

The government has made a substantial investment and concerted effort to develop broiler production. In addition to the subsidies to encourage construction of facilities, subsidies have also been provided to offset some operating costs, including feed and operating capital. However, in spite of these subsidies, broiler production costs for many of the farms in the region exceed the cost of imported broilers (Table 3).

The cost of production may be relatively high, as a result of technical and allocative inefficiencies in production that may be the result of inexperienced management. If it were determined that the relatively high production costs are due to inefficiencies, then a policy of improving efficiency could be implemented. Education and subsidies could be targeted toward the development and delivery of management training programs. Alternatively, the cost of production in the region may be high as a result of the climate and other environmental factors. It may be more efficient to import broilers, in which case the policy of subsidizing production in the region should be reconsidered.

To date no effort has been made to study and measure the technical efficiencies of these broiler farms. Research has been conducted to address the production, financing, and marketing problems. Al-zahrani (1986), tried to determine the marketing and management methods used by the small broiler farms in Alahsa region. Also in 1991 Al-zahrani analyzed the production problems facing the broiler producers in the central region of Saudi Arabia. Alqunibet et al. identified and analyzed the production and marketing problems facing broiler farms in the central region of Saudi Arabia. Alqunibet, Essam, and Sayed measured the important criteria of the different marketing activities pertinent to the Saudi broiler farms, and the impact of the farm's characteristics on the different marketing criteria. This study aims to answer the question of whether the broiler farms in the Central region of Saudi Arabia are technically efficient, and the level of technical efficiency.

The main objective for this paper is to determine the performance of broiler farmers in Saudi Arabia. This study is the first attempt to analyze and compare the technical performance of broiler farmers in the central region of Saudi Arabia. Given this, the aim of this study is to estimate the technical efficiencies of broiler farms in the Central Region of Saudi Arabia, to determine whether the mean technical efficiency differs between small and large broiler farms in the region, and to make recommendations to increase the performance of broiler farms in the region if the results are indicating technical inefficiency.

Methodology

Farm efficiency, and the question of how to measure it, is an important subject in developing countries' agriculture (Parikh, Ali, and Shah). The efficiency of farmers in developing countries is an interesting topic to economists concerned with the problems in developing countries. If the farmers are inefficient in their practices, then it follows that output could be increased with less cost through extension and education (Belbase and Grabowski). A measure of relative producer performance is often useful for policy purposes and the concept of economic efficiency provides a theoretical basis for such a measure (Russell and Young).

The measurement of efficiency has been a popular field of research since Farrell published a seminal paper in 1957. Much research has focused on the economic efficiency of agricultural production, and the analysis has centered on the technical, allocative and scale efficiency of farm production (Chavas and Aliber). Farrell developed the concept of technical efficiency based on the relationships between inputs and outputs (Parikh, Ali, and Shah).

Technical Efficiency

Efficiency in production can be defined in terms of the production function that relates the level of various inputs (Berte). Technical efficiency is a measure of a farm's success in producing maximum output from a given set of input; in other words, technical efficiency refers to the physical relationship between inputs used in the production process. Technical efficiency measures output relative to that of the efficient isoquant. Efficient farms produce on the production frontier or, alternatively stated, on the efficient isoquant. The concept of technical efficiency relates to the question of where a firm or farm uses the best available technology in its production process (Chavas and Aliber).

In general, the aims of measuring farm level efficiency is to estimate the frontier that envelops all the input/output data with those observations lying on the frontier being described as technically efficient. Observations lying below the frontier are considered to be technically inefficient (Fraser and Cordina).

Koopmans (p. 60) provided a formal definition of technical efficiency: "a producer is technically efficient if any output requires a reduction in at least one other output or an increase in at least one input, and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output. Thus a technically inefficient producer could produce the same outputs with less of at least one input, or could use the same inputs to produce more of at least one output."

Farrell Measures of efficiency

The basic ideas underlying the Farrell approach to efficiency measurement are illustrated in Figure 2. This diagram shows the efficient unit isoquant (*II'*) for a group of farms constructed from the input bundles of farms. The farms produce output *y*, by using two inputs (x_1, x_2). A constant returns to scale production function is assumed.

$$y = f(x_1, x_2) \tag{1}$$

The unit isoquant can characterize this function frontier (*II'*) if the farm is observed using (x_1, x_2) to produce *y*. An inefficient farm is at point *P*. The point *Q* is the intersection of the line segment *OQ* with the isoquant (*II'*). According to Farrell the technical efficiency of point *P* is represented by the ratio $\frac{OQ}{OP}$. It is the ratio of inputs needed to produce the output to the inputs actually used to produce output, given the input mix used. (*EE'*) represents the ratio of input prices. The point *Q'* represents the minimum cost combination of x_1 and x_2 on the efficient isoquant. Farrell allocative efficiency is the ratio $\frac{OR}{OQ}$.

Technical efficiency (TE) will take a value between zero and one ($0 < TE \leq 1$). Where a value of one indicates the farm is producing on the production frontier and is fully technically efficient, and hence provides an indicator of the degree of technical inefficiency of the farm. For example, the point Q is technically efficient because it lies on the efficient isoquant. The distance RQ represents the reduction in production costs that would occur if production were to occur at the allocative (and technically) efficient point Q'. Total economic efficiency (*EE*) is defined to be the ratio $\frac{OR}{OP}$, where the distance RP can be interpreted in terms of a cost reduction. The product of technical and allocative efficiency provides the overall economic efficiency, $TE * AE = \frac{OQ}{OP} * \frac{OR}{OQ} = \frac{OR}{OP}$. Zero and one bound all three measures (Coelli, Rao, and Battese). These efficiency measures assume the production function of the fully efficient farm is known. In practice this is not the case, and the efficient isoquant must be estimated from the sample data.

Data Envelopment Analysis (DEA)

The DEA method uses input and output data for a group of farms to construct a piece-wise linear surface over the data points. It defines the frontier with output levels held constant for each farm. Linear programming can be used to estimate the DEA frontier. Observed input and output quantities form a production possibility space, against which the individual farms are compared to determine their technical efficiency (Fraser and Cordina).

DEA optimizes individual observations with the objective of calculating a discrete piecewise frontier determined by the efficient decision-making units (Yin). It has been used in management science to evaluate ex-post the efficiency of achieving an objective from a given level of inputs (Banker, Charnes, and Cooper).

Seiford and Thrall presented a comprehensive review of the methodology and discuss the mathematical approach to efficient frontier of DEA. The term data envelopment analysis was first used by Charnes, Cooper, and Rhodes in 1978 (Seiford, and Thrall). Since then there have been a large number of papers that have extended and applied the DEA approach (Coelli, Rao, and Battese).

There are several reasons for using DEA analysis to assess technical efficiency. First, DEA is useful for identifying the areas that will be most interesting for extension efforts. Because DEA is based on linear programming, many agriculturists are already familiar with it and therefore less effort will be required for them to use this analytical technique than to learn alternative methodologies such as stochastic frontiers. Second, DEA generates detailed information related to input use and the optimal mix of factors, and identifies efficient farms within a sample and those that are most important for benchmarking. Third, the amount of computer software that supports DEA analysis has increased significantly in the last few years; this software is relatively easy to use and the results it generates are easy to understand. The final important reason for using DEA is that it is not necessary to use parametric specifications of functional form to establish the frontier. Therefore, DEA does not require restrictions to functional form that can affect the analysis or skew measures of efficiency (Fraser and Cordina).

Farm Technical Efficiency with (CRS) DEA Model

Following (Coelli, Rao, and Battese) consider the situation with K inputs, M outputs and N farms or decision-making units. For the *ith* farm we have x_i and y_i vectors. So we have $K \times N$ input matrix, X, and the $M \times N$ output matrix, Y, for the entire set of the data. Efficiency is defined as the ratio of the weighted sum of output over the weighted sum of inputs, then $\frac{\sum_{m=1}^{M} u_{im} y_{im}}{\sum_{k=1}^{K} v_{ik} x_{ik}}$ where u_i is an $M \times 1$ vector of output weights and v_i is $K \times 1$vector of input weights. A mathematical programming model can be formulated to determine the optimal weights as follow:

$$(2) \qquad Max_{u_i, v_i} \left(\frac{\sum_{m=1}^{M} u_{im} y_{im}}{\sum_{k=1}^{K} v_{ik} x_{ik}} \right)$$

$$\text{s.t.} \qquad \frac{\sum_{m=1}^{M} u_{im} y_{im}}{\sum_{k=1}^{K} v_{ik} x_{ik}} \leq 1 \qquad k=1,2,\ldots,K$$

$$u_{im}, v_{ik} \geq 0, \forall m, k$$

The linear programming problem finds the vectors of weights u_i and v_i that maximize the efficiency score of the *ith* farm. The above ratio form yields an infinite number of solutions so it is necessary to formulate the problem by imposing the constraint $v'x_i=1$, to equation (2) and change the notation from u and v to μ and v. This is known as the multiplier form of the DEA constant returns to scale model.

$$
(3) \qquad
\begin{aligned}
& Max_{\mu, v}\,(\mu' y_i) \\
& \text{s.t.} \quad v' x_k = 1 \\
& \mu' y_i - v' x_k \leq 0, \qquad\qquad k = 1,2,\ldots,K \\
& \mu,\ v \geq 0
\end{aligned}
$$

Alternatively, the DEA problem can be expressed using the dual form of the model.

$$
(4) \qquad
\begin{aligned}
& \text{Min}_{\theta,\,\lambda}\ \theta_i^{CRS} \\
& \text{s.t.} \quad Y\lambda - y \geq 0 \\
& \theta x_i - X\lambda \geq 0 \qquad\qquad i = 1,2,\ldots, n \\
& \lambda \geq 0
\end{aligned}
$$

where θ_i^{CRS} is a scalar that measures the TE of the ith farm and λ is an $N \times 1$ vector of constants or weights attached to each of the efficient farmers (Sharma, PingSun, and Halina). The estimated value of θ is the efficiency score for the *ith* farm. This estimate will satisfy the restriction $\theta \leq 1$. If $\theta = 1$ the farm is technically efficient, and on the frontier. If $\theta^{CRS} < 1$, then the farm is not on the frontier and is technically inefficient. To derive a technical efficiency score for all farms in the data set, the problem needs to be solved once for each farm.

To estimate the overall economic efficiency (*EE*), we can solve the cost-minimizing DEA model (Fare, Grosskopf, and Lovell) as follows:

(5) $$Min_{\theta_i^{CRS}\lambda} W_i^{'} X_i^{*}$$

$$\text{s. t.}\quad Y\lambda - y \geq 0$$

$$X_i^{*} \geq X\lambda$$

$$\lambda \geq 0$$

where X_i^* is the cost minimizing vector for the ith farm, given its input price vector, W_i, and output level, Y_i, and this equation accounts for input slacks not captured by equation (4), and attributes any input slacks to allocative inefficiency (Ferrier and Lovell). The *EE* can be determined as the ratio of the minimum cost to the observed cost

(6) $$EE_i = \frac{W_i{'} X_i^{*}}{W_i{'} X_i}$$

The allocative efficiency (*AE*) can be derived from equation (4) and equation (6) as follow

(7) $$AE_i = \frac{EE_i}{\theta_i^{CRS}}$$

Farm Technical Efficiency with (VRS) DEA Model

Imposing constant returns to scale, results in the maintained hypothesis that all farms in the data set are operating at the minimum point on the long run average cost function. This may not be the case. For example, a capital constraint may restrict farm size to less than that necessary to achieve minimum LRAC. The CRS model may be expanded to accommodate variable returns to scale (VRS) (Banker, Charnes, and Cooper). Imposing CRS when not all farms are operating at the optimal scale results in measures of technical efficiency that are confounded by scale efficiency (SE).

Alternatively, a VRS specification permits the measure of TE to be decomposed into pure TE and scale efficiency (Fraser and Cordina). The VRS mathematical programming formulation is as follow:

(8)
$$\begin{aligned}
&\mathrm{Min}_{\theta,\lambda}\ \theta^{VRS}\\
&\text{s.t.}\quad Y\lambda - y \geq 0\\
&\theta x_i - X\lambda \geq 0 \qquad\qquad i = 1,2,\ldots, n\\
&N'\lambda = 1\\
&\lambda \geq 0
\end{aligned}$$

where N is an $N \times 1$ vector of ones. The inclusion of the convexity constraint means that the data are enveloped more closely than with the CRS model. This means that the technical efficiency scores derived under a VRS are greater than or equal to those obtained under CRS. The constraint, $N'\lambda = 1$, ensures that a farm is only compared to other farms of similar size.

Scale Efficiencies

The scale efficiency measure may be used to determine the nature of returns to scale for any decision-making unit (Fare, Grosskopf, and Lovell). The main reason for this method is that scale economies can be determined directly both for efficient as well as for inefficient decision making units (Lothgren and Magnus).

Scale efficiency could be calculated by conducting both CRS and VRS DEA. Then the technical efficiency scores obtained from the CRS DEA can be decomposed into two components, one due to scale inefficiency and one due to pure technical inefficiency. If there is a difference in the CRS and VRS technical efficiency scores for a particular farm, then this indicates that the farm has scale inefficiency, which equals the difference between the VRS and the CRS technical efficiency score. Thus, the input-oriented scale efficiency is defined as

$Se_i = \frac{TE_i^{CRS}}{TE_i^{VRS}}$ where $Se_i = 1$ indicates scale efficiency or CRS. $Se_i < 1$ indicates scale inefficiency resulting from either increasing or decreasing returns to scale. But the value of scale efficiency does not indicate whether the firm is operating in an area of increasing or decreasing returns to scale. A DEA specification with a non-increasing returns (NIRS) can be imposed as follows:

$$(9) \qquad \begin{aligned} &\mathrm{Min}_{\theta,\lambda}\ \theta, \\ &\text{s.t} \quad Y\lambda - y \geq 0 \\ &\theta x_i - X\lambda \geq 0 \qquad\qquad i = 1,2,\ldots,n \\ &N'\lambda \leq 1 \\ &\lambda \geq 0 \end{aligned}$$

using the constraint $N'\lambda \leq 1$ to ensure that the i-th farm will not be compared against farms that are substantially larger, but may be compared with farms that are smaller.

The NIRS should be considered with CRS as follow. $Se_i = \frac{TE_i^{CRS}}{TE_i^{NIRS}} \begin{cases} =1 \Rightarrow IRS \\ <1 \Rightarrow DRS \end{cases}$ indicating whether the scale-inefficiency is due to a small output (increasing returns to scale (IRS)) or to a large output (decreasing returns to scale (DRS)) (Lothgren and Magnus). Let θ^{NIRS} represent the TE measure assuming non-increasing returns to scale.

By this measure, $\theta^{CRS}=\theta^{NIRS}$ indicates increasing returns to scale. Alternatively, $\theta^{CRS}<\theta^{NIRS}$ indicates decreasing returns to scale (Fare, Grosskopf, and Lovell).

Consider the CRS and VRS DEA frontiers plotted in Figure 3. The best practice reference technology based on CRS is represented by the line from the origin through C, while based on VRS the frontier goes through A, C, and E. Under CRS when the farm B is operating at point B then the technical inefficiency is the distance BB_c. However, under VRS, the technical inefficiency is the distance BB_v. The difference between the two measures is due to scale inefficiency. This can be interpreted as the ratio of the average product of a farm operating at the point B_v to the average product of the farm operating at a point of constant returns to scale point C. The point b^{CRS} shows the necessary input used if the farm was operating at the optimal scale and technically efficient. The point b^{VRS} shows that under conditions of increasing returns to scale, more input is necessary to produce the given level of output than is indicated if CRS is assumed.

From the Figure 3 we note that farm C is the only one that produced at the CRS frontier and the only one that has the maximum output per input. Farm B would need to increase in scale to reduce scale inefficiency.

"The nature of the scale inefficiencies for a particular farm can be determined by seeing whether NIRS TE score is equal to the VRS TE score" (Coelli, Rao, and Battese, p. 152). If they are equal, as in the case of farm D, then the farm exhibits DRS. If they are unequal, as in the case of farm B, then the farm exhibits IRS.

