Translog Normal - Half Normal Stochastic Frontier Production function–An application to Turmeric Production

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Abstract

The success of business at the farm level mainly depends on the Technical efficiency (TE) of the farm. There are evidences that several farms do not realize the full potential of technology due to factors such as their managerial skills and differences in production environments. The present study was undertaken to quantify and measure technical efficiency score of 180 turmeric farms from north western region of Tamil Nadu using Translog Normal Half-Normal Stochastic Frontier Model (TNHNSFM), to know variations in efficiency among the farms and to analyse the policy implications for improving the efficiency. The maximum estimated technical efficiency was 99.14 per cent while the minimum was 87.02 per cent. The strength of relationship that exists between the observed efficiency and technical efficiency was given by the correlation coefficient $r_{OE} = 0.587$ and the Chi-square value was 1.4386.The significant level of the parameter $\lambda = 1.84$ resulted in the presence of technical inefficiency. Moreover, a greater part of the residual variation in output was associated with the variation in technical inefficiency rather than with measurement error. The estimate of $\gamma = 0.77$ indicated that the difference between the observed output and frontier output was primarily due to the factors which were 77 percent under the control of farms.

Key words: Stochastic Frontier Model, Translog production function, Productivity, Technical Efficiency

1.Introduction

In literature the implicit assumption in production technology is that farms operate with full technical efficiency and the allocative decision-making analysis is carried out with this assumption. This is a major limitation for production analysis. The importance of differentiating technical progress from technical efficiency in production function analysis was first highlighted by Farrell [3], who introduced the concept of frontier production function representing production technology with full technical efficiency (TE). In the context of Indian agriculture, a few empirical studies emerged to estimate the technical efficiency of agricultural production at the farm level. Almost all these estimated the efficiency of rice, maize, cotton, and sugarcane farms in different seasons [5,6,9,10,11].No attempt has been made to measure the efficiency of the crop like turmeric that fetches foreign currency in terms of exports. Moreover, turmeric is one of the oldest spices and had been used in India since ages. The world production of turmeric stands at around 8,00,000 tonnes in which India holds a share of 75-80 percent approximately. India also holds the top position in the list of world's leading exporters.One of the essential objectives of the present study is the investigation of the relationship between endogenous variable y_j and a set *i* of exogenous variables x_{ij}, where the subscript j denotes the j^{th}observation. Specific objectives of the present study are, to model the structure of production in the farms, to measure the technical efficiency score using parametric translog normal half-normal stochastic frontier model and to suggest policies for maximizing production efficiency in turmeric production.

2.Technical Efficiency:Concept

In order to understand how the technology and the technical and allocative efficiencies influence the performance of farms, it is convenient to distinguish three sets of determinants that are responsible for the differences in the performance among the farms. They are,(i) factors related to the farm's ability to choose input quantities that maximize profit;(ii) factors associated with the method of application of the chosen inputs and (iii) the socio-economic and natural environmental conditions of the production process which are not under the control of the units.

3. Data

In India, the state Tamil Nadu is one of the major producers of turmeric with a total area of 16,181 ha. and the production of about 67,250 tonnes. In the northwestern region of Tamil Nadu, two major turmeric growing districts *viz.*, Erode and Coimbatore were considered for the study because they occupy nearly 47 per cent of the turmeric area and 60 per cent of the turmeric production (40,511 tonnes) in Tamil Nadu. The productivity level in this region (5.3 tonnes /ha.) may be enhanced by improved technology and management practices. The present study is based on the primary data for the crop year May 2003 to March 2004. The study was carried out with the data pertaining to 180 households from 18 villages of Coimbatore and Erode districts in the northwestern region of Tamil Nadu. For the selection of turmeric growing households, two stage sampling procedure was followed. A list of different villages located in 38 blocks of Coimbatore and Erode districts were obtained from the respective Agricultural Development Office. From 38 blocks, six blocks *viz.*, Thondamuthur, Avinashi, Annur, Andhiyur. Bhavani and Kodumudi were selected based on the irrigation facilities, soil texture, and farmers' holdings. From each block, three villages were selected at random. From each village ten farmers were selected at random. The criteria used to select farmers for the study were based on the farm holdings, age of the farmer, farming experience, educational level, varieties used and source of seed. A total of 180 households were selected from the northwestern region of Tamil Nadu. The sample consists of one marginal farmer (<1.0 ha), 22 small farmers (1.1 to 2.0 ha), 49 medium farmers (2.1 to 4.0 ha) and 108 large farmers (> 4 ha). Among the 180 households selected, 72 farmers were young (<35 years), 107 middle aged (35- 60 years) and only one old (>60 years) farmer.

