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Full Length Research Paper

Technical efficiency of organic fertilizer in small farms of Nicaragua: 1998-2005

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This article applies frontier production function analysis to small farms in Nicaragua during 1998-2005 (Battese and Coelli, 1988). The objective of this study is to estimate an average function that will provide a picture for the shape of the organic fertilizer technology of an average firm (in our case, agricultural production units). Furthermore, a best-practice scenario for organic fertilizer against which the efficiency of the firms within the primary sector can be measured is presented (Coelli, 1995). The results show an acceptable average of technical efficiency which the makers of public policy in Nicaragua a must consider for the future. This is imperative if we consider economy activity indexes that have increased during this period.

Key words: Technical efficiency, LSMS, organic fertilizer, small farm, panel data.

INTRODUCTION

As a developing country, Nicaragua has many technologies for small farm production systems which have been provided by developed countries. We can see many technologies from traditional to conventional agriculture. So many traditional agricultural policies have encouraged small farmers to lower costs and/or raise income (Alvarez, 2003). Since the beginning of the revolutionary process in Nicaragua, academics and policy makers have been interested in the relative efficiency of small farms in Latin America, Central and Eastern Europe; for instance, Gorton and Davidova (2004) and Battese and Coelli (1995). Thus, it is important to clarify the definitions of terms efficiency and productivity. These words are often used interchangeably; however, they are not precisely the same thing. The first defines the current state of technology on a small farm. The second can be achieved in two ways. One can either improve the state of the technology by inventing new ploughs, pesticides, rotations plan, etc. This is commonly referred to as technological change and can be represented by an upward shift in the production frontier. Alternatively one can implement procedures, such as improved small farmer education, in order to ensure that farmers use the existing technology more efficiently (Coelli, 1995). Here, the focal point will be the first term.

Usually, some people use partial measures of efficiency on a small farm; for example litres of milk per cattle, kilogram of meat per head, yield per hectare and others. It has serious problems because they only consider either the land input or head of cattle and ignore all other input, such as labour, machinery, fuel, fertilizer, pesticide, capital, technology, education and others (Coelli, 1995a). Frequently, the public policy makers use this measure in formulating policy. As a result the efficiency measure is not included.

TECHNICAL EFFICIENCY: A REVIEW OF THE LITERATURE

All authors are in agreement that the recent historical literature for efficiency measurement (Annex Table 3) begins with Farrell (1957). He drew upon the work of Debreu (1951) and Koopmans (1951). It is an approach that considers a firm technically *efficient* if it obtains the maximum attainable output given the amount of inputs and the technology used and *allocative efficiency*, which reflects the ability of a firm to use the inputs in optimal proportions based on their respective prices. These two measurements are then combined in order to provide a measurement of total economic efficiency.

The successive authors following Farrell adjusted and extended his work. Aigner and Chu (1968) measured the estimation of a parametric frontier production function in input/output space. They specified a Cobb-Douglas production function (in log form) for a sample of N firms as:

$$\ln(y_i) = F(x_i;\beta) - \mu_i \qquad , \qquad i = 1,2,\ldots,N \qquad (1)$$

where y_i is the output of the $i-th$ firm; x_i is the vector of input quantities used by the $i-th$ firm; β is a vector of unknown parameters to be estimated; $F(,)$ denotes an appropriate function (in this instance the Cobb-Douglas); and μ_i is a non-negative variable representing inefficiency in production. The parameters of the model were estimated using linear programming, $where\ \sum_{i=1}^{n}\mu_i$ is minimized, subject to the constraints that $\mu_i >= 0,\ i = 1,2,\ldots.N.$

The ratio of observed output of the $i-th$ firm, relative to the potential output defined by the estimated frontier, given the input vector x_i, was suggested as an estimate of the technical efficiency of the $i-th$ firm:

$$TE_i = \frac{y_i}{\exp\left(F(x_i;\beta)\right)} = \exp(-\mu_i)$$

This is an output-oriented calculated as opposed to the input-oriented measure discussed above. It indicates the magnitude of the output of the $i-th$ relative to the output that could be formed by the fully-efficient firm using the same input vector. The output- and input-orientated procedures provide equivalent measures of technical efficiency when constant returns to scale exist, but are unequal when increasing or decreasing returns to scale are present (Fare and Lovell, 1978).