Any linear programming software may be used to solve DEA models. However, to solve for both CRS and VRS efficiency scores for a sample of 100 farms would require

200 separate models. Specialized software has been developed that will solve and summarize the results. For the present study, the Data Envelopment Analysis estimates of the parameters are computed by the DEAP Version 2.1 software, as described by (Coelli)[6].

Data and Variables

To determine the extent to which broiler producers in the Central Region of Saudi Arabia are technically efficient, primary data were collected from a random sample of 40 of the 154 broiler farms in the area. Questionnaires were used for both closed and open farm systems.[7] Data collection was performed in the summer and fall of 1993. The survey covered the Central Region and included three main cities (Riyadh, Kharj, and Qaseem). This is one of the major producing districts in the country.

Broiler farms in the Saudi Central Region are classified into two categories according to their production capacities. The first category includes farms with production capacity of less than three hundred thousand kg/period. The second category includes farms with capacity of more than three hundred thousand kg/period[8]. The data set included 25 farms in the first category, and 15 farms in the second category.

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[6] DEAP 2.1 can be downloaded from the internet by accessing the address for the Center for Efficiency and Productivity Analysis at the University of New England, Armidale, NSW, Australia: http://www.une.edu.au/econometrics/cepa.htm.

[7] There are two kinds of broiler farms in S.A. There are a few traditional farms where the farmers raise a small number of chickens. Specialized farms, use technology such as automatic feed troughs, drinking troughs, cooling and heating system,...etc. This is a closed system if the broiler house is closed and depending on electric power for heating and cooling. The close system is the dominant in the central, eastern, and western regions because of the harsh weather most of the year. The open system is dominant in the southwest regions that have moderate weather.

[8] Since the broilers need 42 days on average to be ready for slaughter, and the broiler house needs at least one week before putting the chicks in the house, and one week after they are out of the house for cleaning and sterilization, we assume the period to be two months.

The questionnaire for the survey was constructed to ask for details about the poultry operations on the farms. In particular, questions were included to determine the number of broilers and the use of inputs, such as labor, feed, and capital. Information also was obtained on some basic personal characteristics of the sample farmers.

Description of variables

For the purpose of efficiency analysis, output of the broiler farms was aggregated into one category. Inputs were aggregated into four categories, namely, chicks, feed, other variable inputs and capital. Output (y) represents a weighted output of live broilers produced (in kilograms) per period; chicks (X_1) represent the total quantity of chicks (in kilograms) per period; feed (X_2) represents the total quantity of feed (in kilograms) per period; other variable inputs (X_3) represent the total of all variable expenses, except chicks and feed (in Saudi Riyals) per period; capital (X_4) represents the total capital investment input including buildings, equipment, and machinery used in the broiler houses (in Saudi Riyals).

The prices of inputs needed to solve for the cost minimizing DEA model are defined as follows: W_1 represents the price of chicks computed as the total chick expenses divided by X_1 (in Saudi Riyal/kg). W_2 represents the price of feed computed as the total of feed expenses divided by X_2 (in Saudi Riyal/kg). Since the other variable costs, X_3, and capital investment input, X_4, are expressed in values. W_3 and W_4 are set equal to 1,000 SR (Sharma, Leung, and Zaleski). Summary statistics of the variables used in the analysis are presented in Table 5.

Results and Analysis

Overall technical, allocative and economic efficiency measures estimated from the DEA approach and their frequency distributions with CRS and VRS are presented in Table 6. Under the constant returns to scale assumption, the estimated mean TE measure for the broiler farms is 72.9%. With the variable returns to scale model the mean technical efficiency was estimated to be 81%. Thus, the costs could be reduced by about 19% if all the farms produced on the efficient cost frontier, indicating that, on average, the farms were technically inefficient.

In terms of TE, only six of the forty farms are fully efficient under the CRS model. But under the VRS model, twelve farms are fully efficient (Figures 4 and 5). The distribution of efficiency scores for the CRS DEA model in Figure 4 show that about 47.5% of the farms in the sample are operating at less than 70% efficiency, while 15% are fully efficient. Results from the VRS DEA model are shown in Figure 5. These efficiency scores show that 30% of the farms in the sample are operating at full efficiency.

Allocative efficiency ranged from 46.3% to 100% (Table 6). The mean allocative (*AE*) and cost or economic (*EE*) efficiency measures estimated from the DEA frontier are 77.9% and 56.4%, respectively, for CRS, and 81.9% and 66.4% for VRS indicating that costs could be reduced by approximately 20%, if all of the farms were allocatively efficient. These results reveal substantial inefficiencies in broiler production in the central region of Saudi Arabia. Approximately 45% of the farms had an allocative efficiency index of 80% or greater. Only 2.5 allocatively efficient. % of farms were classified as fully

The scale efficiency index (Table 6) for the broiler farms in the central region of Saudi Arabia ranged from 46.4% to 100%, with a mean of 90.5%. More than 57% of the farms were over 90% scale efficient, indicating that a greater proportion of overall inefficiency was due to farms operating above the cost frontier than the farms being of an inefficient scale (Featherstone, Langemeier, and Ismet). In terms of scale efficiency, only seven farms are exhibiting CRS, while among the scale inefficient farms, twenty-three farms, or more than 57% of the sample data, exhibit increasing returns to scale. This implies that the farms should be larger than they presently are. Ten farms exhibit decreasing returns to scale. Most of the large farms (>300,000 Kg) exhibit deceasing returns to scale.

To accomplish the second objective of this study, the data were separated into two categories: SMALL farms that produce less than 300,000 kilograms of chicken per period and LARGE farms that produce more than 300,000 kilograms of chicken per period.

Small Farms

The small category consists of farms that produce less than three hundred thousand kg/ period. The nonparametric efficiency results for the small farms with both the CRS and VRS DEA models are estimated for the same number of farms, using the DEAP program. The frequency distributions of the efficiency estimates are presented in Table 7. The mean technical efficiencies estimated for the CRS and VRS DEA approaches are 82.1% and 87.2% indicating that there is substantial inefficiency in farming operations for the small broiler farms in the central region of Saudi Arabia. This result means that the small farms could produced the same level of output at approximately 17.9% less cost if the operation was technically efficient if CRS is assumed, or by 12.8% if VRS is assumed.

TE ranged from 51.2% to 100% with 20% of the small farms fully technically efficient under CRS and 36% of the farms estimated to be a fully technically efficient for the VRS model. The distribution of efficiency scores for the CRS DEA model in Figure 6 shows that about 47.5% of the farms in the sample are operating at less than 70% efficiency, while 15% are fully efficient. The VRS DEA efficiency scores show that 30% of the farms in the sample are operating at full efficiency (Figure 7).

The mean allocative (*AE*) and economic (*EE*) efficiency measures estimated with the DEA model are 71% and 58.5%, respectively, for CRS, and 74.5% and 65.3% for VRS. These results suggest that with the level of inputs used, the farms could produce 29% more output or use 29% less input to obtain the same level of output if CRS is assumed. They could increase their production with the same level of inputs by 25.5% or decrease the use of inputs by 25.5% and produce the same level of output if VRS is assumed.

Large Farms

The large category includes farms that produce more than three hundred thousand kg/ period. The nonparametric efficiency results for the large farms with both the CRS and VRS DEA models are estimated for the same number of farms. The efficiency estimates obtained from the DEA frontier method are presented in Table 8. The mean technical efficiencies estimated for the CRS and VRS DEA approaches are 81.6% and 89.9% indicating that there is substantial inefficiency in farming operations for the large broiler farms in the central region of Saudi Arabia. By this measure, these farms could reduce their cost by approximately 18.4% without reducing their output when CRS are assumed, and by 11.1% if VRS are assumed.

TE ranged from 44.6% to 100%. An average of 33.3% of the large farms are fully technically efficient under CRS and 46.6% farms are estimated to be a fully technically efficient under VRS. The distribution of efficiency scores for the CRS DEA model in Figure 8 shows that 46.6% of the farms in the sample are operating at less than 80% efficiency, while 33.3% are fully efficient. For the VRS DEA model (Figure 9) 46.6% of the farms in the sample are operating at full efficiency.

The mean allocative (*AE*) and economic (*EE*) efficiency measures estimated from the DEA frontier are 84.5% and 68.3%, respectively, for CRS, and 88.5% and 79.5% for VRS. This suggests that for the given the level of inputs used, the farms could produced 15.5% more output or could have used 15.5% less input to obtain the same level of output if CRS is assumed. If VRS is assumed, they could increase their production with the same level of inputs by 11.5% or decrease the use of inputs by 11.5% and produce the same level of output.

Conclusion

The technical, allocative and economic efficiency for a sample of broiler farmers in the central region of Saudi Arabia was determined by the nonparametric frontier approach including the estimation of input-oriented DEA models. The frontier model was estimated under the mathematical programming approach for CRS DEA and VRS DEA. The technical efficiency effects are estimated as a function of various factors, chick quantity, feed quantity, other variable costs, and capital investment cost. The mean technical, allocative and economic efficiencies under variable returns to scale (VRS) were 81%, 81.9% and 66.4%, respectively. The corresponding measures for constant returns to scale (CRS) were 72.9%, 77.9% and 56.4%, respectively. The estimated technical, allocative and economic efficiencies are greater with VRS than with CRS. The small broiler farms are characterized by increasing returns to scale, while the large farms are characterized by decreasing and constant returns to scale under the DEA approach. And, the large farms are more technically, allocatively and economically efficient than the small farms under the VRS DEA. Finally the results indicate that more than 47.5% of the farms had technical efficiency levels less than 70% under CRS, and 45% of the farms had technical efficiency levels less than 70% under VRS.

Relative to other performance studies, the results reveal substantial production inefficiencies for the sample of broiler farmers in the central region of Saudi Arabia and hence, considerable potential for enhancing profitability by reducing the production costs by improving the efficiency. Analysis of various farms shows that farm size has positive and significant effects on technical efficiency levels. Farms operating at full economic efficiency levels have lower production cost.

Also the results suggest that there is opportunity to improve the efficiency of broiler production in the region. It may be appropriate to implement training programs for the managers of broiler farms with a goal of improving efficiency. Additional research will be necessary to determine the comprehensive consequences of the policy of subsidizing broiler production.

TABLE 1

BROILER PRODUCTION IN SAUDI ARABIA, 1983-2000

Year	Production (1,000 tons)
1983	124
1984	143
1985	177
1986	240
1987	246
1988	266
1989	267
1990	270
1991	270
1992	288
1993	324
1994	362
1995	390
1996	397
1997	417
1998	438
1999	460
2000	388

Source: Ministry Of Agriculture and Water. Broiler industry in Saudi Arabia, Department of Economic Studies and Statistics, 1998 KSA.

U.S. Department of Agriculture, Saudi Arabia Broiler and Products Annual 2000. Foreign Agricultural Service, September 13, 2000. GAIN Report. No. SA0013.

TABLE 2

PRODUCTION OF BROILER BY SPECIALIZED FARMS BY REGION IN THE KINGDOM 1998

Region	Production (1,000 birds)	Number of Farms
Eastern	27,924	73
Riyadh	69,335	71
Qaseem	171,698	22
Hail	12,862	3
Tabuk	4,474	8
Medinah	11,580	19
Makkah	103,654	25
Aseer	35,085	48
Al-baha	4,609	6
Jazan	3,435	3
Najran	4,226	8
Al-jouf	1,558	10
N.frontier	707	1
Total	451,147	297

Source: Ministry Of Agriculture and Water. Broiler industry in Saudi Arabia. Department of Economic Studies and Statistics, 1998 KSA.

Table 3

Local Production Price Compared to Price of Imported Broilers

Source	900 grams	1000 grams	1100 grams	1200 grams	1300 grams	1400 grams
Local	$1.95	$2.11	$2.29	$2.53	$2.80	$2.96
Brazilian	$1.52	$1.60	$1.84	$2.00	$2.16	$2.32
French	$1.36	$1.47	$1.60	$1.76	$1.89	$2.03

Source: U.S. Department of Agriculture, Saudi Arabia Poultry and Products Annual 2000. Foreign Agricultural Service, September 13,2000. GAIN Report. No. SA0013.

Table 4

The Economics of Broiler Production (Average Prices in $/ Kg of Live Bird Produced.)

Year	1981	1982[9]	1983[10]	1984[11]	1985[12]	1986[13]	1987	1988	1989	1990
Baby Chick	0.401	0.404	0.394	0.383	0.362	0.341	0.339	0.341	0.344	0.347
Feed	1.048	0.875	0.789	0.710	0.587	0.480	0.587	0.854	0.785	0.785
Rent	0.146	0.146	0.143	0.139	0.137	0.133	0.133	0.133	0.133	0.133
Labor	0.076	0.079	0.077	0.072	0.068	0.066	0.064	0.066	0.066	0.066
Medicine	0.032	0.032	0.031	0.030	0.027	0.026	0.026	0.026	0.026	0.026
Farm Running	0.093	0.093	0.091	0.089	0.085	0.080	0.077	0.080	0.080	0.080
Adjust for Mortality	0.178	0.163	0.151	0.142	0.126	0.112	0.122	0.149	0.144	0.144
Catch & Transportation.	0.046	0.046	0.045	0.044	0.041	0.040	0.040	0.040	0.040	0.040
Process & Packing	0.199	0.202	0.197	0.190	0.181	0.170	0.170	0.170	0.173	0.173
Marketing, tranpt & distr'	0.076	0.079	0.077	0.072	0.068	0.066	0.064	0.066	0.066	0.066
Subsidy w.r.t.1988	0.442	0.538	0.560	0.581	0.631	0.664	0.662	0.00	0.00	0.00
Total	1.853	1.575	1.439	1.292	1.056	0.851	1.497	1.927	1.858	1.863
Profit	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Selling price	2.038	1.732	1.583	1.421	1.161	0.936	1.647	2.120	2.044	2.050
French Retail Price	2.398	2.049	1.688	1.569	1.813	1.895	1.981	1.869	1.869	1.869
Saudi Fresh Retail Price	---	---	---	2.027	2.167	2.109	2.066	2.136	2.082	2.029
Feed Price 1000's SR/Ton	143.19	119.47	108.15	97.06	80.10	65.68	80.10	107.34	138.31	

Source: Riyadh Chamber of Commerce & Industry, Study about the Broiler Exporting Practices of France and Brazil to Saudi Arabia. Riyadh. Saudi Arabia. 1990

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[9] $1=3.415

[10] $1=3.495

[11] $1=3.575

[12] $1=3.645

[13] Since (1986 –2001) $1=3.745

Table 4

The Economics of Broiler Production (Average Prices in $/ Kg of Live Bird Produced.)