The measured values were used to evaluate the technical efficiency score of turmeric production of sample farms by fitting in the translog normal-half normal stochastic frontier model. The translog stochastic frontier model was analyzed using the software package LIMDEP 7.0 (www.econ.uic.edu)

4. Specification of models used

Stochastic Frontier Production Function

An appropriate formulation of a stochastic frontier model in terms of a general production function for the i-th production unit is $y_i = f(x_i, \beta)\exp(v_i - u_i)$ where v_i is the two sided noise component ,u_i is the non-negative technical inefficiency component of the error term [2,4].

The Empirical Model

The productivity of turmeric crop depends mainly on the major inputs *viz.*, seed (x_1) human labour (x_2), machinery (x_3), manure (x_4), fertilizer (x_5), pesticide (x_6) and post harvest expenditure (x_7). Considering the seven inputs, the empirical formulation of translog production function is specified as

$$\ln y = \beta_0 + \sum_{i=1}^{7}\beta_i \ln x_i + \frac{1}{2}\sum_{i=1}^{7}\sum_{i=1}^{7}\beta_{ii}(\ln x_i)^2 + \sum_{i=1}^{7}\sum_{j=1}^{7}\beta_{ij}(\ln x_i)*(\ln x_j) \quad (1)$$

The above production function was first estimated using Ordinary Least Squares (OLS) method. The OLS method shows an average response and does not qualify for the theoretical definition of a production frontier. To overcome this difficulty and to cover extreme values of *y* and ***x***'s the concept of the frontier was meaningfully applied.Consider a situation in which the ith farm is not producing its maximum possible output due to some slackness in production induced by various non-price and socio-economic organizational factors. In a modified neo-classical framework, the production function of the ith farm can be written as follows [12]: $y = f(x;\beta)e^{-u}$ where y is the observed output, $f(x, \beta)$ is the production frontier; x_i is a (kx1) vector of input values, β is a (kx1) vector of technology parameters to be estimated. In other words, exp (-u) which is farm specific, reflects ith farm's ability to produce at its present level, which is otherwise called as ith farm's technical efficiency.

Hence, we have $TE = e^{-u} = \dfrac{y}{f(x;\beta)}$. The following combination of assumption viz: $v_i \sim i.i.d.\ N(0,\sigma_v^2)$ and $u_i \sim i.i.d.\ N^+(0,\sigma_u^2)$, that is non-negative half-normal has been made.

5. Calculation of log-likelihood function

The probability density function of u is given by,

$$f(u) = \frac{2}{\sigma_u\sqrt{2\pi}}\exp\left\{-\frac{u^2}{2\sigma_u^2}\right\}$$

The probability density function of v is given by,

$$f(v) = \frac{1}{\sigma_v\sqrt{2\pi}}\exp\left\{-\frac{v^2}{2\sigma_v^2}\right\}$$

Given the independent assumption, the joint density function of u and v is the product of their individual density functions. Thus,

$$f(u,v) = \frac{2}{2\pi\sigma_v\sigma_u}\exp\left\{-\frac{v^2}{2\sigma_v^2} - \frac{u^2}{2\sigma_u^2}\right\}$$

Making the transformation $\varepsilon = v - u$, the joint density function of u

$$f(u,\varepsilon) = \frac{1}{\pi\sigma_v\sigma_u}\exp\left\{-\frac{u^2}{2\sigma_u^2} - \frac{(\varepsilon+u)^2}{2\sigma_v^2}\right\}$$

The marginal density of ε is obtained by integrating u out of $f(u,\varepsilon)$ which yields

$$f(\varepsilon) = \int_0^\infty f(u,\varepsilon)du$$

$$f(\varepsilon)=\int_0^\infty \frac{1}{\pi\sigma_u\sigma_v}\exp\left\{-\frac{u^2}{2\sigma_u^2}-\frac{(\varepsilon^2+2\varepsilon u+u^2)}{2\sigma_v^2}\right\}du$$