Afriat (1972) specified a model similar to Equation (1), with the exception that μ_i was assumed to have a gamma distribution and the parameters of the model were estimated using the maximum likelihood (ML) method. Richmond (1974) noted that the parameters of Afriat´s model could also be estimated using a method that has become known as corrected ordinary least squares (COLS), where the ordinary least squares (OLS) method provides unbiased estimates of the slope parameters, and the (downward biased) OLS estimator of the intercept parameter is adjusted up the sample moments of the error distribution, obtained from the OLS residuals. Schmidt (1976) added to the discussion on ML frontiers observing that the linear and quadratic programming estimators proposed by Aigner and Chu (1968) are ML estimators if μ_i was assumed to be distributed as exponential or half-normal random variables, respectively.

Timmer (1971) attempts to address one of the primary criticisms of deterministic frontier estimators by making an adjustment to the Aigner and Chu (1968) method which involves dropping a percentage of firms closest to the estimated frontier, and re-estimating the frontier using the reduced sample. The arbitrary nature of the selection of some percentage to be omitted means that Timer's probabilistic frontier approach has not been widely followed. An alternative approach to the solution of the ´noise´ problem has, however, been widely adopted. This method is the subject of the following section on stochastic frontiers.

Aigner et al. (1977) and Meeusen and van den Broeck (1977) independently proposed the estimation of a stochastic frontier production function, where noise is accounted for by adding a symmetric error (v_i) to the non-negative error in (1) to provide:

$$\ln(y_i) = F(x_i;\beta) + v_i - \mu_i \qquad ,i = 1,2,\ldots,N \qquad (3)$$

The parameters of this model are estimated by ML, given suitable distributional assumptions for the error terms. Aigner et al. (1977) assumed that v_i has normal distribution and μ_i has either the half-normal or the exponential distribution.

STOCHASTIC FRONTIER PRODUCTION FUNCTION MODEL

The specification of the model detailed in Battese and Coelli (1988, 1992, 1995) and Battese et al. (1989) with the program FRONTIER Version 4.1 Coelli (1996) is the method applied to obtain ML estimates. The Cobb-Douglas production function is estimating where all the input and output data before creating the data file for using the program are logged (Coelli, 1996). This model can be expressed in Equation (3); (Aigner et al., 1977; Meeusen and van den Broeck, 1977).

The program FRONTIER41 requires five files for his execution (Coelli, 1996): a) the executable file FRONTIER41.EXE, b) the start-up file FRONT41.000, c) A data file (in our case ee98-dta.txt, ee01-dta.txt, ee05-dta.txt), d) An instruction file (in our case ee98-ins.txt, ee01-ins.txt, ee05-ins.txt), e) An output file (in our case ee98-out.txt, ee01-out.txt, ee05-out.txt).

After typing ¨FRONT41¨ to begin the execution, the structure of the instruction file is listed as follows (e.g ee01-dta):

```
ee01-dta.txt    DATA FILE NAME
ee01-out.txt    OUTPUT FILE NAME
1               1=PRODUCTION FUNCTION, 2=COST FUNCTION
y               LOGGED DEPENDENT VARIABLE (Y/N)
22              NUMBER OF CROSS-SECTIONS
1               NUMBER OF TIME PERIODS
22              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
```

Table 1. Exchange rate, annual inflation and farm sample.

LSMS year	Exchange rate average (C$x US)	Annual Inflation (%)	Farm sample
1993	6.35	19.5	--------
1998	10.5821	18.5	42
2001	13.4438	4.7	22
2005	16.7333	9.58	48

Source: CBN and LSMS (1993, 1998, 2001, 2005).

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.

Thus, we estimate the Cobb-Douglas production frontier as follows:

$$\ln(Q_i) = \beta_0 + \beta_1 \ln(K_i) + \beta_2 ln(L_i) + (V_i - U_i), \quad (4)$$

Where, Q_i, K_i and L_i are output, input capital and labour, respectively, and V_i and U_i are assumed normal and half-normal distributed, respectively. The text files ee98-dta, ee01-dta, ee05-dta contain 42, 22 and 48 observations respectively on firm-id, time-period, Q, K and L, in that order (Table 1).