Year	1981	1982[9]	1983[10]	1984[11]	1985[12]	1986[13]	1987	1988	1989	1990
Baby Chick	0.401	0.404	0.394	0.383	0.362	0.341	0.339	0.341	0.344	0.347
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Rent	0.146	0.146	0.143	0.139	0.137	0.133	0.133	0.133	0.133	0.133
Labor	0.076	0.079	0.077	0.072	0.068	0.066	0.064	0.066	0.066	0.066
Medicine	0.032	0.032	0.031	0.030	0.027	0.026	0.026	0.026	0.026	0.026
Farm Running	0.093	0.093	0.091	0.089	0.085	0.080	0.077	0.080	0.080	0.080
Adjust for Mortality	0.178	0.163	0.151	0.142	0.126	0.112	0.122	0.149	0.144	0.144
Catch & Transportation.	0.046	0.046	0.045	0.044	0.041	0.040	0.040	0.040	0.040	0.040
Process & Packing	0.199	0.202	0.197	0.190	0.181	0.170	0.170	0.170	0.173	0.173
Marketing, tranpt & distr'	0.076	0.079	0.077	0.072	0.068	0.066	0.064	0.066	0.066	0.066
Subsidy w.r.t.1988	0.442	0.538	0.560	0.581	0.631	0.664	0.662	0.00	0.00	0.00
Total	1.853	1.575	1.439	1.292	1.056	0.851	1.497	1.927	1.858	1.863
Profit	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Selling price	2.038	1.732	1.583	1.421	1.161	0.936	1.647	2.120	2.044	2.050
French Retail Price	2.398	2.049	1.688	1.569	1.813	1.895	1.981	1.869	1.869	1.869
Saudi Fresh Retail Price	---	---	---	2.027	2.167	2.109	2.066	2.136	2.082	2.029
Feed Price 1000's SR/Ton	143.19	119.47	108.15	97.06	80.10	65.68	80.10	107.34	138.31	

Source: Riyadh Chamber of Commerce & Industry, Study about the Broiler Exporting Practices of France and Brazil to Saudi Arabia. Riyadh. Saudi Arabia. 1990

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[9] $1=3.415

[10] $1=3.495

[11] $1=3.575

[12] $1=3.645

[13] Since (1986 –2001) $1=3.745

TABLE 5

Variables and Average Values for the Data of Saudi Arabian Broiler Farms

Variable	Units	Mean	S.D	Low	High
output	Kilograms				
All		252,620	187,400	27,758	966,821
Small		142,140	62,517	27,758	300,000
Large		436,750	181,690	300,631	966,821
Chicks	Kilograms				
All		7,827.5	6,839.3	820	37,678
Small		4,227.1	2,323.9	820	10.755
Large		13,828	7,701.9	6,720	37,678
Feed	Kilograms				
All		629,840	582,560	68,333	3,412,833
Small		333,160	185,470	68,333	840,000
Large		1,124,300	683,610	450,000	3,412,833
OVC	Saudi Riyal				
All		111,450	149,110	16,000	870,344
Small		55,441	58,097	16,000	314,800
Large		204,800	203,010	44,000	870,344
Capital inputs	Saudi Riyal				
All		4,635,400	6,912,900	332,000	43,040,180
Small		2,422,400	997,330	332,000	4,900,000
Large		8,323,800	1,039,700	900,000	43,040,180

Source: Research sample data

TABLE 6

DISTRIBUTION OF TECHNICAL (TE), ALLOCATIVE (AE), AND ECONOMIC (EE) EFFICIENCY MEASURES OF BROILER FARMS IN THE CENTRAL REGION OF S.A. FROM THE DEA MODELS

	TE			AE		EE	
Farm	**CRS**	**VRS**	**Scale**	**CRS**	**VRS**	**CRS**	**VRS**
1	0.478	0.543	0.880	0.884	0.826	0.423	0.449
2	0.724	0.765	0.946	0.760	0.721	0.550	0.552
3	0.582	0.687	0.848	0.733	0.636	0.427	0.437
4	0.792	0.840	0.944	0.881	0.832	0.698	0.699
5	1.000	1.000	1.000	0.978	1.000	0.978	1.000
6	0.753	0.819	0.920	0.820	0.755	0.618	0.618
7	0.485	0.505	0.960	0.853	0.819	0.413	0.414
8	0.755	0.802	0.942	0.766	0.726	0.578	0.583
9	0.608	0.616	0.988	0.786	0.793	0.478	0.488
10	0.980	1.000	0.980	0.795	0.783	0.779	0.783
11	0.522	0.559	0.935	0.780	0.733	0.407	0.410
12	0.810	0.810	0.999	0.875	0.881	0.708	0.713
13	0.759	0.794	0.956	0.874	0.851	0.663	0.676
14	0.648	0.652	0.993	0.690	0.780	0.447	0.509
15	0.926	1.000	0.926	0.594	0.570	0.550	0.570
16	0.646	0.647	0.999	0.787	0.908	0.509	0.587
17	0.698	0.733	0.952	0.754	0.719	0.526	0.527
18	0.659	0.670	0.984	0.840	0.828	0.553	0.555
19	0.693	0.769	0.901	0.830	0.748	0.575	0.575
20	0.890	0.950	0.936	0.790	0.740	0.703	0.703
21	0.714	0.757	0.943	0.858	0.811	0.613	0.614
22	0.398	0.665	0.598	0.859	0.865	0.342	0.575
23	0.634	1.000	0.634	0.826	1.000	0.524	1.000
24	1.000	1.000	1.000	1.000	1.000	1.000	1.000
25	0.891	1.000	0.891	0.642	0.582	0.572	0.582
26	0.816	0.864	0.944	0.671	0.757	0.548	0.654
27	0.547	0.874	0.626	0.886	0.785	0.485	0.686
28	0.572	0.937	0.611	0.908	0.767	0.519	0.718
29	1.000	1.000	1.000	0.669	0.806	0.669	0.806
30	0.920	0.920	1.000	0.656	0.825	0.603	0.759
31	1.000	1.000	1.000	0.463	0.610	0.463	0.610
32	1.000	1.000	1.000	0.838	1.000	0.838	1.000
33	0.649	0.743	0.873	0.811	0.934	0.527	0.694
34	0.616	0.619	0.995	0.717	0.911	0.442	0.564
35	0.599	0.609	0.984	0.686	0.762	0.411	0.464
36	1.000	1.000	1.000	0.628	0.805	0.628	0.805
37	0.367	0.370	0.994	0.653	0.965	0.240	0.357
38	0.831	0.884	0.940	0.750	0.918	0.623	0.811
39	0.723	1.000	0.723	0.835	1.000	0.604	1.000
40	0.464	1.000	0.464	0.715	1.000	0.332	1.000
Mean	**0.729**	**0.810**	**0.905**	**0.779**	**0.819**	**0.564**	**0.664**

Source: Research sample data

TABLE 7

DISTRIBUTION OF TECHNICAL (TE), ALLOCATIVE (AE), AND ECONOMIC (EE) EFFICIENCY MEASURES OF SMALL BROILER FARMS IN THE CENTRAL REGION OF S.A. FROM THE DEA MODELS

	TE		AE		EE	
Farm	**CRS**	**VRS**	**CRS**	**VRS**	**CRS**	**VRS**
1	0.512	0.543	0.824	0.826	0.423	0.449
2	0.776	0.782	0.709	0.706	0.550	0.552
3	0.761	0.769	0.561	0.568	0.427	0.437
4	0.909	0.954	0.769	0.732	0.698	0.699
5	1.000	1.000	0.978	1.000	0.978	1.000
6	0.890	0.893	0.694	0.692	0.618	0.618
7	0.584	0.613	0.708	0.675	0.413	0.414
8	0.794	0.802	0.729	0.726	0.578	0.583
9	0.692	0.781	0.691	0.625	0.478	0.488
10	1.000	1.000	0.779	0.783	0.779	0.783
11	0.634	0.678	0.643	0.604	0.407	0.410
12	0.881	0.939	0.804	0.760	0.708	0.713
13	0.800	0.804	0.829	0.841	0.663	0.676
14	0.773	1.000	0.578	0.806	0.447	0.806
15	1.000	1.000	0.55	0.570	0.550	0.570
16	0.892	1.000	0.57	1.000	0.509	1.000
17	0.861	0.967	0.611	0.545	0.526	0.527
18	0.787	0.838	0.703	0.662	0.553	0.555
19	0.852	0.852	0.675	0.675	0.575	0.575
20	0.981	1.000	0.717	0.703	0.703	0.703
21	0.866	0.905	0.708	0.678	0.613	0.614
22	0.515	0.672	0.663	0.856	0.342	0.575
23	0.772	1.000	0.678	1.000	0.524	1.000
24	1.000	1.000	1.000	1.000	1.000	1.000
25	1.000	1.000	0.572	0.582	0.572	0.582
Mean	**0.821**	**0.872**	**0.710**	**0.745**	**0.585**	**0.653**

Source: Research sample data

TABLE 8

DISTRIBUTION OF TECHNICAL (TE), ALLOCATIVE (AE), AND ECONOMIC (EE) EFFICIENCY MEASURES OF LARGE BROILER FARMS IN THE CENTRAL REGION OF S.A. FROM THE DEA MODELS

	TE		AE		EE	
Farm	**CRS**	**VRS**	**CRS**	**VRS**	**CRS**	**VRS**
26	1.000	1.000	0.709	0.855	0.709	0.855
27	0.790	0.874	0.781	0.785	0.617	0.686
28	0.694	0.937	0.866	0.767	0.601	0.718
29	1.000	1.000	0.862	1.000	0.862	1.000
30	0.920	0.920	0.830	0.841	0.763	0.774
31	1.000	1.000	0.638	0.688	0.638	0.688
32	1.000	1.000	1.000	1.000	1.000	1.000
33	0.780	0.790	0.906	0.926	0.706	0.731
34	0.672	0.789	0.943	0.962	0.634	0.759
35	0.599	0.773	0.815	0.782	0.488	0.604
36	1.000	1.000	0.808	0.817	0.808	0.817
37	0.446	0.514	0.966	0.937	0.431	0.481
38	0.877	0.887	0.880	0.915	0.772	0.811
39	0.949	1.000	0.801	1.000	0.760	1.000
40	0.518	1.000	0.866	1.000	0.449	1.000
Mean	**0.816**	**0.899**	**0.845**	**0.885**	**0.683**	**0.795**