Define $\sigma=\sqrt{\sigma_u^2+\sigma_v^2}$;

$\lambda=\dfrac{\sigma_u}{\sigma_v}$ .Simplifying,

$$f(\varepsilon)=\frac{1}{\pi\sigma_u\sigma v}\exp\left\{-\frac{\varepsilon^2}{2\sigma^2}\right\}\int_0^\infty \exp\left\{-\frac{1}{2}\left[\left(\frac{\sigma^2}{\sigma_u^2\sigma_v^2}\left(u+\frac{\varepsilon\sigma_u^2}{\sigma^2}\right)^2\right)\right]\right\}du$$

Define $\dfrac{\sigma}{\sigma_u\sigma_v}\left(u+\dfrac{\varepsilon\sigma_u^2}{\sigma^2}\right)=t$.

Thus $f(\varepsilon)=\dfrac{2}{\sigma}\phi\left(\dfrac{\varepsilon}{\sigma}\right)\Phi\left(-\dfrac{\varepsilon\lambda}{\sigma}\right)$

where $\sigma=\sqrt{\sigma_u^2+\sigma_v^2}$, $\lambda=\dfrac{\sigma_u}{\sigma_v}$ and $\Phi(\cdot),\phi(\cdot)$ are the standard normal cumulative distribution and density functions respectively. The marginal density function $f(\varepsilon)$ is asymmetrically distributed, with mean and variance as below. $E(\varepsilon)=-E(u)=-\sigma_u\sqrt{\dfrac{2}{\pi}}$

Similarly, $V(\varepsilon)=\dfrac{\pi-2}{\pi}\sigma_u^2+\sigma_v^2$

The normal half-normal distribution contains two parameters σ_u and σ_v. Aigner *et al.*, [1] suggested $[1-E(-u)]$ as an estimator of the mean technical efficiency of all producers.Lee and Tyler [7] proposed

$E(\exp(-u))=2(1-\Phi(\sigma_u))\exp\left\{\dfrac{\sigma_u^2}{2}\right\}$ which is preferred to $[1-E(-u)]$ since (1-u) indicates only the first term in the power series expansion of $\exp(-u)$. Unlike $[1-E(-u)]$, $E(\exp(-u))$ is consistent with the definition of technical efficiency. The log-likelihood function for a sample of N producers is

$$\ln L=-\left(\frac{N}{2}\right)(\ln 2\pi+\ln\sigma^2)+\sum_{i=1}^{N}\left\{\ln\Phi\left(\frac{-\varepsilon_i\lambda}{\sigma}\right)-\frac{1}{2}\left(\frac{\varepsilon_i}{\sigma}\right)^2\right\}$$

where $y_i=x_i^{'}\beta+\varepsilon$ with β and x_i being [1xK] vectors.

Measurement of technical efficiency would be done once the parameters are estimated using log-likelihood function.

6.Measure of Technical Efficiency using Normal Half-Normal Stochastic Frontier Model

Since $f(u/\varepsilon)$ is distributed as $N^+(\mu_*,\sigma_*^2)$, the mean of this distribution can serve as a point estimator of u_i, which is given by

$$E(u/\varepsilon)=\int_0^\infty uf(u/\varepsilon)du$$

$$E(u/\varepsilon)=\int_0^\infty u\frac{1}{\sigma_*\sqrt{2\pi}}\left[1-\Phi\left(-\frac{\mu_*}{\sigma_*}\right)\right]^{-1}\exp\left\{-\frac{1}{2}\left(\frac{u-\mu_*}{\sigma_*}\right)^2\right\}du$$

Define $t=\dfrac{u-\mu_*}{\sigma_*}$ so that

$E(u_i/\varepsilon_i)=\sigma_*\left[\dfrac{\phi(\varepsilon_i\lambda/\sigma)}{1-\Phi(\varepsilon_i\lambda/\sigma)}-\left(\dfrac{\varepsilon_i\lambda}{\sigma}\right)\right]$.Estimates of u_i can be obtained from

$$TE_i=\exp\left(-\hat{u}_i\right)=\exp\{-E(u_i/\varepsilon_i)\}$$

7.Results and Discussion

Summary statistics of the survey variables gathered from 180 farmers observed from northwestern region ofTamil Nadu are reported in Table 1