PANEL DATA

The survey of Living Standards Measurement Study LSMS of the National Institute of Information and Development (NIID) was used for this work (World Bank, 2006). NIID provided statistical information each five years beginning in 1993. Currently, we have the surveys of 1993, 1998, 2001 and 2005. The goals of NIID are to identify the real data and corresponding documentation needed by policy analysts and researchers as well as how best to collect such information accurately from households. Therefore, in this study it will be used as the panel data (Carletto, 2009), and so the output indicators for production function, the input indicators for capital and labour were provided.

SSPS is the program that processes the information in each year where each panel data was made with Q_i, L_i and K_i . Exchange rates, annual inflation and sample were considered as shown in Table 1. Q_i represents the output of the crop and livestock activities from each small farm expressed in dollars, K_i represents the total cost of organic fertilizer used by each small farm. It is expressed in dollars, and r L_i expresses the total labour of each of the small farm; all these factors are expressed in dollars. This panel data permit simultaneously investigates both technical change and technical efficiency change over time (Coelli, 1995b).

As soon as the information of panel data is processed then it is a translated excels program and text file earlier mentioned in Battese and Coelli (1995). The data are listed by observation. They are presented in the following order: Firm number (an integer in the range 1 to N; Table 1). Period number (an integer in the range 1 to T, in our case is always 1 because this cross-sectional data).

lnQ_{it}
lnL_{it}
lnK_{it}

Finally, the program FRONTIER 4.1 is used for estimating the production function model where the dependent variable is logged.

TECHNICAL EFFICIENCY ESTIMATES

The mean technical efficiency had a diversity trend. In 1998, the small farms that applied organic fertilizer obtained a mean TE of 0.32; in 2001 it reached 0.62; however, it reached 0.24 in 2005 (Annex Table 1). The Cod LSMS keep up a correspondence to ID of each small farm of the data base. Possible reasons for this behaviour are prices, unfavorable climatic conditions and limited financial access. AEMI during 1998 to 2005 increased to 112.7, 142.7 and 150.9 respectively for agricultural activity, and 110.1, 140.7 and 173.5 respectively for livestock activities. In addition, AFPI also increased to 169.0, 199.3 and 283.6 respectively in 1998, 2001 and 2005 (CBN, 2008). This is consistent with several other dairy studies including Moreira et al. (2009), Bravo-Ureta et al. (2010), Zuniga (2009) and Park and Lohr (2010). Using Equation (4), we can see that the elasticity of the frontier production function was 0.68 and -0.16 in 1998, -0.12 and 0.31 in 2001 and 0.33 and 0.14 in 2005 respectively (Annex Table 2). In small farms, the partial elasticity of the output (y) with respect to the cost of or-ganic fertilizer was of 0.68, -0.12 and 0.33 in 1998, 2001 and 2005 respectively. So the perceptual change in the agricultural activities (output) allocated them a variation of 1% in the input organic fertilizer kept on constant the input labour.

In addition, the partial elasticity of the output (y) with deference to the input labour was of -0.16, 0.31 and 0.14 in 1998, 2001 and 2005 respectively. So the labour measures perceptual change in the agricultural activities (output) which allocated them a variation of 1% keep on constant the cost of the organic fertilizer. The returns to scale were as follows: a) the small farms obtained (0.5161) decreasing returns to scale; when they duplicated the inputs, the agricultural activities will grow less than twice in 1998, b) the small farms obtained (0.1829) decreasing returns to scale; when they duplicated the inputs the agricultural activities will grow less of twice in (2001c) the small farms obtained (0.4856) decreasing returns to scale; when they duplicated the inputs the agricultural activities will grow less than twice in 2005.

CONCLUSION

In the period of the study, the small farms that have used organic fertilizer obtained decreasing returns to scale. The mean technical efficiency was not greater than 0.62. The elasticity of the agricultural production in respect to the organic fertilizer and labour was less than 1. The small farms have adequate efficiencies mean, although the public policy does not promote the use of organic fertilizer. The maker of public policy must consider this when they think about local development planning.