Source: Research sample data

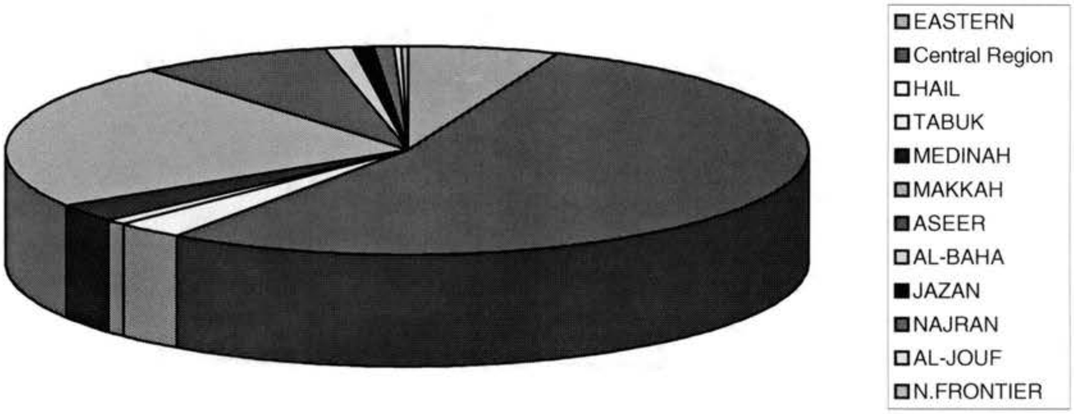

Figure1. Production of broiler by specialized farms by region in Saudi Arabia

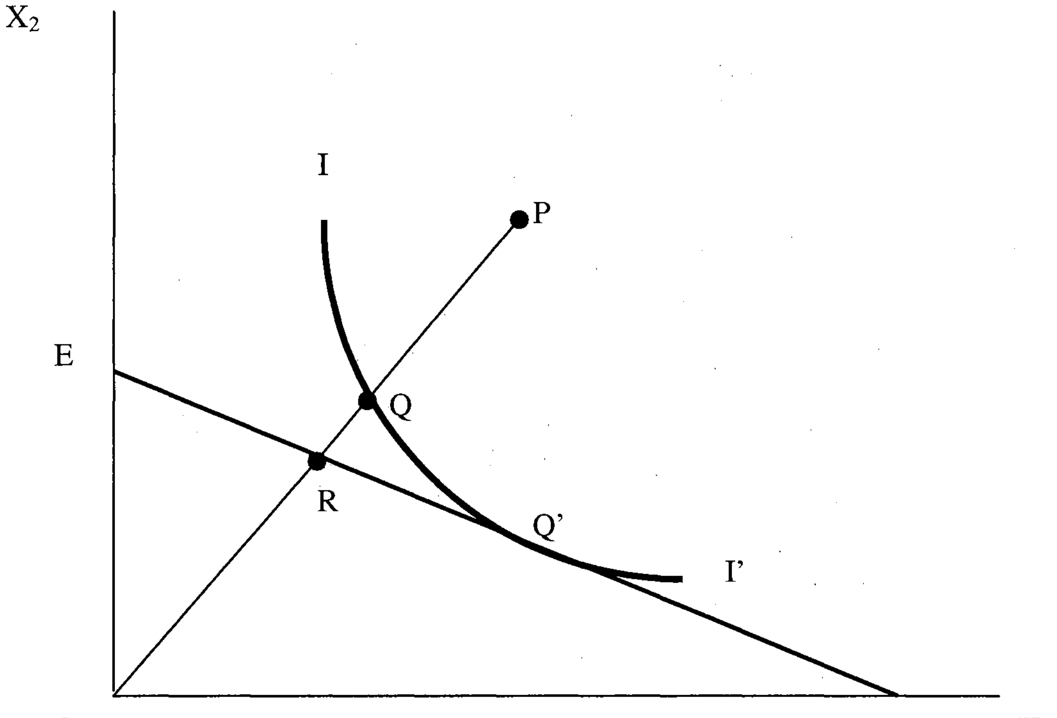

Figure 2. Farrell's measure of efficiency

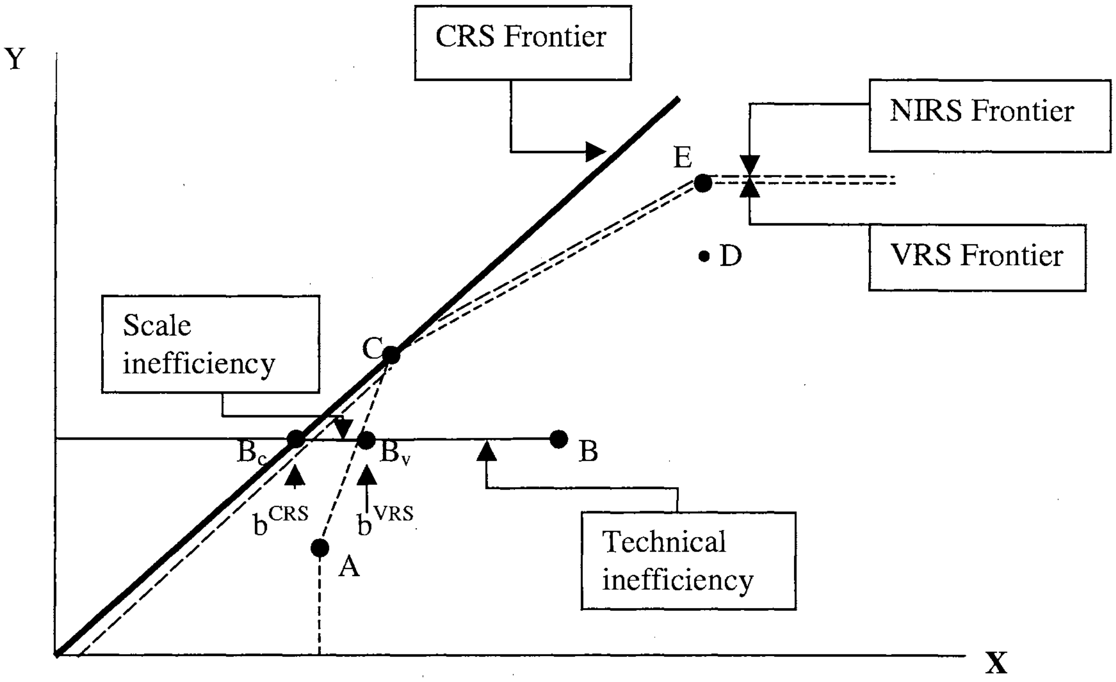

Figure 3. Calculation of scale economies in DEA

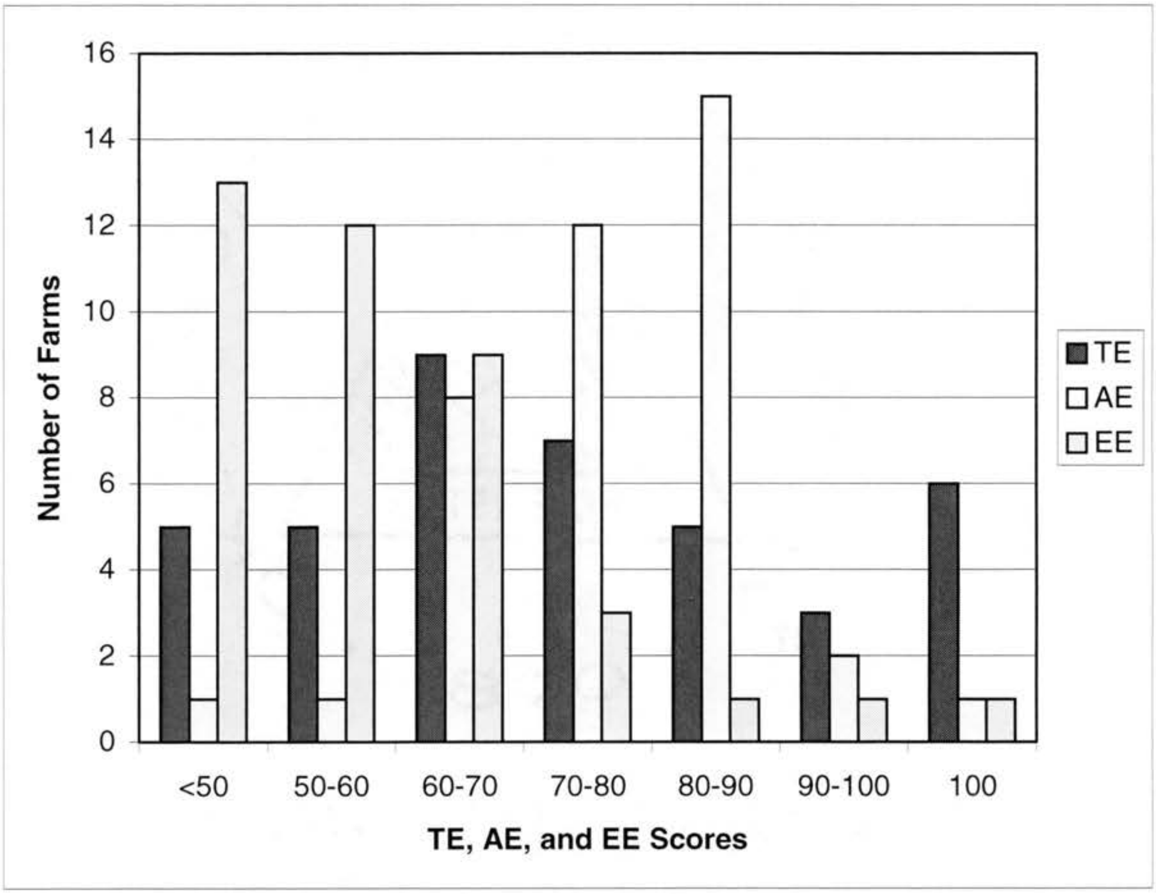

Figure 4. Frequency distribution of TE, AE, and EE scores as determined under the assumption of constant returns to scale for broiler farms in the central region of Saudi Arabia

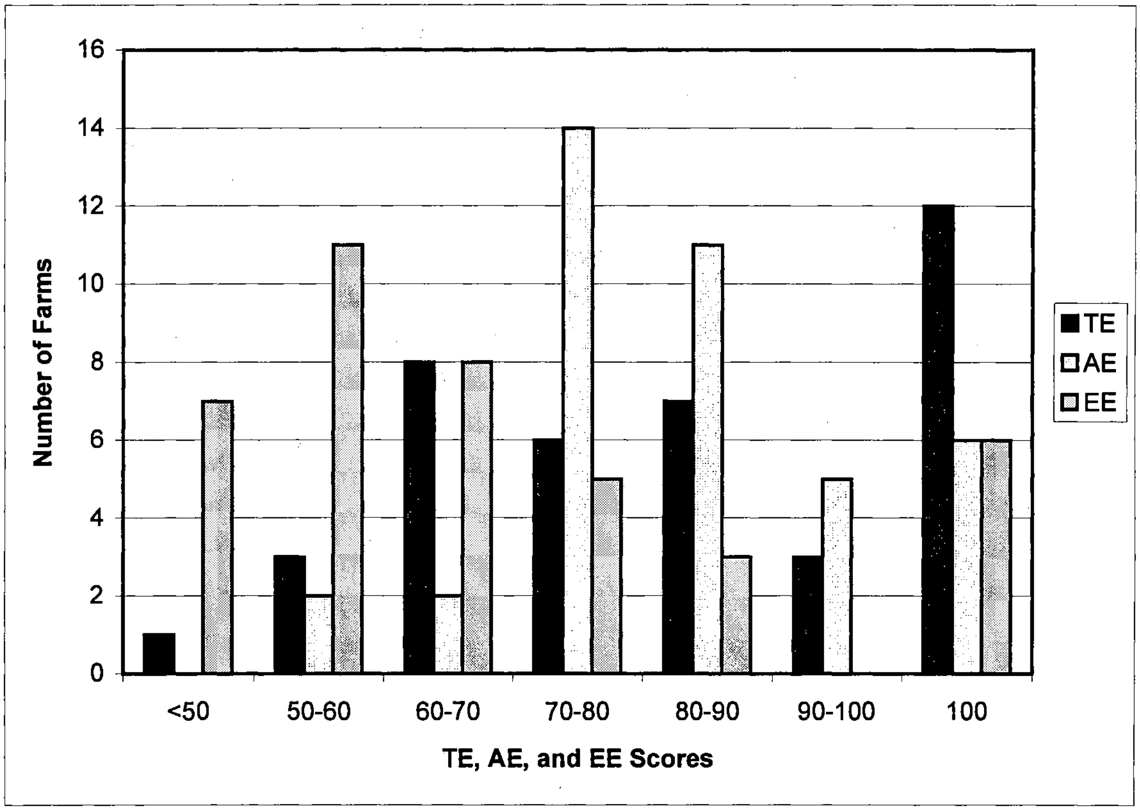

Figure 5. Frequency distribution of TE, AE, and EE scores as determined under the assumption of variable returns to scale for broiler farms in the central region of Saudi Arabia

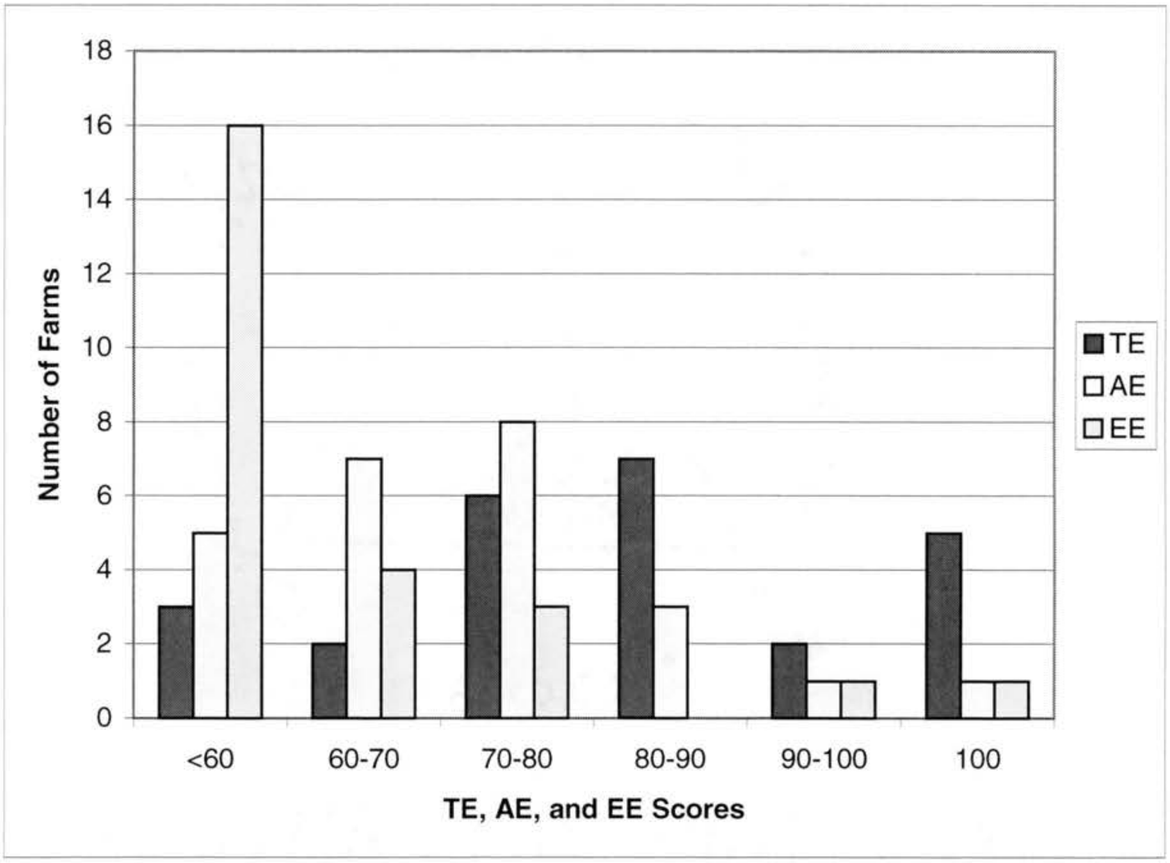

Figure 6. Frequency distribution of TE, AE, and EE scores as determined under the assumption of constant returns to scale for small broiler farms in the central region of Saudi Arabia

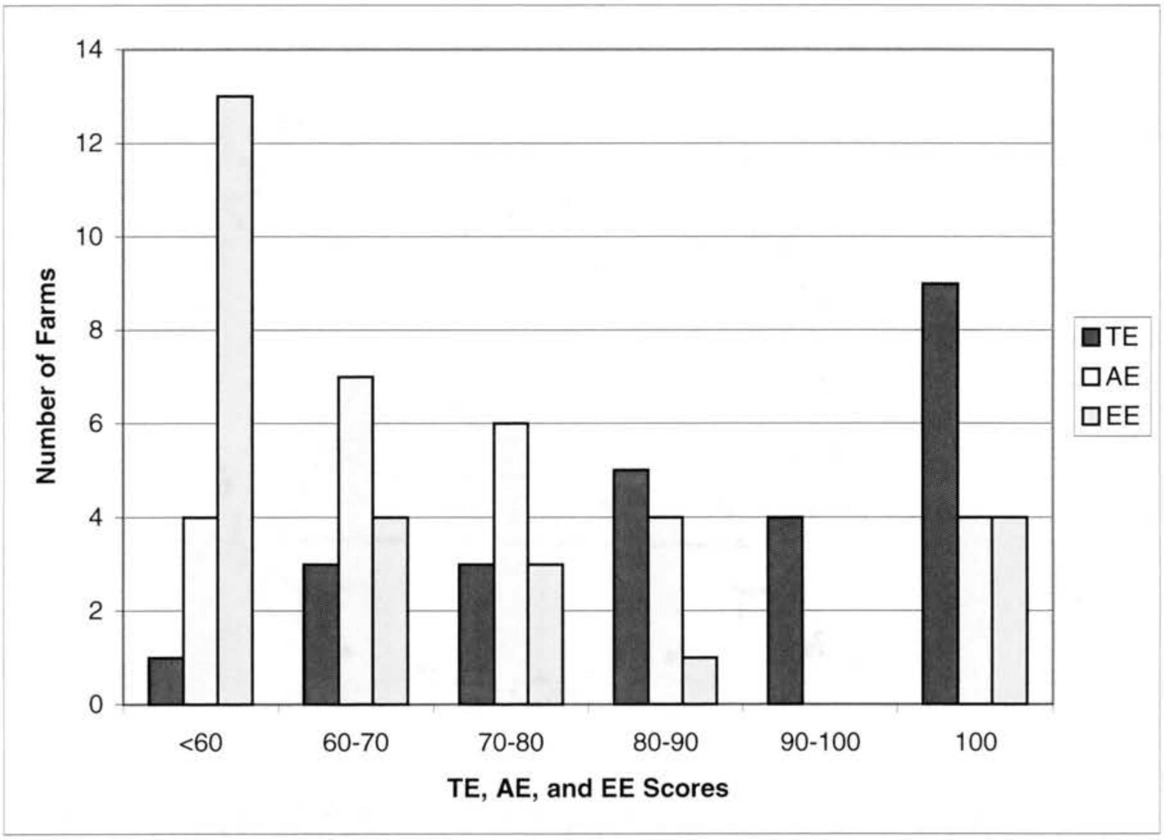

Figure 7. Frequency distribution of TE, AE, and EE scores as determined under the assumption of variable returns to scale for small broiler farms in the central region of Saudi Arabia

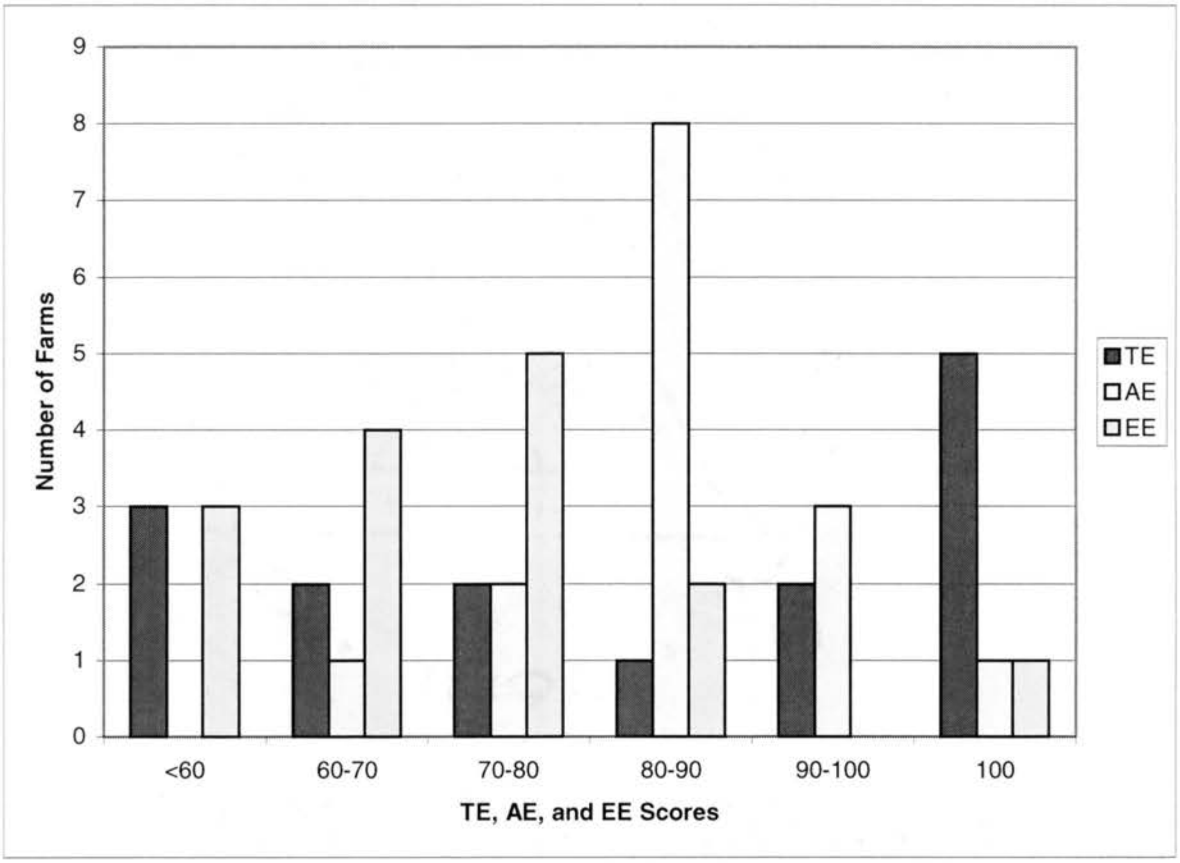

Figure8. Frequency distribution of TE, AE, and EE scores as determined under the assumption of constant returns to scale for large broiler farms in the central region of Saudi Arabia

