Do Farm Programs Explain Mean and Variance of Technical Efficiency? Stochastic Frontier Analysis

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Abstract

Past literature has examined the importance of farm programs on the volatility and returns on general and agriculture economic growth. The objective of this study was to assess the impact of farm program payments on technical efficiency. The study used aggregate state level panel data from the U.S agricultural sector. Results indicate production increasing with increasing units of inputs. Results from this study indicate that farm program payments play an important role in technical efficiency. For example, farm program payments indicate a negative and positive effect on mean and variance of technical efficiency in the long-run and short-run, respectively.

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1. Introduction

Among the first pieces of the New Deal legislation proposed by incoming President Franklin D. Roosevelt in 1933 was a farm program designed to address declines in farm prices and net farm income. The federal crop insurance program was initiated in 1938 to provide protection to farmers against crop loss due to natural disasters, including drought, excessive moisture and unusual weather. Since 1933, the design of federal agricultural policies, including farm programs and crop insurance programs, are amended or new programs are introduced with the authorization of a new farm bill. Although federal agricultural policies in the United States are rarely intended to alter the structure of agriculture, the effect of these policies and/or technology on the farm economic structure has long been an economic and political concern. The widely held view is that a major, if not the most significant mechanism for changes in farm economic structure, is the effect of institutional forces like federal agricultural policies. While the causes of the switch to different kinds of programs are still controversial, as are the predicted outcomes, there is strong interest in the potential effects of farm programs and crop insurance on the farm economic structure.

Studies have examined the importance of technology and farm programs on farm economic structural changes in input use and output production mix using primal production function, and dual cost function or profit function. Given the changes in input use and output production, interest has grown in understanding how technology and different kind of federal farm policies have affected the technical efficiency of the U.S. agriculture sector.

Past literature has examined the importance of liquidity, solvency and efficiency financial variables on the volatility and returns on general and agriculture economic growth. However, the importance of liquidity, solvency, and efficiency, on technical efficiency and productivity[2] has yet to be documented. Therefore, the objective of this paper is to examine the importance of farm programs variables on the technical efficiency of the U.S. agriculture sector using stochastic frontier analysis framework. Specific objectives include estimate the technical efficiency of the U.S. agriculture sector and second examine the role of farm program variables affecting technical efficiency. The study uses panel state data for the U.S agricultural sector for the period, 1960-2004.

1.1 Literature review of farm programs and technical efficiency

Let us move towards the history of various farm programs conducted in US farm which is said to be originated as the result of New Deal Legislation proposed by President Franklin D. Roosevelt in 1933 (which is also considered as one of the reasons for the change in the US farm productivity) to address the issue of declining Farm price and Net farm income. Actually, it was the government's effort to deal with the great depression. The Adjustment act brought the 'major price support' (Bowers, Rasmussen, & Baker, 1984, p. iv) for farmers by government. As a result, federal farm program originated to protect farmers against crop loss due to natural disaster and still is in force (Rasmussen, 1985; Shaik, Helmers and Atwood, 2005). Though, there is a clear impact of price on productivity, it is emphasized in different papers that farm programs and crop insurance have also altered the structure and productivity in US farm.

[2] Two alternative approaches - nonparametric programming and parametric stochastic frontier analysis have gained popularity due to their own strength and weakness in efficiency and productivity literature. Within parametric stochastic frontier analysis approach there has been increased emphasis on the type of distribution (exponential proposed by Aigner, Lovell and Schmidt, 1977, normal-gamma proposed by Greene, 1990), methods (parametric, semi-parametric and Bayesian), distinguish between cross individual heterogeneity and inefficiency (Greene, 2004) and finally empirical applications.

For empirical implementation of the distance function, a functional form must be specified for its empirical representation (Morrison et al., 2000). Researchers in this area have used Cobb–Douglas form for the estimation of production frontier which keeps special importance in a multi-output and -input context. Others have calculated efficiency for farm programs using cross-section or panel data series to estimate a frontier Cobb- Douglas production function for US Agriculture. Frontier estimation model has also been used in the analysis of efficiency patterns of New Zealand sheep and beef farming with panel data (Morrison et al., 2000).

The past literature uses two-stage linear programming followed by discrete choice tobit model to examine the relationship between finance and technical or economic efficiency of production. The two-step process has been the subject of analysis by earlier researchers. However, the two-step process might be faced with bias due to omitted or left out variables (see Wang and Schmidt 2002) or heteroskedasticity (Greene 2004). Hence, following Greene (2004) instead of a two-step process, a heterogeneity stochastic frontier model is used to examine the importance of farm financial variables on technical efficiency and productivity.

