On the Estimation of Stochastic Production Frontiers with Self-Selectivity: Jasmine and Non-Jasmine Rice in Thailand[†]

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ABSTRACT

This study attempts to analyse factors, especially neck blast and technical efficiency, affecting Jasmine and non-Jasmine rice production in Thailand. Stochastic production frontier estimation methods are used. Since the observed output levels were not sampled randomly from the population due to the farmer's decision on the selectivity of growing Jasmine or non-Jasmine rice, the stochastic production frontier estimation method had to be modified to include a self-selectivity variable to eliminate biasing estimated parameters.

Key words: Thailand, Neck blast, Stochastic production frontier, Self-selectivity, Jasmine rice, Non-Jasmine rice, Technical efficiency

INTRODUCTION

Rice is an important cereal crop for the Thai socially and economically, being the country's major export commodity in the continually-expanding world market and earning 30–50 billion Baht of foreign exchange annually. In 1998, Thailand held up to 25.17% of market share in the international rice trade. However, competition in the world market has been intense due to the substantial volume of rice export (even within the Asian region) from Vietnam, Pakistan, China and Myanmar. One good strategy for Thailand is therefore the switch to promoting production and export of good or unique quality rice which has relatively less intense competition in the world market.

Fragrant rice, unique for its aroma, has been cultivated in Thailand from the prevailing over 50 varieties but among which the most popular for planting and consumption being Jasmine rice as its market demand is high both internally and internationally. About 60% of Jasmine rice output is used domestically for direct consumption, processing in food product industry, as seeds for planting and as animal feed (Office of Agricultural Economics, 1998). In export market, Jasmine rice is popularly demanded in certain Asian and Middle East countries such as Singapore, Hong Kong, China and Iran and the demand continues to grow.

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Nonetheless, the fragrant rice share in the world rice market is still very low, accounting for less than 1.2% of the total international rice trade (Department of Agriculture, and Department of Agricultural Extension, 1997) and thus, suggesting the opportunity for enlarging further its world market share. Meanwhile, competition in fragrant rice export remains light as there exists only a few major exporters which include Thailand, Pakistan and India. Particularly, Thailand exported about 1.449 million tons of milled Jasmine rice in 1996, a 16.2% increase from 1995 level and 10 times the 1987 volume. In terms of value, the share of Jasmine rice in Thailand's total rice export earning had increased from 4.11% in 1987 to 39.01% in 1996. The more rapid increase in the share in export value than in export volume implies that Jasmine rice is greatly demanded in the world market (Table 1).

Table 1. Jasmine rice export volumes and values versus total export rice volumes and values during 1988–1997.

Year	Volume and value of total rice export		Volume and value of Jasmine rice exports		Percent of Jasmine rice export to total rice export	
	Volume (tons)	Value (million baht)	Volume (tons)	Value (million Baht)	Volume	Value
1988	4,824,956	33,045	148,544	1,358	3.08	4.11
1989	6,086,029	44,802	687,606	6,623	11.30	14.78
1990	3,934,138	27,258	701,651	4,463	17.83	23.71
1991	4,015,066	29,559	823,109	8,261	20.50	27.95
1992	4,806,474	35,665	1,101,122	11,594	22.91	32.51
1993	4,804,669	31,495	1,064,049	10,559*	22.15	33.53
1994	4,757,292	38,355	1,142,882	13,806*	24.02	36.00
1995	6,002,487	47,213	1,246,976	13,666*	20.77	28.95
1996	5,288,788	49,043	1,448,913	19,130*	27.40	39.01
1997	5,567,570	na.	1,244,203	27,252	22.35	na.

Source: Department of Foreign Trade, Ministry of Commerce.