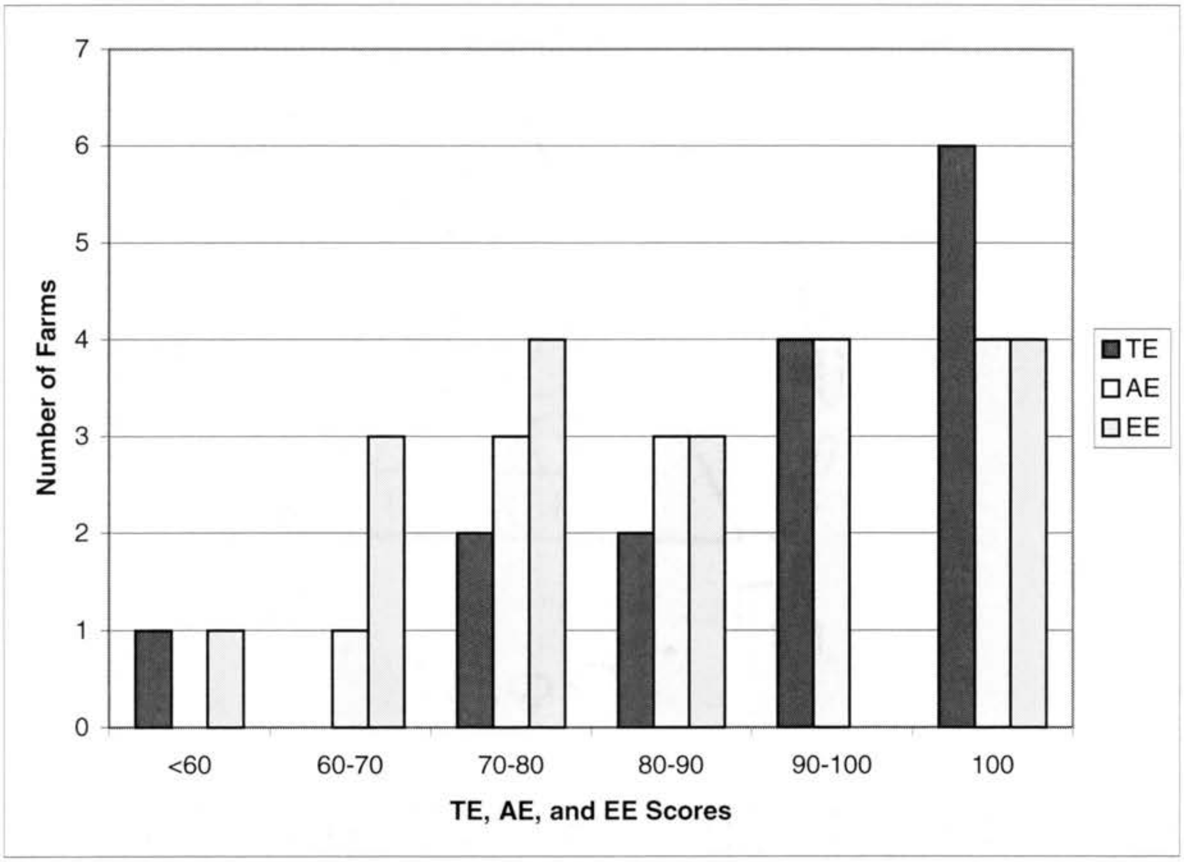

Figure 9. Frequency distribution of TE, AE, and EE scores as determined under the assumption of variable returns to scale for large broiler farms in the central region of Saudi Arabia

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Paper III

TECHNICAL EFFICIENCY OF BROILER FARMS IN THE CENTRAL REGION OF SAUDI ARABIA: STOCHASTIC FRONTIER APPROACH

TECHNICAL EFFICIENCY OF BROILER FARMS IN THE CENTRAL REGION OF SAUDI ARABIA: STOCHASTIC FRONTIER APPROACH

ABSTRACT

Broiler farms in Saudi Arabia have received major support and incentives from the government. Broiler farms in Central Saudi Arabia require high investment costs and competent management. These farms have recently experienced a wide range of technical and managerial problems. Some farms are operated at less than full capacity while others have ceased operations. The aim here is to determine the performance of the farms that remain, to measure their technical efficiency, and to determine if the mean technical efficiency differs between small and large farms. The stochastic frontier approach (SFA) is used to estimate the technical efficiency of broiler farms in the central region of Saudi Arabia. The mean technical efficiency of small farms will be compared with that of large farms to determine if policy instruments should be targeted toward small or large farms.

Key words: broiler farms, technical efficiency, stochastic frontier production function, parametric model, Saudi Arabia

TECHNICAL EFFICIENCY OF BROILER FARMS IN THE CENTRAL REGION OF SAUDI ARABIA: STOCHASTIC FRONTIER APPROACH

Introduction

Measurement of the efficiency of agricultural production is an important issue in developing countries. A measure of producer performance is often useful for policy purposes, and the concept of economic efficiency provides a theoretical basis for such a measure (Russell and Young).

Broiler farms are among the important agricultural industries in Saudi Arabia. The government gave free land, long-term loans without interest, and subsidies such as 50% of feed costs, and 30% of the equipment costs (drinking troughs, automatic feed troughs, incubators, hatchers including related electric equipment, animal feed mixers, automatic cages with all its accessories, slaughtering, freezing and cooling equipment, egg handling and cleaning equipment, cartons for packing chicks, bags for packing feed and cages for traveling hens). Additional incentives included free tariffs for some broiler farm machinery, free inoculations, transportation services and communication facilities.

These subsidies were implemented to encourage the private sector to invest in the industry. As a result, the number of broiler farms increased from 239 farms, producing 124,000 tons in 1983 to 318 in 1999 producing 460,000 tons (Table 1). Ten new farms are under construction, and 412 potential new farms are under study. The broiler farms are considered one of the highest priority areas and have received substantial support and incentives from the Saudi Arabian government. Total loans to broiler farms from the agricultural bank reached 1,462 million SR by 1996 ($390 million). This accounted for 23% of all loans provided for specialized agricultural projects in the country during 1996

(SAAB). Many (32%) of the farms are located in the Central Region that includes Riyadh, Kharj, and Qassim (Table 2). This region includes 50 % of the total production capacity of broiler farms Kingdomwide (Figure 1).

In spite of the sizable investment in these farms, most are not operating at full production capacity. More than 40% of the current broiler farms are unable to meet their debt obligations (Ministry of Agriculture and Water).

The government has made a substantial investment and concerted effort to develop broiler production. In addition to the subsidies to encourage construction of facilities, subsidies have also been provided to offset some operating costs, including feed and operating capital. However, in spite of these subsidies, broiler production costs for many of the farms in the region exceed the cost of imported broilers (Table 3).

The cost of production may be relatively high, as a result of technical and allocative inefficiencies in production that may be the result of inexperienced management. If it were determined that the relatively high production costs are due to inefficiencies, then a policy of improving efficiency could be implemented. Education and subsidies could be targeted toward the development and delivery of management training programs. Alternatively, the cost of production in the region may be high as a result of the climate and other environmental factors. It may be more efficient to import broilers, in which case the policy of subsidizing production in the region should be reconsidered.

To date no effort has been made to study and measure the technical efficiencies of these broiler farms. Research has been conducted to address the production, financing, and marketing problems. Al-zahrani (1986), tried to determine the marketing and management methods used by the small broiler farms in Alahsa region. Also in 1991 Al-zahrani analyzed the production problems facing the broiler producers in the central region of Saudi Arabia. Alqunibet et al. identified and analyzed the production and marketing problems facing broiler farms in the central region of Saudi Arabia. Alqunibet, Essam, and Sayed measured the important criteria of the different marketing activities pertinent to the Saudi broiler farms, and the impact of the farm's characteristics on the different marketing criteria. This study aims to answer the question of whether the broiler farms in the Central region of Saudi Arabia are technically efficient, and the level of technical efficiency.

The main objective for this paper is to determine the performance of broiler farmers in Saudi Arabia. This is the first attempt to analyze and compare the technical performance of broiler farmers in the central region of Saudi Arabia. Given this, the aim of this study is to estimate the technical efficiencies of broiler farms in the Central Region of Saudi Arabia, to determine whether the mean technical efficiency differs between small and large broiler farms in the region, and to make recommendations to increase the performance of broiler farms in the region if the results are indicating technical inefficiency.

Methodology

Farm efficiency, and the question of how to measure it, is an important subject in developing countries' agriculture (Parikh, Ali, and Shah). The efficiency of farmers in developing countries is an interesting topic to economists concerned with the problems in developing countries. If the farmers are inefficient in their practices, then it follows that output could be increased with less cost through extension and education (Belbase and Grabowski). A measure of relative producer performance is often useful for policy purposes and the concept of economic efficiency provides a theoretical basis for such a measure (Russell and Young).

The measurement of efficiency has been a popular field of research since Farrell published a seminal paper in 1957. Much research has focused on the economic efficiency of agricultural production, and the analysis has centered on the technical, allocative and scale efficiency of farm production (Chavas and Aliber). Farrell developed the concept of technical efficiency based on the relationships between inputs and outputs (Parikh, Ali, and Shah).

Technical Efficiency

Efficiency in production can be defined in terms of the production function that relates the level of various inputs (Berte). Technical efficiency is a measure of a farm's success in producing maximum output from a given set of input; in other words, technical efficiency refers to the physical relationship between inputs used in the production process. Technical efficiency measures output relative to that of the efficient isoquant. Efficient farms produce on the production frontier or, alternatively stated, on the efficient isoquant. The concept of technical efficiency relates to the question of where a firm or farm uses the best available technology in its production process (Chavas and Aliber).

In general, the aims of measuring farm level efficiency is to estimate the frontier that envelops all the input/output data with those observations lying on the frontier being described as technically efficient. Observations lying below the frontier are considered to be technically inefficient (Fraser and Cordina).

Koopmans (p. 60) provided a formal definition of technical efficiency: "a producer is technically efficient if any output requires a reduction in at least one other output or an increase in at least one input, and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output. Thus a technically inefficient producer could produce the same outputs with less of at least one input, or could use the same inputs to produce more of at least one output."

Farrell Measures of efficiency

The basic ideas underlying the Farrell approach to efficiency measurement are illustrated in Figure 2. This diagram shows the efficient unit isoquant (*II'*) for a group of farms constructed from the input bundles of farms. The farms produce *y* output, by using two inputs (x_1, x_2). A constant returns to scale production function is assumed.

$$y = f(x_1, x_2) \tag{1}$$

The unit isoquant can characterize this function frontier (*II'*) if the farm is observed using (x_1, x_2) to produce *y*. An inefficient farm is at point *P*. The point *Q* is the intersection of the line segment *OQ* with the isoquant (*II'*). According to Farrell the technical efficiency of point *P* is represented by the ratio $\frac{OQ}{OP}$. It is the ratio of inputs needed to produce the output to the inputs actually used to produce output, given the input mix used. (*EE'*) represents the ratio of input prices. The point *Q'* represents the minimum cost combination of x_1 and x_2 on the efficient isoquant. Farrell allocative efficiency is the ratio $\frac{OR}{OQ}$.

Technical efficiency (TE) will take a value between zero and one (0< TE ≤ 1). Where a value of one indicates the farm is producing on the production frontier and is fully technically efficient, and hence provides an indicator of the degree of technical inefficiency of the farm. For example, the point *Q* is technically efficient because it lies on the efficient isoquant. The distance *RQ* represents the reduction in production costs that would occur if production were to occur at the allocative (and technically) efficient point *Q'*. Total economic efficiency (*EE*) is defined to be the ratio $\frac{OR}{OP}$, where the distance *RP* can be interpreted in terms of a cost reduction. The product of technical and allocative efficiency provides the overall economic efficiency $TE * AE = \frac{OQ}{OP} * \frac{OR}{OQ} = \frac{OR}{OP}$. Zero and one bound all three measures (Coelli, Rao, and Battese). These efficiency measures assume the production function of the fully efficient farm is known. In practice this is not the case, and the efficient isoquant must be estimated from the sample data.

Data and Variables

To determine the extent to which broiler producers in the Central Region of Saudi Arabia are technically efficient, primary data were collected from a random sample of 40 of the 154 broilers farms in the area. Questionnaires were used for both closed and open farm systems[14]. Data collection was performed in the summer and fall of 1993. The survey covered the Central Region and included three main cities (Riyadh, Kharj, and Qaseem). This is one of the major producing districts in the country.

Broiler farms in the Saudi Central Region are classified into two categories according to their production capacities. The first category includes farms with production capacity of less than three hundred thousand kg/period[15]. The second category includes farms with capacity more than three hundred thousand kg/period. The data set included 25 farms in the first category, and 15 farms in the second category.

The questionnaire for the survey was constructed to ask for details about the poultry operations on the farms. In particular, questions were included to determine the number of broilers and the use of inputs, such as labor, feed, and capital. Information was also obtained on some basic personal characteristics of the sample farmers.

Description of variables

For the purpose of efficiency analysis, output of the broiler farms was aggregated into one category. Inputs were aggregated into four categories, namely, chicks, feed, other variable inputs, and capital. Output (y) represents a weighted output of live broilers produced (in kilograms) per period; chicks (X_1) represent the total quantity of chicks (in

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[14] There are two kinds of broiler farms in S.A. There are a few traditional farms where the farmers raise a small number of chickens. Specialized farms, use technology such as automatic feed troughs, drinking troughs, cooling and heating system,...etc. This is a closed system if the broiler house is closed and depending on the electric power for heating and cooling, this system is the dominant in the central, eastern, and western regions because of the harsh weather most of the year. The open system is dominant in the southwest regions that have moderate weather.

[15] Since the broilers need 42 days on average to be ready for slaughter, and the broiler house needs at least one week before putting the chicks in the house, and one week after they are out of the house for cleaning and sterilization, we assume the period to be two months.

kilograms) per period; feed (X_2) represents the total quantity of feed (in kilograms) per period; other variable inputs (X_3) represent the total of all variable expenses, except chicks and feed (in Saudi Riyals) per period; capital (X_4) represents the total capital investment input including buildings, equipment, and machinery used in the broiler houses (in Saudi Riyals). A summary of statistics of the variables used in the analysis is presented in Table 5. To describe how the inefficiency effects in the stochastic frontier production function vary across farmers, the variables used are the age of farmers (in years), experience (in years), family size (adults plus /children), and the number of days of feeding chickens (per period).

Econometric Model

Producer performance and productivity evaluation has become an important subject for research studies in economics and management. This evaluation involves the measurement and analysis of the efficiency of producing broilers (Yin). The parametric Stochastic Frontier Analysis (SFA) technique can be used to measure production efficiency and the performance of producers. Parametric methods focus on central tendencies (Seiford and Thrall), and can be used if a functional form is known or assumed that relates the independent variables to the dependent variable. Also the object of the SFA method is to fit a single regression plane through the data.

Bravo-Ureta and Rieger presented four methods for calculating technical efficiency. These four methods are parametric in the sense that they assume a specific functional form for the production frontier: 1) a deterministic production frontier estimated via linear programming; 2) a statistical production frontier estimated by corrected ordinary least squares; 3) a statistical production frontier that assumes a gamma-distributed efficiency term and is estimated using maximum-likelihood techniques; and 4) a stochastic production frontier with a composed error structure which is also estimated using maximum-likelihood techniques. The first three methods are deterministic, which means that the entire deviation from the frontier is attributed to inefficiency. The fourth method, by contrast, attributes only part of the deviation from the frontier to inefficiency.

The first method to measure the technical, allocative, and economic efficiency was proposed by Farrell assuming that the production function is known. But, since the underlying production function is seldom known in practice, Farrell suggests that the production function could be estimated from the sample data using parametric or non-parametric functions. Aigner and Chu estimated a parametric frontier production function of a Cobb-Douglas form, for a sample of data. The model was defined by

$$\ln(y_i) = \ln\, x_i\beta - u_i \qquad i=1,2,\ldots,N \tag{2}$$

where ln (y_i) is the output of the *ith* farm, $ln(x_i)$is the logarithm of input quantities used by *i*th farm, β is an unknown parameter, and u_i is random shock. In 1970, Afriat used maximum likelihood (ML) with a gamma distribution to estimate the parameters of the model in equation (2). Also, Richmond used corrected ordinary least square (COLS) to estimate the parameters of Afriat's model. A common criticism of the first three deterministic methods, is that no account is taken for the effects of the measurement errors and other noise along the frontier (Coelli, Rao, and Battese).