On the other hand, the possible causes of the phenomenon were the climate conditions, limited access to credit, and traditional technology when the mean technical efficiency was lower than 0.50. The use of chemical fertilizer is a problem for soil and water contamination; however, our small famers as yet are not convinced of it. Some small farmers use organic fertilizer although their profitability is low but they are convinced of their contribution to environment. It is an effort towards good agricultural practice that the makers of public policy must include in their inputs.

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ANNEX

Table 1. Technical efficiency estimate by year and firm (Agricultural Unit Production).

1998		2001		2005	
Cod LSLM	**Eff. Est**	**Cod LSLM**	**Eff. Est**	**Cod LSLM**	**Eff. Est**
44800	0.27587582E+00	727	0.58435054E+00	813	0.63195969E+00
53800	0.45539402E+00	780	0.76754498E+00	814	0.98470029E-01
60600	0.19669639E+00	782	0.35779096E+00	949	0.10890517E-01
60700	0.20861501E+00	813	0.73728061E+00	978	0.41034025E-01
164600	0.20010149E+00	1058	0.66503258E+00	1060	0.47103932E+00
225000	0.44527360E+00	1157	0.68710254E+00	1100	0.95126428E-01
225300	0.50003614E+00	1317	0.72234939E+00	1118	0.81505860E-01
226700	0.50149960E+00	1320	0.56242032E+00	1119	0.15630801E-01
228000	0.19927807E+00	1330	0.43083492E+00	1120	0.34570595E-01
286600	0.43322370E+00	1382	0.54758716E+00	1147	0.39064303E+00
363600	0.21364826E+00	1737	0.55396471E+00	1267	0.48209897E+00
368100	0.30248142E+00	2101	0.69421311E+00	1412	0.19760349E-01
372300	0.70110634E-01	2561	0.61684623E+00	1458	0.24196026E-01
372400	0.34234618E+00	3287	0.73788183E+00	1591	0.81829340E-01
398500	0.27880242E+00	3859	0.78276409E+00	1660	0.14657910E+00
403300	0.12467686E+00	4019	0.51529052E+00	1685	0.40003259E+00
439100	0.53788311E+00	4150	0.65310611E+00	1700	0.21585076E-01
439101	0.45616531E+00	4291	0.53159551E+00	1917	0.10252029E+00
440900	0.99196268E-01	4300	0.52916993E+00	2179	0.36184029E-01
441500	0.31534888E+00	4375	0.60923318E+00	2279	0.97145070E-01
442910	0.37622531E+00	4387	0.68057842E+00	2280	0.88683760E-02
445200	0.47326049E+00	4303	0.75129323E+00	2646	0.14576869E-01
443000	0.26644029E+00			2698	0.14423565E+00
443200	0.30042213E+00			2716	0.35164372E+00
443300	0.56203407E+00			2784	0.35882877E+00
445200	0.64185264E+00			2854	0.52697778E+00
446500	0.24235634E+00			2963	0.18201504E+00
446600	0.11863627E+00			3252	0.37735282E-02
448700	0.47546522E+00			3346	0.68892112E+00
449300	0.97912026E-01			3613	0.45522480E+00
449600	0.48400653E+00			4004	0.54992002E+00
450500	0.33116249E+00			4336	0.47457774E+00
451000	0.42074982E+00			6065	0.29962025E+00
451200	0.22234542E-01			6070	0.65374034E+00
451400	0.43103199E+00			6141	0.64634913E-01
451500	0.63157428E+00			6888	0.80658911E+00
451900	0.55066837E+00			7547	0.34759975E-01
457800	0.42461867E+00			7818	0.68869324E+00
461300	0.62471491E-01			7835	0.13023163E-01
461310	0.82274398E-01			7844	0.59027102E+00
463300	0.26793699E+00			8155	0.12631525E-01
596300	0.30377191E+00			8296; 8323	0.14355671E-01
				8329; 8460	0.76823809E+00
				8836; 8903	0.81632570E-01
				10215	0.51073839E-02
					0.81273970E-01
					0.40645877E+00
					0.44423522E-01
Mean efficiency	0.32675618E+00		0.62355595E+00		0.24182954E+00

The Cod LSMS keep up a correspondence to ID of each small farm of the data base.