Thailand has put its efforts to promote Jasmine rice production since 1959, extending throughout the country and successfully, particularly in Northeastern and Northern regions, Consequently, Jasmine rice area continued to increase from 9.945 million rai in 1979/80 crop year to 17.3 million rai in 1997/98 with an output growth from 2.51 million ton to 4.66 million ton in the corresponding years (Table 2). Although output has expanded, the Ministry of Agriculture and Cooperatives still aims to improve the productivity of Jasmine rice to yield 330 kg/rai by 2001 (Department of Agriculture, and Department of Agricultural Extension, 1997). Currently, the five-year average (1993/94–1997/98) yield of Jasmine rice at the farm level stands at only 265.8 kg/rai compared to an average of 341 kg/rai for ordinary rice yield in the same period (Table 2).

Table 2. Planted area, total output and yield of all varieties of rice compared with those for Jasmine rice during crop years 1989/90 to 1997/98.

Year	All varieties of rice			Jasmine rice				
	Planted area (million rai)	Total output (million tons)	Yield/rai (kg/rai)	Planted area (million rai)	Total output (million tons)	Yield/rai (kg/rai)	% of total rice planted area	% of total rice output
1989/90*	59.195	18.48	312	9.945	2.51	253	16.80	13.58
1990/91*	58.210	14.90	256	10.710	2.780	260	18.40	18.66
1991/92*	55.176	17.52	317	10.545	2.770	263	19.11	15.81
1992/93**	56.295	17.30	307	11.321	2.782	246	20.11	16.08
1993/94**	59.251	18.45	311	12.908	3.120	242	21.80	16.90
1994/95**	60.677	21.71	358	13.615	3.750	275	22.40	17.30
1995/96**	63.353	22.02	347	14.621	4.050	277	23.10	18.40
1996/97**	63.700	22.43	352	15.400	4.101	266	24.18	18.28
1997/98**	61.200	20.64	337	17.300	4.664	269	28.27	22.60

Source : * Chueamueangpan (1993).
** Institute of Agricultural Research, Office of Agricultural Economics, Ministry of Agriculture and Agricultural Cooperatives (1999).

Jasmine rice is the rice variety the Rice Research Institute of the Department of Agriculture recommends as being appropriate paddy breed for rainy season cropping in Northern and Northeastern regions. It has characteristic traits of being resistant to drought, root knot nematode, acidic as well as saline soils but not resistant to such diseases as blast, bacterial leaf blight, yellow-orange leaf of rice nor to certain insect pests including brown plant hopper *Nilaparvata lugens (Stal)* and rice green leafhopper *Nephotettix virescens (Distant)* (Boonduang and Uchin, 1990).

Blast disease in rice is caused by the fungi *Pyricularia oryzae* and is a serious problem which often damages farmers' crops. Its first widespread outbreak in Thailand took place in 1992, afflicting about 200,084 hectares of rice area and 70% of which was in the northern region where RD6, RD8, RD10, Mei Nong, Niaw Ubon and Niaw San Pa Tong varieties were planted and greatly damaged by the disease. Another serious outbreak occurred in 1995 in the northern provinces of Chiang Rai, Chiang Mai, Phayao, Lampang and Lamphun.

Apart from such risk factors as pests and diseases, the physical environment like flood/drought and soil condition in specific locality can be major reasons causing Jasmine rice yield to be much lower than that of ordinary rice which is also still very low on the average. One of the crucial questions becomes how great is the possibility to realize the Jasmine rice yield of 330 kg/rai targeted by the Ministry of Agriculture and Cooperatives, given the aforementioned risk factors and the present production technologies used by Thai farmers.

Neck blast disease can cause drastic damage when it occurs. Quite naturally plant scientists view conducting biotechnological research to eradicate or ameliorate the disease's effect on yield as useful. Economists acknowledge the impact of disease but also ask how the effect of the disease interacts with other controllable and uncontrollable factors, including technical efficiency, on rice production. Since large numbers of rice varieties are cultivated in Thailand and Jasmine rice has become the primary export variety as well as the leading variety in the domestic market, the answers to these questions are pertinent to both Jasmine and non-Jasmine rice.