The Stochastic Frontier Production Functions

Frontier production functions can be estimated for both cross-sectional and panel data. Coelli, Rao and Battese, Kalirajan and Shand, and Bravo-Ureta and Pinheiro provide reviews of the application of frontier production functions to estimate the technical efficiency for both types of data. Aigner, Lovell, and Schmidt using cross sectional data proposed the stochastic frontier function. Panel data are used by various models such as Battese and Coelli (1988, 1992), Kumbhakar, Cornwell, Schmidt, and Battese, Hesmati, and Hjalmarsson. Stochastic frontier models are widely used in the analysis of efficiency, especially in developing countries. Battese and Hassan evaluated cotton farmers in Pakistan. Battese studied the effects of quality of irrigation water on crop yields in Pakistan. Lundvall and Battese considered firm size and age efficiency in Kenya. Kalirajan and Shand studied firm specific technical efficiency in Malaysia. There are no previous applications of stochastic frontier models in the analysis of broiler efficiency in Saudi Arabia.

The main strengths of the stochastic frontier approach are that it deals with stochastic noise. Tests of hypotheses regarding production structure technology and the existence of inefficiency can be performed on a stochastic frontier. The main problems with the stochastic frontier production function are, that the selection of a distributional form for the inefficiency effects may be arbitrary, the production function must be specified by a particular functional form, and the stochastic frontier approach is only well-developed for single –output technology (Coelli, Rao and Battese).

A production function can be specified for cross-sectional data with an error term containing two components one that accounts for technical inefficiency (v_i) and a second one that accounts for random effects (u_i). The frontier production function proposed by Aigner, Lovell and Schmidt is as follows:

(3) $$y_i = f(x_i; \beta) + \varepsilon_i \qquad i=1, 2, ..., n$$

where y_i is the quantity of output of the *ith* farm; X_i is a ($kx1$) vector of quantities of input employed by the *ith* farm to produce y; β is a vector of unknown production function parameters to be estimated; and ε_i is an error term made up of two components,

(4) $$\varepsilon_i = v_i - u_i$$

The v_i's are assumed to be independent and identically distributed random errors having a normal distribution with mean zero and variance σ_v^2. Thus, the v_i accounts for measurement error and other factors that are beyond the farmers control. The v_i's are assumed to be independent of the u_i's that are non-negative random errors ($u_i \geq 0, \ \forall i$). The u_i's are assumed to account for technical inefficiency in production and assumed to be independent and identically distributed exponential or half-normal random variables.

If we combine equation (3) and (4), assuming a Cobb-Douglas specification, the stochastic frontier production function for this study could be rewritten as follows:

(5) $$\ln y_i = \beta_0 + \sum_{i=1}^{m} \beta_j \ln x_{ij} + v_i - u_i \qquad i=1,2,\ldots, n$$

where y_i is the output of farm i, x_{ij} is the amount of input j used by farm i, β_j are parameter to be estimated. The output values are bounded above by the stochastic variable, exp ($X_i\beta + v_i$). The random error, v_i, can be positive or negative and so the stochastic frontier. To illustrate the basic feature of the model following Coelli, Rao, and Battese, assume two farms, i and j, producing two outputs, y_i and y_j, using two inputs, x_i and x_j. The inputs are represented on the horizontal axis and the outputs on the vertical axis. Assuming diminishing returns to scale of the deterministic component of the frontier model, $y = exp\ (x\beta)$, the observed input-output are presented on Figure 3 by the point marked with × above the value of x_i, but the value of stochastic frontier output, $y_i^* \equiv exp\ (X_i\beta + v_i)$, is marked by the point$\otimes$ above the production function because the random error v_i, is positive. Similarly, the jth farm has a negative random error v_j, so the frontier output will be below the production function (Coelli, Rao, and Battese).

Technical efficiency (TE) of farm *i* is the ratio of actual output for the *ith* farm (y_i), relative to the potential output, defined by the frontier function, given the input vector $exp\ (x_i\beta)$, is used to define the TE of the *i*th farm.

$$TE_i = \frac{y_i}{\exp(x_i\beta)} = \frac{\exp(x_i\beta - u_i)}{\exp(x_i\beta)} = \exp(-u_i) \tag{6}$$

Where y_i is the observed output, and exp ($x_i\beta$) is the estimated value of the frontier output. This is called an output-oriented Farrell measure of technical efficiency. The parameters, β, can be estimated where $\sum_{i=1}^{n} u_i$ is minimized, subject to the constraints that $u_i \geq 0$, i=1,2...n (Coelli, Rao, and Battese). This efficiency measure takes the values between 0 and 1 with smaller ratio indicating greater inefficiency.

Maximum- Likelihood Estimation:

Assuming independence between v_i and u_i, the parameters of the stochastic frontier function (β), defined by equation (5), can be estimated using the maximum-likelihood (ML) method. ML is computationally demanding. It requires numerical maximization of the likelihood function. The ML estimator is asymptotically efficient. According to Coelli, Rao and Battese, the basic elements of obtaining ML estimators for the parameters of the stochastic frontier model are consistent with the case of a half-normal distribution for the technical inefficiency effects.

Battese and Corra showed the log-likelihood function is equal to

$$(7)\quad \ln L(y\mid\beta,\gamma,\sigma^2)=-\frac{N}{2}\ln(\frac{\pi}{2})-\frac{N}{2}\log(\sigma_S^2)+\sum_{i=1}^{N}\ln[1-\phi(Z_i)]-\frac{1}{2\sigma_S^2}\sum_{i=1}^{N}(\ln y_i-x_i\beta)^2$$

where $\sigma^2=\sigma_u^2+\sigma_v^2,\gamma=\sigma_u/\sigma_v$, $Z_i=\frac{(\ln y_i-x_i\beta)}{\sigma_S}\sqrt{\frac{\gamma}{1-\gamma}}$, and ϕ (.) is the cumulative distribution function of the standard normal random variable. The ML estimates β,σ^2_s and γ are obtained by finding the maximum of the log-likelihood function defined in equation (7). The ML estimators are consistent and asymptotically efficient (Coelli, Rao, and Battese). The parameters of the stochastic frontier model may be estimated by software such as FRONTIER Version 4.1 (Coelli, 1996). This program uses a three-step procedure to obtain the maximum likelihood estimates[16]:

1. Ordinary Least Squares (OLS) is used to estimate all β-parameters and σ_S^2. These parameters are unbiased with the exception of the intercept, β_0 ;
2. Grid search is used to estimate γ, where the likelihood function is evaluated for a number of values of γ between zero and one, with the β parameters obtained from the first step, and adjusting for the intercept β_o and σ_S^2 using corrected ordinary least square formula.
3. Use the best estimate from the second step as starting values in an iterative procedure, to obtain the maximum likelihood estimates.

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[16] FRONTIER 4.1 can be downloaded from the internet by accessing the address for the Center for Efficiency and Productivity Analysis at the University of New England, Armidale, NSW, Australia: http://www.une.edu.au/econometrics/cepa.htm.

Mean Technical Efficiency:

Assuming that the non-negative random variable associated with technical inefficiency in production, u_i' s, are independently and identically distributed half-normal random variables, and the mathematical expectation of the technical efficiency, $TE_i = \exp(-u_i)$, then

$$E[\exp(-u_i)] = 2[1 - \Phi(\sigma_S \sqrt{\gamma})] \exp(-\gamma\sigma_S^2 / 2) \tag{8}$$

By substituting the maximum likelihood estimators for the relevant parameters in equation (8) the mean technical efficiency can be determined (Coelli, Rao, and Battese).

Testing Distributional Assumption:

A common criticism of the stochastic frontier model is the distributional assumption (Schmidt). If the distributional assumptions are incorrect, then the maximum likelihood estimates are incorrect (Carter and Cubbage). The null hypothesis for the frontier model which is defined by equation (7) is that there are no technical inefficiency effects in the model, H_o: $\sigma^2 = 0$ and H_a: $\sigma^2 > 0$, where, σ^2 is the variance of the normal distribution that is truncated at zero to obtain the distribution of u_i. To test the above hypothesis, the Wald statistic involves the ratio of the maximum likelihood estimator for σ^2 to its estimated standard error (Aigner, Lovell, and Schmidt). Coelli, Rao, and Battese use the equivalent set of hypotheses such as H_0 : $\gamma=0$ versus H_a: $\gamma>0$, using the Wald test, which is asymptotically distributed as a standard normal random variable. The test is a one-sided test because γ cannot be negative. The one-sided generalized likelihood-ratio test is used when ML estimation is involved because it has the correct size, where the critical value for a test of size α is given by $\chi^2_{1,(2\alpha)}$ (Coelli, 1995).

(9)
$$LR = -2\ln\left[\frac{L(H_0)}{L(H_a)}\right]$$

where $L(H_0)$ is the value of the likelihood function for the frontier model, in which the parameter restrictions are specified by the null hypothesis; and $L(H_a)$ is the value of the likelihood function for the general frontier model. If the null hypothesis is true, then γ has approximately chi-square (or mixed chi-square) distribution $\frac{\chi_0^2}{2}+\frac{\chi_a^2}{2}$ with degrees of freedom equal to the difference between the parameters estimated under H_0 and H_a, respectively[17] (Ajibefun, Battese and Kada).

Model Formulation

The model proposed for the analysis of broiler production, involving a stochastic frontier production function is presented in terms of a Cobb-Douglas production function as follows:

(10)
$$\ln(Y_i) = \beta_0 + \beta_1 \ln(X_{1i}) + \beta_2 \ln(X_{2i}) + \beta_3 \ln(X_{3i}) + \beta_4 \ln(X_{4i}) + V_i - U_i$$

where the subscript, i, denotes the ith farm in the sample, i=1,2, …, n, where n is the number of farms. (Y_i) represents a weighted output of live broilers produced (in kilograms) per period; (X_{1i}) represent the total quantity of chicks (in kilograms) per period; (X_{2i}) represents the total quantity of feed (in kilograms) per period; (X_{3i}) represent the total of all variable expenses, except chicks and feed (in Saudi Riyals); (X_{4i}) represent the capital investment inputs including buildings, equipment and

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[17] Since the sample size is not very large, the distribution of the test statistics are likely to be poorly approximated using asymptotic theory ((Ajibefun, Battese and Kada).

machinery used for the broiler houses (in Saudi Riyals); β's are unknown parameters for the production function.

The V_i's are random errors associated with measurement errors in the broiler production, or the combined effect of input variables not included in the production function (Battese). The V_i's are assumed to be identically and independently distributed N $(0,\sigma_v^2)$ random variables.

The U_i's are non-negative random variables, associated with technical inefficiency of production, assumed to be identically and independently distributed. The technical inefficiency effect for the *i*th farm, U_i , is obtained by truncation (at zero) of the normal distribution with mean, μ_i, and variance,σ^2, (Battese and Hassan). Such that

$$\mu_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} \tag{11}$$

where Z_{1i} denotes the age of farmers in years; Z_{2i} represents the experience in years; Z_{3i} represents the number of feeding days of raising chickens (per period); Z_{4i} denotes the size of the farmer's family (adults and children); and the δs are unknown parameters to be estimated.

Results and Analysis

All farms

The maximum likelihood (ML) estimates of the parameters in the Cobb-Douglas stochastic frontier production function equations (10) and (11) are estimated using the program, FONTIER 4.1, which estimates the variance parameters in terms of $\sigma_s^2 = \sigma^2 + \sigma_v^2$ and $\gamma = \sigma^2 / \sigma_s^2$. The maximum likelihood (ML) estimates of the parameters in the

Cobb-Douglas stochastic frontier production function are presented in Table 6. The signs of the slope coefficients of the stochastic frontier production function are positive except for the coefficient for capital investment. The sign for the capital investment is negative but not significantly different from zero. These estimated coefficients are not highly significant, except the quantities of chicks used. The empirical results in Table 6 indicate that the elasticity of broiler production with respect to chicks was estimated to be 0.86. This indicates that, if the chicks quantities increased by one percent, then the total production would increase by 0.86 percent. Moreover, the elasticity of feed and other variable cost are positive values, 0.047 and 0.033, respectively. Thus, if the quantities of feed and other variables costs increase by one percent, then total production would be expected to increase by 0.047% and 0.033% respectively.

The log-likelihood for the full stochastic frontier model is calculated to be 7.7585 and the value for the OLS fit of the production function is calculated to be 5.8046 which is less than that for the full frontier model. This implies that the generalized likelihood-ratio statistic for testing for the absence of the technical inefficiency effects from the frontier is calculated to be (Coelli, Rao, and Battese) LR=-2{5.8046-7.7585}=3.9078 which is insignificant since it does not exceed the critical value. By this measure the null hypothesis of no technical inefficiency effects in broiler production in Saudi Arabia is accepted.

If significant, the negative elasticity estimate for capital investment would imply that there would be a reduction in broiler production as spending on the capital investment increased. This would suggest that the farmer tended to spend too much on this factor.

The estimate of the γ parameter associated with the variance in the stochastic frontier was 0.881625 and statistically significant for an alpha level of 5%. This indicates that the stochastic frontier model may be significantly different from the deterministic frontier.

The maximum likelihood estimates for the coefficients of the inefficiency model are presented in Table 6. The estimated coefficient for age of the farmers is negative that not significant. The coefficients for experience and days of feeding are positive. This indicates that farmers with more experience tended to be less technically efficient and the farmers who are using more feed during the period of production are less technically efficient than the farmers who use less feed. The coefficient of family size in the inefficiency model is negative which indicates that larger families operate more technically efficient farms.

Table 7 presents a summary of technical efficiency indexes calculated from the estimated production frontiers. These values range from 0.53 to 0.96, with mean technical efficiency estimated to be 0.89. This implies that the broiler farms in the Central Region of Saudi Arabia are producing chicken to about 89 percent of the potential frontier production levels, implying that the production is about 11% below the frontier. This also means that a significant proportion of broiler production is lost due to technical inefficiency. The variation in the level of technical efficiency may be a result of farm specific characteristics such as the nature of technology and the farmer's management skills in attaining higher levels of productive efficiency (Ben-Belhassen). Given the levels of their inputs and the technology currently being used, 35% of the sample farms had technical efficiencies less than 90%. About 20% of the farms had technical efficiencies between 80-90%, and 65% of the sample had technical efficiency more than 90% but less than 96% (Figure 4).

Small Farms

The small farm category consists of farms that produce less than three hundred thousand kilograms per period. The maximum likelihood (ML) estimates of the parameters of the Cobb-Douglas stochastic frontier model are presented in Table 8. The results of the OLS average production function are also included in the Table.

These estimated coefficients are not highly significant, except the quantities of chicks used. The empirical results in Table 8 indicate that the elasticity of frontier production with respect to chicks was estimated to be 0.86. This indicates that, if the chicks quantities increased by one percent, then the total production of broilers would increase by 0.86 percent. The elasticity of feed, and other variable cost inputs are not different from zero. If significant, a negative elasticity estimate implies that there will be a reduction in broiler production as spending on feed and other variables increased, which indicates that the farmer tended to spend too much on these variables.

The log-likelihood for the full stochastic frontier model is calculated to be 15.0368 and the value for the OLS fit of the production function is calculated to be 7.3350 which is less than that for the full frontier model. This implies that the generalized likelihood-ratio statistic for testing for the absence of the technical inefficiency effects from the frontier is calculated to be (Coelli, Rao, and Battese) LR=-2{15.0368-7.3350}=15.4036 which is significant since it exceed the critical value. This test indicates that the null hypothesis of no technical inefficiency effects in broiler production in Saudi Arabia is rejected.

The estimate of the γ parameter associated with the variance in the stochastic frontier was 0.9999 and statistically significant for an alpha level of 5%, and estimated standard error of 0.00024. However, since γ is not significantly different from one, this indicates that the stochastic frontier model may not be significantly different from the deterministic frontier, in which there are no random errors in the production function.

The maximum likelihood estimates for the coefficients of the inefficiency model are presented in Table 8. The estimated coefficient for age of the farmers is negative which indicates that older farmers are more technically efficient in broiler production than younger farmers. The coefficients for experience and days of feeding are positive. This indicates that farmers with more experience and more feeding days, tended to be less technically efficient than the farmers who had less experience and used less feed during the period of production. The coefficient of family size in the inefficiency model is negative which indicates that larger families operated more efficient broiler farms.