Table 1Summary statistics of the variable

	Yield (Kg.)	Seed (Rs)	Hum (Rs)	Machinery (Rs)	Manure (Rs)	Fertiliser (Rs)	Pesticide (Rs)	PHT (Rs)
Mean	2423.33	4514.44	7252.58	957.78	3494.44	3530.00	430.37	2488.56
Median	2500.00	4500.00	7220.00	850.00	3000.00	3155.00	437.50	2500.00
Std. Deviation	196.292	265.102	676.790	258.928	878.020	1.630E3	106.783	301.496
Range	1200	1100	5160	1250	4000	6355	600	2405
Minimum	1800	3850	5240	500	2000	1300	110	1645
Maximum	3000	4950	10400	1750	6000	7655	710	4050

The translog production function model considered for the study involved a total of 35 independent variables. Ordinary Least Square (OLS) estimates Table 2 of the parameters of stochastic frontier model ascertained that the inputs used in the model were able to explain 73 per cent of the variations in the turmeric production. The inputs manure, fertilizer and pesticide were allocated efficiently as they have expected signs whereas, seed, human labour, machinery and post harvest expenditure were of inefficient allocation. The Ordinary Least Square (OLS) estimates discussed above were of average performance. Hence, to study about the farm specific performances, Maximum Likelihood Estimates (MLE) were obtained and presented in Table 3.

The inputs manure, fertilizer and pesticide were allocated efficiently as they have expected signs whereas, seed, human labour, machinery and post harvest expenditure were of inefficient allocation. A direct comparison of the parameters estimated for the average (OLS) and stochastic function (MLE) showed close similarity between the intercepts and input coefficients. Further, by the specification of the likelihood function, the difference between the production function estimated by the OLS and frontier function can be statistically shown by the 5 per cent significant level of λ= 1.84. The significant level of the parameter λ showed that there exists sufficient evidence to suggest the presence of technical inefficiency. The estimates of the error variances σ_u^2 and σ_v^2 were 0.00306 and 0.00090 respectively as shown in Table 3. Therefore, it could be easily seen that the variance of one-sided error, σ_u^2 is larger than the variance of the random error, σ_v^2. Thus, the value of λ= 1.84 of more than one clearly showed the dominant share of the estimated variance of the one-sided error term, u, over the estimated variance of the whole error term.

Table 2 Ordinary Least Square Estimates of Average Performance Using Translog Normal Half-Normal Stochastic Frontier Model

Variables	Parameters	Coefficients
Constant	β_0	266.506
ln_{Sed}	β_1	-38.949
ln_{Hum}	β_2	-9.841

ln_{Mac}	β_3	-6.133
ln_{Man}	β_4	0.087*
ln_{Fer}	β_5	0.382
ln_{Pes}	β_6	4.238
ln_{Pht}	β_7	-11.765
ln_{Sed} x ln_{Sed}	β_{11}	2.378
ln_{Hum} x ln_{Hum}	β_{22}	-0.767
ln_{Mac} x ln_{Mac}	β_{33}	-0.320
ln_{Man} x ln_{Man}	β_{44}	-0.688**
ln_{Fer} x ln_{Fer}	β_{55}	-0.074
ln_{Pes} x ln_{Pes}	β_{66}	-0.111
ln_{Pht} x ln_{Pht}	β_{77}	-0.192
ln_{Sed} x ln_{Hum}	β_{12}	0.739
ln_{Sed} x ln_{Mac}	β_{13}	0.098
ln_{Sed} x ln_{Man}	β_{14}	-0.308
ln_{Sed} x ln_{Fer}	β_{15}	0.006
ln_{Sed} x ln_{Pes}	β_{16}	0.068
ln_{Sed} x ln_{Pht}	β_{17}	1.761
ln_{Hum} x ln_{Mac}	β_{23}	0.559
ln_{Hum} x ln_{Man}	β_{24}	0.666
ln_{Hum} x ln_{Fer}	β_{25}	0.106
ln_{Hum} x ln_{Pes}	β_{26}	-0.421
ln_{Hum} x ln_{Pht}	β_{27}	0.376
ln_{Mac} x ln_{Man}	β_{34}	0.100
ln_{Mac} x ln_{Fer}	β_{35}	0.103
ln_{Mac} x ln_{Pes}	β_{36}	0.218
ln_{Mac} x ln_{Pht}	β_{37}	-0.055
ln_{Man} x ln_{Fer}	β_{45}	0.126
ln_{Man} x ln_{Pes}	β_{46}	0.131
ln_{Man} x ln_{Pht}	β_{47}	-0.008
ln_{Fer} x ln_{Pes}	β_{56}	-0.035
ln_{Fer} x ln_{Pht}	β_{57}	-0.293
ln_{Pes} x ln_{Pht}	β_{67}	-0.346
* Significant at 5% level		R^2 = 0.728
** Significant at 1% level		N = 180