Table 2. The final MLE estimates, LR test and log likelihood function by year.

Parameter/Years	Coefficient	Standard – error	t-ratio
1998			
Beta 0	0.51257171E+01	0.22646486E+01	0.22633610E+01
Beta 1	0.68177627E+00	0.27656399E+00	0.24651665E+01
Beta 2	-0.16564550E+00	0.10974495E+00	0.16123173E+01
Sigma-squared	0.60844150E+01	0.10351238E+01	0.46566710E+01
Gamma	0.70550210E+00	0.18676191E+00	0.15753986E+01
Mu is restricted to be zero			
Eta is restricted to be zero			
Log likelihood function = -0.75582499E+03			
LR test of the one-sided error = 0.29559405E+00			
2001			
Beta 0	0.66124564E+01	0.19184257E+01	0.34468139E+01
Beta 1	-0.12634720E+00	0.25247873E+00	-0.50042710E+00
Beta 2	0.30927510E+00	0.14484356E+00	0.21352354E+01
Sigma-squared	0.94582114E+00	0.12806942E+01	0.73852224E+00
Gamma	0.49469860E+00	0.13786277E+01	0.35883407E+00
Mu is restricted to be zero			
Eta is restricted to be zero			
Log likelihood function = -0.26406868E+02			
LR test of the one-sided error = 0.32918825E-01			
2005			
Beta 0	0.61366553E+01	0.70250379E+00	0.87354053E+01
Beta 1	0.33620030E+00	0.13128292E+00	0.25608838E+01
Beta 2	0.14294425E+00	0.11581727E+00	0.12342222E+01
Sigma-squared	0.85436689E+01	0.21549854E+01	0.39646065E+01
Gamma	0.97295128E+00	0.28514026E-01	0.34121849E+02
Mu is restricted to be zero			
Eta is restricted to be zero			
Log likelihood function = -0.92214279E+02			
LR test of the one-sided error = 0.20078413E+01			

Source: Panel data 1998 to 2005.

Table 3. Outline of efficiency measurement approach by authors.

Authors	Year	Approach
Debreu Koopmans	1951 1951	Simple measure of firm efficiency which could account for multiple inputs
Farrel	1957	Technical efficiency and price efficiency (allocative efficiency)= overall efficiency (economic efficiency)
Aigner and Chu	1968	Specified a Cobb-Douglas production function (in log form) for a sample of N firms
Fare and Lovell	1978	Output-orientated measure as opposed to the input-oriented before
Afriat	1972	Specified a model similar to Aigner, except by (μ_i) that was estimated by ML
Richmond	1974	Corrected ordinary least square (COLS)
Schmidt	1976	ML frontier
Timmer	1971	Re-estimating the frontier using the reduced sample
Aigner et al. and Meeusen and van den Broeck	1977	Estimation of a stochastic frontier production function

Table 3. Contd.

Aigner et al.	1977	Assumed that (v_i) had normal distribution and (μ_i) had either the half –normal or the exponential distribution
Stevenson	1980	Specification of more general distributional forms: truncated-normal
Greene	1990	Two-parameter gamma
Greene	1980_a	Particular class of distribution could be assumed for the (μ_i), which circumvent these regularity problem. The noise criticism, however, would still remain
Greene	1992	Software LIMDEP econometric package automate ML method
Coelli	1992-1994	FRONTIER PROGRAM automate ML method
Schmidt and Waldman	1980	Finite sample properties of the half-normal frontier model are investigated in Monte Carlos experiment in Olsen: sample sizes smaller than 400
Coelli	1992	Computer program for stochastic frontier Version 4.1
Coelli	1995_a	Recent developments in frontier modeling and efficiency measurement
Coelli	1995_b	The ML estimator should be used in preference to the COLS
O´Donnell et al.	2008	Metafrontier concepts introduced for analysis efficiency and productivity

Source: Author´s outline.