Table 7 presents a summary of technical efficiency indexes calculated from the estimated production frontier. These values range from 0.45 to 0.99, with mean technical efficiency estimated to be 0.83. This implies that the SMALL broiler farms in the Central Region of Saudi Arabia are producing chicken to about 83% of the potential frontier production levels, given the levels of their inputs and the technology currently being used. Fifty-six percent of the small sample farms had technical efficiencies greater than 90%. About 36% percent of the farms had technical efficiencies less than 80% (Figure 5).

Large Farms

Farms that produce more than three hundred thousand birds per period were classified as large. The maximum likelihood (ML) estimates of the parameters are presented in Table 9. The signs of the slope coefficients of the stochastic frontier production function are positive as expected, except for the quantities of chick used and the capital investment. The capital investment is negative, implying the law of diminishing returns in broiler production. The estimated coefficients are significant except for the quantities of chick's variable.

The empirical results in Table 9 indicate that the elasticity of frontier production with respect to chicks was estimated to be -0.163 this indicates that, if the chicks quantities decreased by one percent, then the total production of broiler for this sized farms would increase by 0.163 percent. Moreover, the elasticity of feed and other variable cost are positive values, 0.658 and 0.260, respectively. Thus, if the quantities of feed and other variables costs increase by one percent, then 0.658 and 0.260 would increase the total production of broilers respectively.

The negative elasticity estimate for capital investment implies that there will be a reduction in broiler production as spending on the capital investment inputs increased, which indicates that the farmer tended to spend too much on this variable.

The log-likelihood for the full stochastic frontier model is calculated to be 15.5268 and the value for the OLS fit of the production function is calculated to be 5.7361 which is less than that for the full frontier model. This implies that the generalized likelihood-ratio statistic for testing for the absence of the technical inefficiency effects from the frontier is calculated to be (Coelli, Rao, and Battese) LR=-

2{15.5268-5.7361}=19.5814 which is significant since it exceeds the critical value. The null hypothesis of no technical inefficiency effects in broiler production in Saudi Arabia is rejected.

The estimate of the γ parameter associated with the variance in the stochastic frontier was 0.02692 and statistically significant for an alpha level of 5%. Since γ is significantly different from one, the stochastic frontier model may be significantly different from the deterministic frontier.

The maximum likelihood estimates for the coefficients of the inefficiency model are presented in Table 9. The estimated coefficient for age of the farmers is negative which indicates that older farmers are more technically efficient in broiler production than younger farmers. The coefficients for experience and days of feeding are positive, indicating that farmers with more experience tended to be less technically efficient and the farmers who are using more feed during the period of production are less technically efficient than the farmers who has less experience and use less feed. The coefficient for the family size variable is negative. This indicates that larger families are more technically efficient in broiler production.

Table 7 presents a summary of technical efficiency indexes calculated from the estimated production frontiers. These values range from 0.57 to 0.99, with mean technical efficiency estimated to be 0.82. This implies that the broiler farms in the Central Region of Saudi Arabia are producing chicken to about 82 percent of the potential frontier production levels, implying that the production is about 18% below the frontier. Given the levels of their inputs and the technology currently being used. Sixty percent of the large sample farms had technical efficiencies less than 90%. Forty-seven percent of the large sample farms had technical efficiency less than 80%. About 40% of the farms had technical efficiencies between 90-100% (Figure 6).

Conclusions

The purpose of this study was to contribute to the evaluation of the performance of the broiler industry in Saudi Arabia, and to determine the difference in mean technical efficiency across small and large farms. This study generated estimates of stochastic frontier production functions for broiler farms in the Central Region of Saudi Arabia. Technical efficiency estimates were generated for twenty-five small sized farms and fifteen large sized farms.

According to the technical efficiency studies, the results show relatively substantial technical inefficiency on broiler farms in the central region of Saudi Arabia. The mean technical efficiency was estimated to be 89 percent, 83 percent, and 82 percent for all, small and large farms, respectively. While the technical efficiency level was found to be higher among the large sized farms, this may be attributed in part to differences in sample size.

While, in general the results suggest relatively inefficient production, a few farms with problems were identified. Technical efficiency on fourteen of the forty farms was determined to be less than 90 percent. Fourteen of the small sized farms had a technical efficiency of less than 90 percent. However, nine of the fifteen large farms were found to have a technical efficiency of less than 90 percent. These results suggest that efforts to improve efficiency could be concentrated on assisting those farms identified with low levels of technical efficiency.

Another interesting finding is the negative sign on the capital investment coefficient. This suggests that the Saudi Agricultural Bank should carefully review lending policies for capital investment in broiler production.

The results reveal substantial production inefficiencies for sample broiler farmers in the central region of Saudi Arabia and hence considerable potential for enhancing profitability by reducing the production costs by improving the efficiency. Analysis of various farms shows that farm size has positive and significant effects on technical efficiency levels, so that if the farms operate at full capacity the farmers could reduce their production cost per unit of output.

Also the results suggest that there is opportunity to improve the efficiency of broiler production in the region. It may be appropriate to implement training programs for the managers of broiler farms with a goal of improving efficiency. Additional research will be necessary to determine the comprehensive consequences of the policy of subsidizing broiler production.

TABLE 1

BROILER PRODUCTION IN SAUDI ARABIA, 1983-2000

Year	Production (1,000 tons)
1983	124
1984	143
1985	177
1986	240
1987	246
1988	266
1989	267
1990	270
1991	270
1992	288
1993	324
1994	362
1995	390
1996	397
1997	417
1998	438
1999	460
2000	388

Source: Ministry Of Agriculture and Water. Broiler industry in Saudi Arabia, Department of Economic Studies and Statistics, 1998 KSA.

U.S. Department of Agriculture, Saudi Arabia Broiler and Products Annual 2000. Foreign Agricultural Service, September 13, 2000. GAIN Report. No. SA0013.

TABLE 2

PRODUCTION OF BROILER BY SPECIALIZED FARMS BY REGION IN THE KINGDOM 1998

Region	Production (1,000 birds)	Number of Farms
Eastern	27,924	73
Riyadh	69,335	71
Qaseem	171,698	22
Hail	12,862	3
Tabuk	4,474	8
Medinah	11,580	19
Makkah	103,654	25
Aseer	35,085	48
Al-baha	4,609	6
Jazan	3,435	3
Najran	4,226	8
Al-jouf	1,558	10
N.frontier	707	1
Total	451,147	297

Source: Ministry Of Agriculture and Water. Broiler industry in Saudi Arabia. Department of Economic Studies and Statistics, 1998 KSA.

TABLE 3

LOCAL PRODUCTION PRICE COMPARED TO PRICE OF IMPORTED BROILERS

Source	900 grams	1000 grams	1100 grams	1200 grams	1300 grams	1400 grams
Local	$1.95	$2.11	$2.29	$2.53	$2.80	$2.96
Brazilian	$1.52	$1.60	$1.84	$2.00	$2.16	$2.32
French	$1.36	$1.47	$1.60	$1.76	$1.89	$2.03

Source: U.S. Department of Agriculture, Saudi Arabia Poultry and Products Annual 2000. Foreign Agricultural Service, September 13, 2000. GAIN Report. No. SA0013.

TABLE 4

THE ECONOMICS OF BROILER PRODUCTION (AVERAGE PRICES IN $/ KG OF LIVE BIRD PRODUCED.)

Year	1981	1982[18]	1983[19]	1984[20]	1985[21]	1986[22]	1987	1988	1989	1990
Baby Chick	0.401	0.404	0.394	0.383	0.362	0.341	0.339	0.341	0.344	0.347
Feed	1.048	0.875	0.789	0.710	0.587	0.480	0.587	0.854	0.785	0.785
Rent	0.146	0.146	0.143	0.139	0.137	0.133	0.133	0.133	0.133	0.133
Labor	0.076	0.079	0.077	0.072	0.068	0.066	0.064	0.066	0.066	0.066
Medicine	0.032	0.032	0.031	0.030	0.027	0.026	0.026	0.026	0.026	0.026
Farm Running	0.093	0.093	0.091	0.089	0.085	0.080	0.077	0.080	0.080	0.080
Adjust for Mortality	0.178	0.163	0.151	0.142	0.126	0.112	0.122	0.149	0.144	0.144
Catch & Transportation.	0.046	0.046	0.045	0.044	0.041	0.040	0.040	0.040	0.040	0.040
Process & Packing	0.199	0.202	0.197	0.190	0.181	0.170	0.170	0.170	0.173	0.173
Marketing, tranpt & distr'	0.076	0.079	0.077	0.072	0.068	0.066	0.064	0.066	0.066	0.066
Subsidy w.r.t.1988	0.442	0.538	0.560	0.581	0.631	0.664	0.662	0.00	0.00	0.00
Total	1.853	1.575	1.439	1.292	1.056	0.851	1.497	1.927	1.858	1.863
Profit	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Selling price	2.038	1.732	1.583	1.421	1.161	0.936	1.647	2.120	2.044	2.050
French Retail Price	2.398	2.049	1.688	1.569	1.813	1.895	1.981	1.869	1.869	1.869
Saudi Fresh Retail Price	---	---	---	2.027	2.167	2.109	2.066	2.136	2.082	2.029
Feed Price 1000's SR/Ton	143.19	119.47	108.15	97.06	80.10	65.68	80.10	107.34	138.31	

Source: Riyadh Chamber of Commerce & Industry, Study about the Broiler Exporting Practices of France and Brazil to Saudi Arabia. Riyadh. Saudi Arabia. 1990

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[18] $1=3.415
[19] $1=3.495
[20] $1=3.575
[21] $1=3.645
[22] Since (1986 –2001) $1=3.745

TABLE 5

VARIABLES AND AVERAGE VALUES FOR THE DATA OF SAUDI ARABIAN BROILER FARMS

Variable	Units	Mean	S.D	Low	High
Output	Kilograms				
All		252,620	187,400	27,758v	966,821
Small		142,140	62,517	27,758	300,000
Large		436,750	181,690	300,631	966,821
Chicks	Kilograms				
All		7,827.5	6,839.3	820	37,678
Small		4,227.1	2,323.9	820	10.755
Large		13,828	7,701.9	6,720	37,678
Feed	Kilograms				
All		629,840	582,560	68,333	3,412,833
Small		333,160	185,470	68,333	840,000
Large		1,124,300	683,610	450,000	3,412,833
OVC	Saudi Riyal				
All		111,450	149,110	16,000	870,344
Small		55,441	58,097	16,000	314,800
Large		204,800	203,010	44,000	870,344
Capital inputs		Saudi Riyal			
All		4,635,400	6,912,900	332,000	43,040,180
Small		2,422,400	997,330	332,000	4,900,000
Large		8,323,800	1,039,700	900,000	43,040,180

Source: Research sample data

TABLE 6

ORDINARY LEAST SQUARES (OLS) ESTIMATE OF THE AVERAGE PRODUCTION FUNCTION AND MAXIMUM LIKELIHOOD (ML) ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION FOR ALL SIZED BROILER FARMS IN CENTRAL SAUDI ARABIA

Variable	OLS estimate		ML estimate	
	Coefficient	Std-error	Coefficient	Std-error
Production Function				
Intercept	4.4675**	(0.7831)	4.9616**	(0.7395)
ln (Chicks)	0.8670**	(0.1307)	0.7783**	(0.1264)
ln (feed)	0.0474	(0.1288)	0.1012	(0.1148)
ln (otherV.C.)	0.0331	(0.0783)	0.0487	(0.0723)
ln (capital)	-0.052	(0.0656)	-0.084	(0.0613)
Inefficiency Model				
Intercept			1.4495	(4.3167)
ln (Age)			-4.516	(8.7343)
ln (Experience)			4.8867	(8.7396)
ln (Family size)			-2.506	(4.6588)
ln (Feeding days)			1.3248	(2.6730)
Variance Parameters				
σ^2	0.0500		0.2257	(0.3349)
γ			0.8816**	(0.1791)
Log-likelihood		5.8046		7.7585
LR Test (one-side Error)				3.9078
Mean Efficiency				0.89

Source: Research sample data

(**) Denote t-statistic significance level of 5%.

(***) Denote t-statistic significance level of 10%.

TABLE 7

TECHNICAL EFFICIENCY MEASURE OBTAINED USING THE COBB-DOUGLAS STOCHASTIC FRONTIER PRODUCTION FUNCTIONS MODELS FOR ALL, SMALL, AND LARGE SIZE BROILER FARMS

	Technical Efficiency		
Farm Number	All Farms	Small Farms	Large Farms
1	0.80	0.54	
2	0.89	0.79	
3	0.88	0.83	
4	0.93	0.93	
5	0.94	0.93	
6	0.94	0.90	
7	0.79	0.68	
8	0.93	0.75	
9	0.90	0.93	
10	0.92	0.98	
11	0.86	0.73	
12	0.93	0.92	
13	0.92	0.79	
14	0.84	0.75	
15	0.90	0.92	
16	0.93	0.89	
17	0.93	0.99	
18	0.88	0.87	
19	0.91	0.87	
20	0.92	0.97	
21	0.86	0.92	
22	0.53	0.45	
23	0.69	0.58	
24	0.93	0.96	
25	0.88	0.81	
26	0.93		0.77
27	0.91		0.91
28	0.91		0.78
29	0.94		0.94
30	0.93		0.87
31	0.80		0.67
32	0.96		0.90
33	0.94		0.90
34	0.92		0.87
35	0.91		0.57
36	0.88		0.77
37	0.74		0.67
38	0.95		0.69
39	0.96		0.98
40	0.94		0.99
Mean	**0.89**	**0.83**	**0.82**

Source: Research sample data

TABLE 8

ORDINARY LEAST SQUARES (OLS) ESTIMATE OF THE AVERAGE PRODUCTION FUNCTION AND MAXIMUM LIKELIHOOD (ML) ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION FOR SMALL SIZED BROILER FARMS IN CENTRAL SAUDI ARABIA

Variable	OLS estimate		ML estimate	
	Coefficient	Std-error	Coefficient	Std-error
Production Function				
Intercept	4.4625**	(1.3088)	5.9664**	(0.6372)
ln (Chicks)	0.9511**	(0.1575)	0.8676**	(0.0890)
ln (feed)	-0.097	(0.1345)	-0.038	(0.0516)
ln (other V.C.)	-0.058	(0.0924)	-0.070***	(0.0562)
ln (capital)	0.0907	(0.1341)	0.0067	(0.0388)
Inefficiency Model				
Intercept			-0.048	(0.9829)
ln (Age)			-0.655	(0.7496)
ln (Experience)			0.9416	(0.8164)
ln (Family size)			-0.598	(0.7378)
ln (Feeding days)			0.2803***	(0.2685)
Variance Parameters				
σ^2	0.04069		0.0870**	(0.0257)
γ			0.9999**	(0.0003)
Log-likelihood		7.3350		15.0368
LR Test (one-side Error)				15.4036
Mean Efficiency				0.83

Source: Research sample data
(**) Denote t-statistic significance level of 5%.
(***) Denote t-statistic significance level of 10%.

TABLE 9

ORDINARY LEAST SQUARES (OLS) ESTIMATE OF THE AVERAGE PRODUCTION FUNCTION AND MAXIMUM LIKELIHOOD (ML) ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION FOR LARGE SIZED BROILER FARMS IN CENTRAL SAUDI ARABIA

Variable	OLS estimate		ML estimate	
	Coefficient	Std-error	Coefficient	Std-error
Production Function				
Intercept	5.2137**	(2.0687)	4.8710**	(0.8326)
ln (Chicks)	0.2030	(0.2461)	-0.163***	(0.1361)
ln (feed)	0.3550	(0.2962)	0.6582**	(0.0879)
ln (other V.C.)	0.2101***	(0.1214)	0.2603**	(0.0572)
ln (capital)	-0.105	(0.0885)	-0.156**	(0.0398)
Inefficiency Model				
Intercept			-2.960**	(2.2527)
ln (Age)			-1.449**	(0.2923)
ln (Experience)			2.4040**	(0.5945)
ln (Family size)			-0.322**	(0.0908)
ln (Feeding days)			0.2842**	(0.0562)
Variance Parameters				
σ^2	0.0408		0.0096**	(0.0015)
γ			0.0269	
(0.0419)				
Log-likelihood		5.7361		15.5268
LR Test (one-side Error)				19.5815
Mean Efficiency				0.82

Source: Research sample data

(**) Denote t-statistic significance level of 5%.