This further implied that greater part of the residual variation in output was associated with the variation in technical inefficiency rather than with 'measurement error', which was associated with uncontrollable factors related to the production process. Moreover, both λ and σ variables of northwestern region of Tamil Nadu entered the output of all farms positively and significantly. The estimate of γ , which is the ratio of the variance of farm-specific performance of technical efficiency to the total variance of output was 0.77, indicating that the difference between the observed and frontier output was primarily due to the factors which were 77 per cent under the control of farms.

Estimation of Technical Efficiency using TNHNSFM

The level of technical efficiency for each of the 180 sample farms was calculated using the software package LIMDEP 7.0. The maximum estimated technical efficiency was 99.14 per cent while the minimum was 87.02 per cent and the same maximum score was 95 per cent and the minimum score was 59 per cent using the non-parametric model Data Envelopment Analysis [8]. The mean level of technical efficiency was 95.72 percent, which implied that the sample farms realized 95.72 percent of their technical abilities.

Table 3 Maximum Likelihood Estimates of the Translog Normal Half-Normal Stochastic Frontier Model

Variables	Parameters	Coefficients	Variables	Parameters	Coefficient
Constant	β_0	288.686	ln_{Sed} x ln_{Fer}	β_{15}	- 0.065
ln_{Sed}	β_1	-41.875	ln_{Sed} x ln_{Pes}	β_{16}	- 0.011
ln_{Hum}	β_2	-9.926	ln_{Sed} x ln_{Pht}	β_{17}	2.011

$\ln_{Mac}$	β_3	-5.518	$\ln_{Hum}$ X $\ln_{Mac}$	β_{23}	0.502
$\ln_{Man}$	β_4	1.605	$\ln_{Hum}$ X $\ln_{Man}$	β_{24}	0.504
$\ln_{Fer}$	β_5	0.516	$\ln_{Hum}$ X $\ln_{Fer}$	β_{25}	0.068
$\ln_{Pes}$	β_6	5.498	$\ln_{Hum}$ X $\ln_{Pes}$	β_{26}	- 0.489
$\ln_{Pht}$	β_7	-17.414	$\ln_{Hum}$ X $\ln_{Pht}$	β_{27}	0.662
$\ln_{Sed}$ X $\ln_{Sed}$	β_{11}	2.912	$\ln_{Mac}$ X $\ln_{Man}$	β_{34}	0.113
$\ln_{Hum}$ X $\ln_{Hum}$	β_{22}	-0.736	$\ln_{Mac}$ X $\ln_{Fer}$	β_{35}	0.109
$\ln_{Mac}$ X $\ln_{Mac}$	β_{33}	-0.319	$\ln_{Mac}$ X $\ln_{Pes}$	β_{36}	0.217
$\ln_{Man}$ X $\ln_{Man}$	β_{44}	-0.637*	$\ln_{Mac}$ X $\ln_{Pht}$	β_{37}	- 0.073
$\ln_{Fer}$ X $\ln_{Fer}$	β_{55}	-0.050	$\ln_{Man}$ X $\ln_{Fer}$	β_{45}	0.170*
$\ln_{Pes}$ X $\ln_{Pes}$	β_{66}	-0.104	$\ln_{Man}$ X $\ln_{Pes}$	β_{46}	0.152
$\ln_{Pht}$ X $\ln_{Pht}$	β_{77}	-0.212	$\ln_{Man}$ X $\ln_{Pht}$	β_{47}	0.161
$\ln_{Sed}$ X $\ln_{Hum}$	β_{12}	0.735	$\ln_{Fer}$ X $\ln_{Pes}$	β_{56}	- 0.022
$\ln_{Sed}$ X $\ln_{Mac}$	β_{13}	0.083	$\ln_{Fer}$ X $\ln_{Pht}$	β_{57}	- 0.275
$\ln_{Sed}$ X $\ln_{Man}$	β_{14}	-0.593	$\ln_{Pes}$ X $\ln_{Pht}$	β_{67}	- 0.387*
$\lambda = \frac{\sigma_u}{\sigma_v}$					1.845*
$\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$					0.063**
Log- likelihood					305.877
Estimated variances of the underlying variables					
v					0.0009
u					0.0031
ε					0.0040
γ = Var(u)/Var (ε)					0.7750
* Significant at 5% level		** Significant at 1 % level			