Stochastic frontier model, introduced by Aigner, Lovell, Schmidt; Meeusen, van den Broeck; and Battesse and Cora in 1977 decomposes the error term, ε into random error, v and u inefficiency. Stochastic frontier analysis has become a popular tool to model the production relationship between input and output quantities and has been primarily used to estimate the technical efficiency[3] of firm. In 1982, Jondrow, Materov, Lovell, and Schmidt suggested a

[3] Efficiency concept introduced by Farrell (1957) is defined as the distance of the observation from the production frontier and measured by the observed output of a firm, state or country relative to realized output, i.e., output that could be produced if it were 100 % efficient from a given set of inputs.

method to estimate firm specific inefficiency measures. Since it was introduced in 1977, the stochastic frontier analysis has been evolving theoretically with surge in empirical application. Furthermore, progress has been made on extending to fixed effects, random effects and random parameters panel models, time invariant and time variant models, correcting for heteroskedasticity and heterogeneity and alternative distributions (normal- half normal, normal-exponential and normal-gamma) of u technical efficiency term. Additionally, research has investigated the influence of a broader set of determinants of technical efficiency, namely geographic variables, market structure conduct and performance hypothesis, policy variables and size of the firm.

2. Stochastic frontier model to include efficiency

Following Greene (1993, 2004) the stochastic frontier model can be used to represent a Cobb-Douglas production function as

(1) $$y = f\left(\mathbf{x};\boldsymbol{\beta}\right) + v - u$$

where y is the output and $\mathbf{x}$ is a vector of inputs used in the production function, $\boldsymbol{\beta}$ is the vector coefficients associated with inputs, v represents the random error and $v \sim N\left(0,\sigma_v^2\right)$, u represents the one-sided inefficiency and can be represent with alternative distributions.

Following Shaik and Mishra (2010), equation (1) with alternative distribution can be extended by introducing heterogeneity in the variance of one-sided inefficiency, u as

$$\text{(2a)} \quad \begin{aligned} & y = f(\mathbf{x};\boldsymbol{\beta}) + v - u \\ & \sigma_{\mathrm{u}}^2 = \exp(\boldsymbol{\delta}'\mathrm{Z}) \end{aligned}$$

or by introducing heterogeneity in the mean of one-sided inefficiency, u as

$$\text{(2b)} \quad \begin{aligned} & y = f(\mathbf{x};\boldsymbol{\beta}) + v - u \\ & \mu_{\mathrm{u}} = \exp(\boldsymbol{\delta}'\mathrm{Z}) \end{aligned}$$

where σ_{u}^2 is the variance of the inefficiency term, σ_{v}^2 is the variance of the random error. The variance can be modeled as a function of variables Z. Here we defined the σ_{u}^2 variance and μ_{u} mean of the inefficiency term as a function of level, short-run and long-run farm program risk variables.

2.1 Panel gamma SML stochastic frontier models

The above time-series or cross-section stochastic frontier model can be extended to one- and two-way fixed or random effects panel model. The basic panel stochastic frontier production function can be represented

$$\text{(5)} \quad \begin{aligned} & y_{it} = f(\mathbf{x}_{it};\boldsymbol{\beta}) + v_{it} - u_{it} \\ & or \\ & y_{it} = f(\mathbf{x}_{it};\boldsymbol{\beta}) - u_{it} + v_{it} \end{aligned}$$

where $i = 1,....,N$ cross section observations and $t = 1,....,T$ number of years, y is the output and $\mathbf{x}$ is a vector of inputs used in the production function.

Let us start with one-way error disturbance stochastic frontier production function

$$\text{(6)} \quad \begin{aligned} & y_{it} = f(\mathbf{x}_{it};\boldsymbol{\beta}) + v_{it} - u_{it} \\ & v_{it} = \mu_i + \varepsilon_{it} \end{aligned}$$

where μ_i represents the temporally invariant cross-section or spatial effect and ε_{it} represents the remainder random error.

If μ_i representing individual cross-sectional units are assumed to be fixed, a one-way fixed effects stochastic frontier production function can be written as

(7) $$y_{it} = f\left(\mathbf{x}_{it};\boldsymbol{\beta}, Z_{\mu};\mu_i\right) - u_{it} + \varepsilon_{it}$$

where Z_{μ} is a vector of individual cross-sectional dummies and μ_i are the associate parameters of the cross-sectional dummies.