(***) Denote t-statistic significance level of 10%.

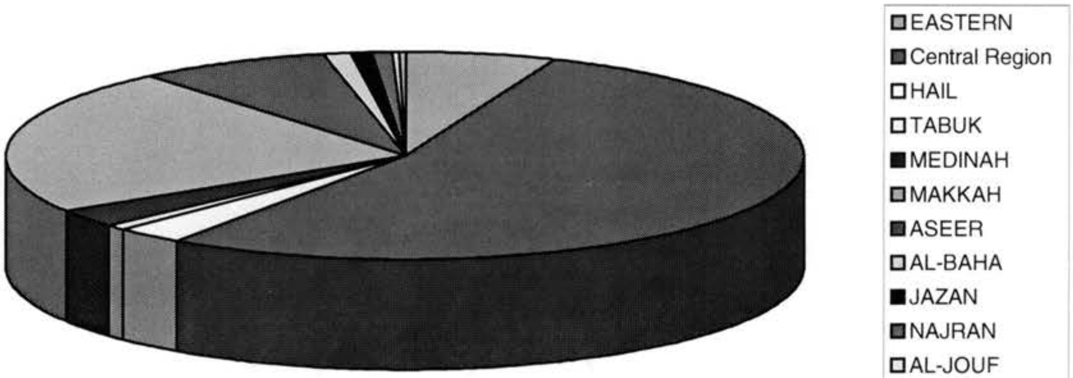

Figure1. Production of broiler by specialized farms by region in Saudi Arabia

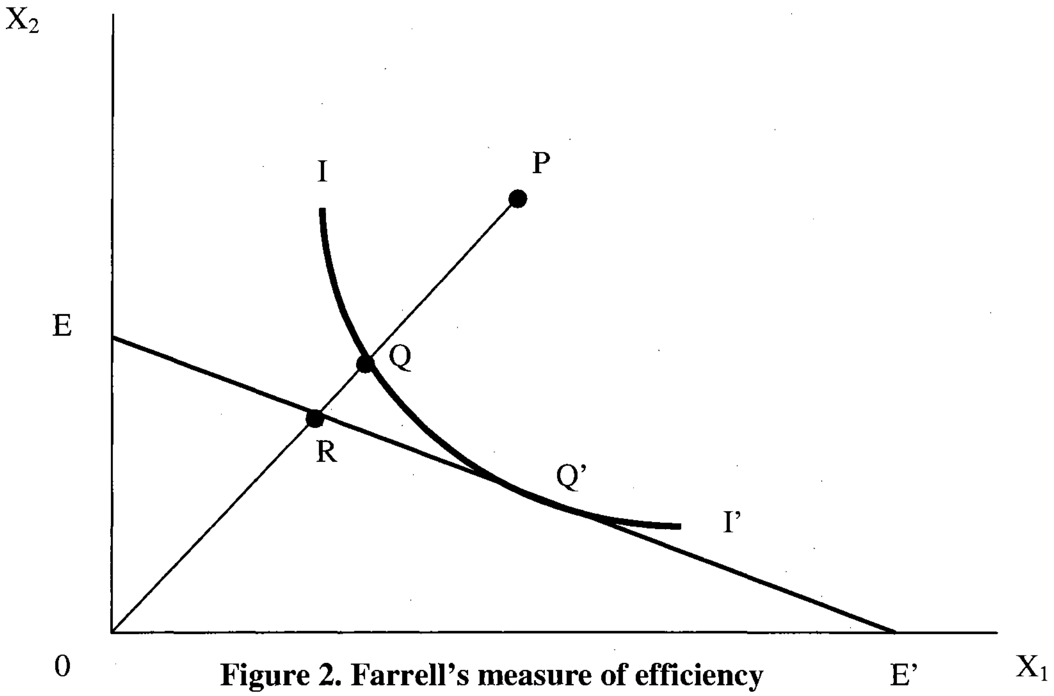

Figure 2. Farrell's measure of efficiency

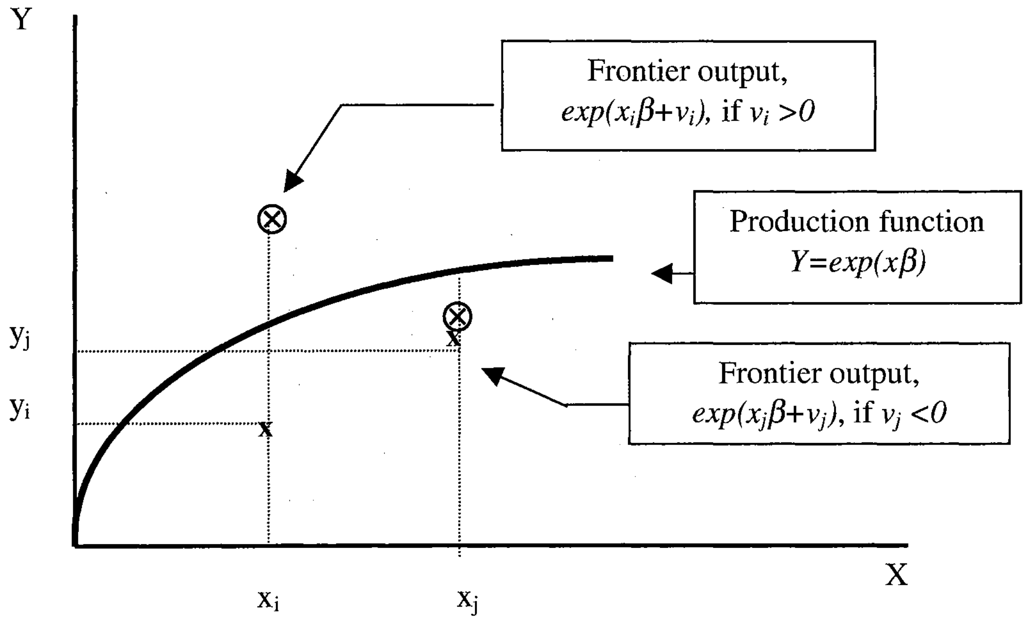

Figure 3. The Stochastic frontier production function

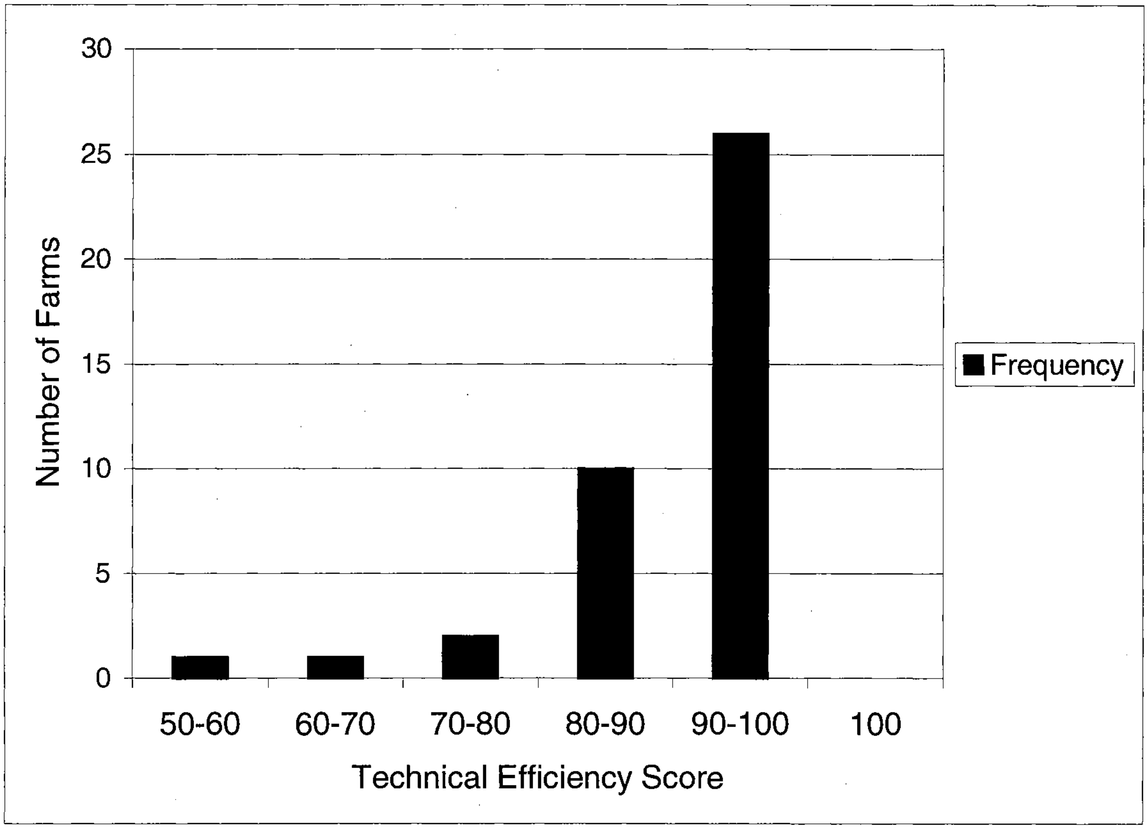

Figure 4. Frequency distribution of technical efficiency score of broiler farms in the central region of Saudi Arabia

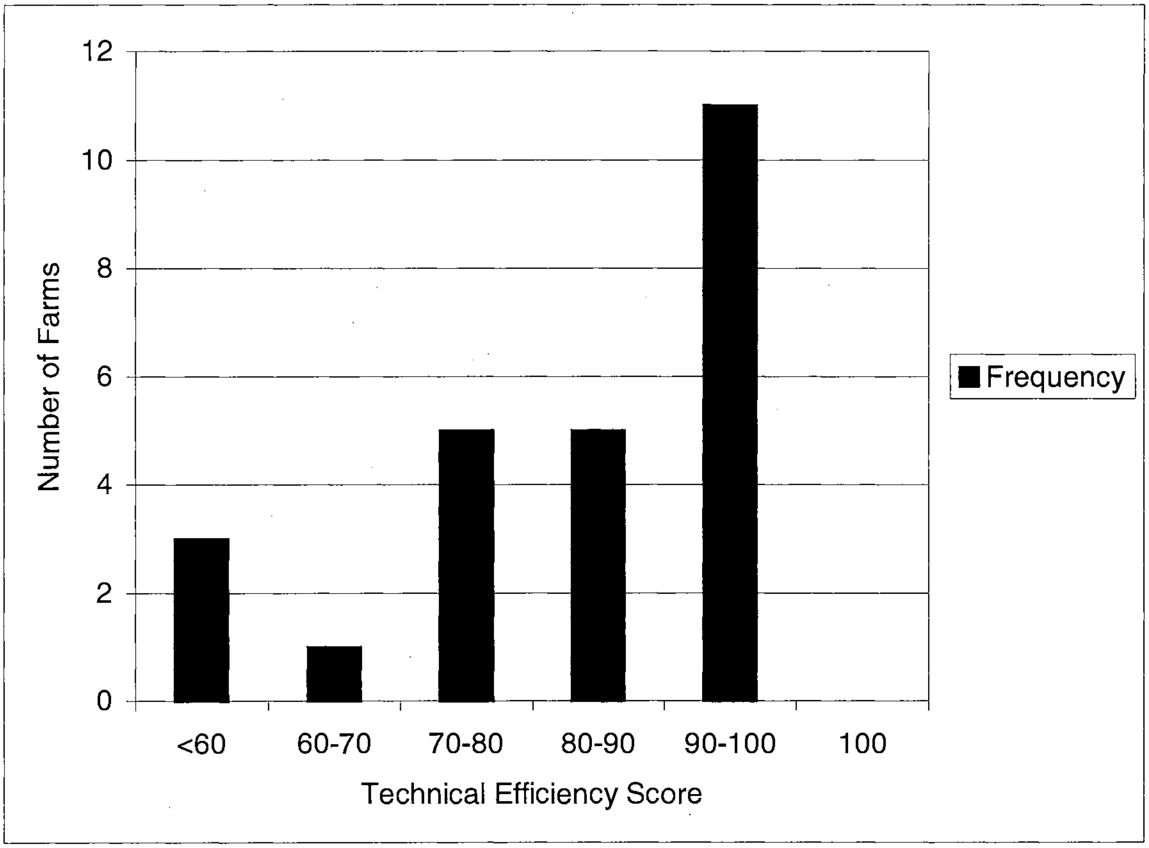

Figure 5. Frequency distribution of technical efficiency of small broiler farms in the central region of Saudi Arabia.

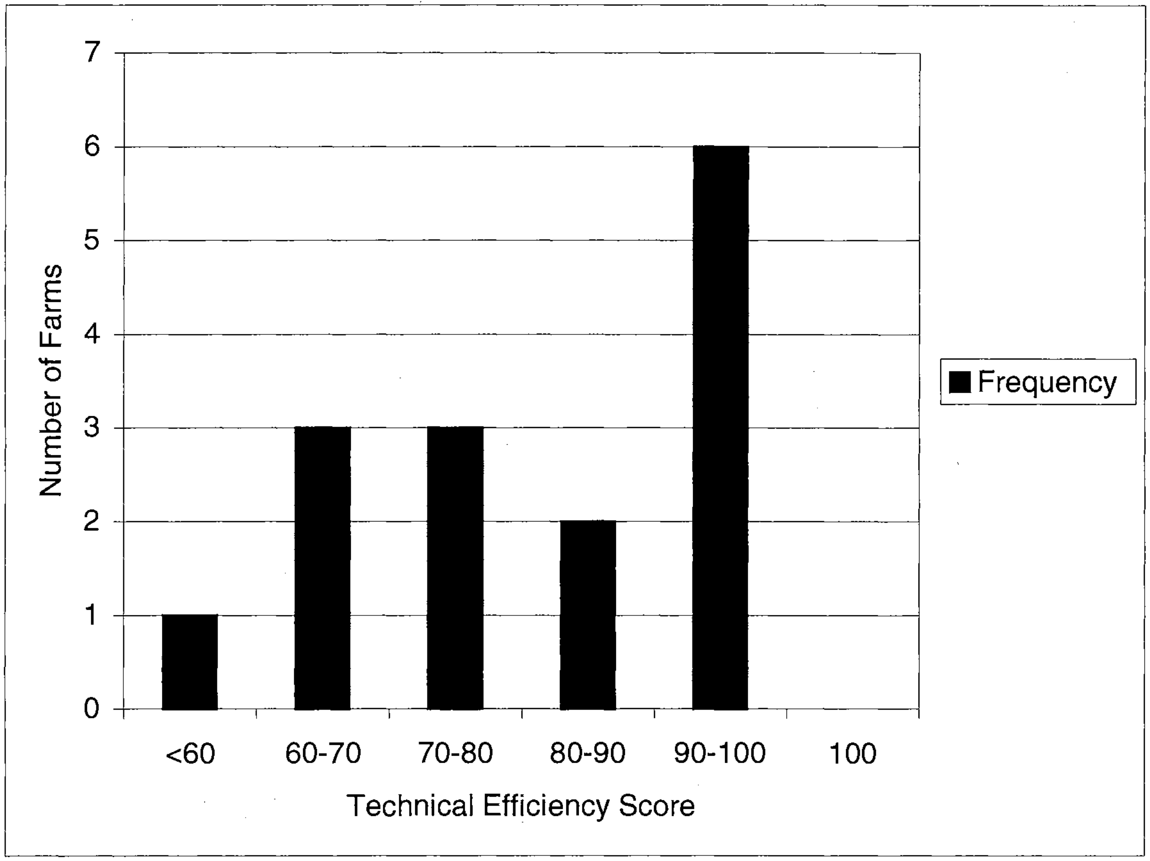

Figure 6. Frequency distributions of technical efficiency of large broiler farms in the central region of Saudi Arabia

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