However, for better indication of the distribution of individual efficiencies, a frequency distribution of predicted technical efficiencies within ranges of five using TNHNSFM is depicted in Table 4 which showed that 27 per cent of sample farms operated below a technical efficiency of 95 per cent indicating scope to increase turmeric production by 5 per cent with the efficient allocation of inputs and using the same technology.

Table 4 Frequency Distribution of Farm Specific Technical Efficiency Estimates Using Translog Normal Half–Normal Stochastic Frontier Model

EfficiencyScore (per cent)	No. of Farms	Percentage
Below 85	-	-
85 – 90	4	2.22
90 – 95	44	24.45
95 – 100	132	73.33

Moreover, the highest number of farms (132) was found in the technical efficiency class of 95-100 per cent. However, the model range lies between 87.02 per cent and 99.14 per cent and no farm has reported a technical efficiency score of less than 85 per cent.The strength of relationship that exists between the observed efficiency and technical efficiency is given by the correlation coefficient $r_{OE} = 0.587$.

Empirically Estimated Translog Normal Half-Normal Production Function: The estimated translog normal half-normal production function is given by

$$\begin{aligned}
\text{PROD} = (288.686)\quad & Sed^{-41.875}\quad Hum^{-9.926}\quad Mac^{-5.518}\quad Man^{1.605}\quad Fer^{0.516}\quad Pes^{5.498}\quad Pht^{-17.414} \\
& \exp\{(2.912)(\ln Sed)(\ln Sed)+(-0.736)(\ln Hum)(\ln Hum)+(-0.319)(\ln Mac)(\ln Mac)\}\times \\
& \exp\{(-0.637)(\ln Man)(\ln Man)+(-0.050)(\ln Fer)(\ln Fer)+(-0.104)(\ln Pes)(\ln Pes)\}\times \\
& \exp\{(-0.212)(\ln Pht)(\ln Pht)+(0.735)(\ln Sed)(\ln Hum)+(0.083)(\ln Sed)(\ln Mac)\}\times \\
& \exp\{(-0.593)(\ln Sed)(\ln Man)+(-0.065)(\ln Sed)(\ln Fer)+(-0.011)(\ln Sed)(\ln Pes)\}\times \\
& \exp\{(2.011)(\ln Sed)(\ln Pht)+(0.502)(\ln Hum)(\ln Mac)+(0.504)(\ln Hum)(\ln Man)\}\times \\
& \exp\{(0.068)(\ln Hum)(\ln Fer)+(-0.489)(\ln Hum)(\ln Pes)+(0.662)(\ln Hum)(\ln Pht)\}\times \\
& \exp\{(0.113)(\ln Mac)(\ln Man)+(0.109)(\ln Mac)(\ln Fer)+(0.217)(\ln Mac)(\ln Pes)\}\times \\
& \exp\{(-0.073)(\ln Mac)(\ln Pht)+(0.170)(\ln Man)(\ln Fer)+(0.152)(\ln Man)(\ln Pes)\}\times \\
& \exp\{(0.161)(\ln Man)(\ln Pht)+(-0.022)(\ln Fer)(\ln Pes)+(-0.275)(\ln Fer)(\ln Pht)\}\times \\
& \exp\{(-0.387)(\ln Pes)(\ln Pht)\}
\end{aligned}$$

Conclusion

Productivity enhancement in turmeric production is one of the most important goals of Indian farming. Based on the technical efficiency of the most efficient farm, the average potential to increase the production of the turmeric farming system was determined as 3.45. Moreover, it was found that manure played a major role and was allocated efficiently by the most efficient farm.

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