Instead of estimating too many parameters (dummies), it is possible to assume μ_i as random leading to one-way random effects model. The one-way random panel stochastic frontier production function can be represented as

(8) $$y_{it} = f\left(\mathbf{x}_{it};\boldsymbol{\beta}\right) - u_{it} + \mu_i + \varepsilon_{it}$$

where μ_i is the temporally invariant spatial error, normally distributed with mean zero, variance σ_{μ}^2, ε_{it} the remainder error is normally distributed with mean zero, variance σ_{ε}^2, and μ_i are independent of ε_{it}. Further, $\mathbf{x}_{it}$ are independent of μ_i and ε_{it} for all i and t.

Similarly, the two-way error disturbance stochastic frontier production function can be represented as

(9) $$\begin{aligned} y_{it} &= f\left(\mathbf{x}_{it};\boldsymbol{\beta}\right) + v_{it} - u_{it} \\ v_{it} &= \mu_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

where μ_i represents the temporally invariant cross-section or spatial effect, λ_t represents the spatially invariant time-series or temporal effect, and ε_{it} represents the remainder random error.

If μ_i and λ_t representing individual cross-sectional and time-series units, respectively are assumed to be fixed, a two-way fixed effects stochastic frontier production function can be written as

(10) $$y_{it} = f\left(\mathbf{x}_{it};\boldsymbol{\beta},Z_{\mu};\mu_i,Z_{\lambda};\lambda_t\right) - u_{it} + \varepsilon_{it}$$

where Z_{μ} is a vector of individual cross-sectional dummies and μ_i are the associate parameters of the cross-sectional dummies, Z_{λ} is a vector of individual time-series dummies and λ_t are the associate parameters of the times-series dummies.

Similarly, it is possible to assume μ_i and λ_t as random leading to two-way random effect model. The two-way random panel stochastic frontier production function can be represented as

(11) $$y_{it} = f\left(\mathbf{x}_{it};\boldsymbol{\beta}\right) - u_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where μ_i is temporally invariant spatial error and $\mu_i \sim N\left(0,\sigma_{\mu}\right)$, λ_t is spatially invariant temporal error and $\lambda_t \sim N\left(0,\sigma_{\lambda}\right)$, and μ_i, λ_t and ε_{it} are independent. Further, $\mathbf{x}_{it}$ is independent of μ_i, λ_t and ε_{it} for all i and t.

3. Data and variables used in the analysis

The U.S. Department of Agriculture's Economic Research Service (ERS) constructs and publishes the state and aggregate production accounts for the farm sector[4]. The features of the state and national production accounts are consistent with gross output model of production and are well documented in Ball et al. (1999). Output is defined as gross production leaving the farm, as opposed to real value added. Price of land is based on hedonic regressions. Specifically the price of land in a state is regressed against land characteristics and location (state dummy). Prices of capital inputs are obtained on investment goods prices, taking into account the flow of capital services per unit of capital stock in each state (Ball et al, 2001). Table 1 presents the summary statistics of the output, input and farm program payment risk variables.

4. Empirical application and results

To examine the importance of farm program payments, short-run and long-run farm program risk on the mean and variance of technical efficiency of U.S. agriculture sector panel stochastic frontier model is estimated. The output and inputs in the production function equation is estimated using the logs of the variables and the farm program payments, long-run and short-run farm program risk variables in the mean and variance inefficiency function is estimated in levels.

A Cobb-Douglas functional form was specified for panel stochastic frontier models. The long and short-run farm program risk variable was specified in the inefficiency mean and variance function. The Cobb-Douglas functional form with variance function specified as

[4] The data are available at the USDA/ERS website http://www.ers.usda.gov/data/agproductivity/.

$$Output_{it} = \beta_0 + \beta_1 Capital_{it} + \beta_2 Land_{it} + \beta_3 Labor_{it} + \beta_4 Chemicals_{it}$$

(12a)
$$+ \beta_5 Energy_{it} + \beta_6 Materials_{it} + \beta_7 Year + \varepsilon_{it}$$

$$\sigma_{\mathrm{u}}^2 = \gamma_{0,u} + \gamma_{1,u} FP_{it} + \gamma_{1,u} LR\,FP\,risk_{it} + \gamma_{2,u} SR\ \ FP\,risk_{it}$$

and the mean inefficiency function specified as

$$Output_{it} = \beta_0 + \beta_1 Capital_{it} + \beta_2 Land_{it} + \beta_3 Labor_{it} + \beta_4 Chemicals_{it}$$

(12b)
$$+ \beta_5 Energy_{it} + \beta_6 Materials_{it} + \beta_7 Year + \varepsilon_{it}$$

$$\mu_{\mathrm{u}} = \gamma_{0,u} + \gamma_{1,u} FP_{it} + \gamma_{1,u} LR\,FP\,risk_{it} + \gamma_{2,u} SR\ \ FP\,risk_{it}$$

Where $LR\,FP\,risk$ is the long run farm program risk defined as the cumulative standard deviation of the financial variables, $SR\,FP\,risk$ is the short run farm program risk defined as a five-year moving standard deviation of the farm program payment variables.

4.1 Results

Parameter coefficients of stochastic frontier production function are presented in Table 2 for mean and variance farm program inefficiency function. A nice feature about using logarithms is that the slope coefficient measures the elasticity of endogenous variable with respect to exogenous variation, that is, by the percentage change in endogenous variable given a percentage change in exogenous variation. Column 2 of table 2 presents estimates of variance function. Results in table 2 suggest the input variables in the production are all positive and significantly related to output production. The production function results are consistent with production theory, i.e., an increase in the quantity of input leads to increase in quantity of output produced.

The results from the model indicate an input elasticity of 0.455 for material which is relative higher to the other inputs. A 100 percent increase in the use of material input would increase the output by 45 percent, which indicates agricultural production can be increased 45 percent by increasing the use of material inputs in agricultural production. Energy input has an elasticity of 0.115 and ranks second with respect to the magnitude of contributions to agricultural output. Farmland with an elasticity of 0.099 ranks third and chemicals with an elasticity of 0.074 ranks fourth in terms of contributions to agricultural output. Capital with an elasticity of 0.142 and labor with an elasticity of 0.060 are at the bottom, showing that these inputs have a smaller positive influence on agricultural output. Year—proxy for technology—is positively related to agricultural output. The agriculture production returns to scale is 0.803 and 0.815, respectively without and with the inclusion of technology. The input elasticities estimated are not that different between the mean function and variance function stochastic frontier models.

The long-run farm program risk (variability in farm program payments) variable in the inefficiency mean and variance function is positive and significant. This indicates with an increase in the variation of farm program payments increases the mean and variation in the inefficiency in the long run. In contrast, short-run farm program risk variable has a negative and significant impact on the inefficiency variance. The negative sign indicates short-run variation in farm program payment would decrease the variation in the inefficiency variance. The level farm program payment did not significantly affect the mean or variance inefficiency function.

5. Conclusion

Farms have to a certain extent used farm program payments in assessing, benchmarking and monitoring farm performance. Past literature has examined the importance of farm programs on the volatility and returns on general and agriculture economic growth. The objective of this study was to assess the impact of farm program payments on technical efficiency. The study used aggregate state level panel data from the U.S agricultural sector. Results indicate production increasing with increasing units of inputs. Results from this study indicate that farm program payments play an important role in technical efficiency. For example, farm program payments indicate a negative and positive effect on mean and variance of technical efficiency in the long-run and short-run, respectively.

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Wang, H. and P. Schmidt, 2002. "One-Step and Two-Step Estimation of the Effects of Exogenous Variables on Technical Efficiency Levels." *Journal of Productivity Analysis* 18, 129-144., Input and Farm Program variables of U.S. agriculture sector, 1961-2004.

Table 1. Summary statistics of Output, Input and Farm Program variables of U.S. agriculture sector, 1961-2004.

	Mean	Std. dev	Minimum	Maximum
Output	142.11	47.90	59.52	336.10
Capital	107.73	28.16	39.38	219.24
Land	79.98	17.30	33.57	104.96
Labor	58.58	21.53	14.39	134.60
Chemicals	231.67	221.31	28.82	3180.54
Energy	118.73	31.40	51.79	322.73
Materials	130.54	46.79	41.58	388.40
Year	41.14	38.35	1.06	354.71
Farm program (FP) payments	103,921	128,950	3.22	683,970
Short-run FP risk	80,371	118,395	3.22	848,366
Long-run FP risk	142.11	47.90	59.52	336.10

Table 2. Panel Stochastic Frontier Production Function results for mean and variance of farm program payment risk variables.

	Variance (inefficiency)		Mean (inefficiency)	
	Coefficient	**P[|Z|>z]**	**Coefficient**	**P[|Z|>z]**
Constant	-22.422	< 0	-22.518	< 0
Capital	0.065	< 0	0.069	< 0
Land	0.099	< 0	0.099	< 0
Labor	0.060	< 0	0.058	< 0
Chemicals	0.074	< 0	0.074	< 0
Energy	0.115	< 0	0.117	< 0
Materials	0.455	< 0	0.453	< 0
Year	0.012	< 0	0.012	< 0
Inefficiency (u)				
Constant	-5.904	< 0	-0.482	0.1558
Farm program(FP)	-0.111	0.1571	-0.025	0.2462
Long-run FP risk	0.510	< 0	0.110	0.0247
Short-run FP risk	-0.235	0.0187	-0.050	0.1589