To investigate technical efficiency and the impact of other inputs, it is necessary to first estimate a production frontier. Since farmers usually choose one variety to grow on a specific parcel of land, the production function of each variety should be estimated by taking into account the variety chosen. In an experimental plot framework, selection would not be a problem because Jasmine and non-Jasmine varieties would be assigned to various plots by using randomization. Parameters of the production functions could be easily estimated by dividing the sample into two sub-samples; one sub-sample with the Jasmine observations and the other sub-sample with the non-Jasmine observations. Separate production functions (frontiers) could be estimated for each variety. However, in a field setting, farmers do not choose varieties randomly. Varieties are assigned to given parcels because farmers typically have knowledge which indicates that a particular variety will do better on a given plot than other varieties. Because of choosing of fields by the farmer, a problem called selectivity in the statistical sense may arise. If the problem exists, then failure to model the selectivity problem explicitly will result in biased estimates of the production function parameters.

Since each farmer makes his or her decision about the variety to be grown, the observed output levels are not sampled randomly from the populations of Jasmine and non-Jasmine rice. There is a variable $Z_i'\gamma$ such that an observation is drawn from the specified model only when $Z_i'\gamma$ crosses some threshold. This implies that the observation is from the subpopulation of the model associated with the selected values of $Z_i'\gamma$. If the observed data are still treated as having been randomly sampled from the population of the model, it potentially biases the estimated parameters. An auxiliary model generating $Z_i'\gamma$ would lead to the general solution of the selectivity problem. To eliminate biased estimates, information about this auxiliary model is incorporated in the estimation of the model (Maddala, 1983; Greene, 1995). This method is relevant to the switching regression model with endogenous switching to be discussed below.

The main objective of this study is to estimate stochastic frontiers with self-selectivity in order to investigate factors affecting outputs of Jasmine and non-Jasmine rice. These factors include production inputs, physical and environmental factors, disease occurrence and technical efficiency. Factors affecting technical inefficiency are investigated as well.

METHODOLOGY

1. Switching Regression Model with Endogenous Switching: A Two-Stage Estimation Method

Many models, in which the behavior of agents is described by two regression equations, have single criterion functions that determine which of these two equations is applicable. A model where a farmer has to choose between two production functions, Jasmine and non-Jasmine rice, with a criterion function that indicates which production function may be written as:

Jasmine rice: $$y_{1i} = X_{1i}'\beta_1 + u_{1i} \text{ iff } Z_i'\gamma \geq u_i \quad (1)$$

Non-Jasmine rice: $$y_{2i} = X_{2i}'\beta_2 + u_{2i} \text{ iff } Z_i'\gamma < u_i \quad (2)$$

where y_{1i} is Jasmine rice output of the i^{th} farm; y_{2i}, non-Jasmine rice output of the i^{th} farm; X_{1i}, the Jasmine rice input vector; X_{2i}, the non-Jasmine rice input vector; β_1 and β_2, the parameter vectors; u_{1i} u_{2i}, and u_i are normally-distributed random error terms with mean zero. u_{1i} and u_{2i}, have variances σ_1 and σ_2 while u_i has a unit variance. It is assumed that the u_i are correlated with u_{1i} and u_{2i} (Maddala, 1983). This model is similar to Goldfeld and Quandt's switching regression model. Since u_i is correlated with u_{1i} and u_{2i}, Maddala and Nelson (1975) call this model as "a switching regression model with endogenous switching". The endogeneity arises from the correlation of the three random error terms.

Define an indicator variable

$$I_i = 1 \quad \text{if } Z_i'\gamma \geq u_i$$

$$I_i = 0 \quad \text{otherwise}$$

where Z_i is a vector of exogenous variables explaining the decision to grow Jasmine or non-Jasmine rice and γ, the vector of relevant parameters. In the case that sample separation is observable, I_i can be obtained. The probit maximum likelihood estimator can then be used to estimate γ. Since γ can be estimated only up to a scale factor, it is then assumed that u_{1i}, u_{2i} and u_i have a trivariate normal distribution with mean vector zero and covariance matrix

$$\Sigma = \begin{bmatrix} \sigma^2_1 & \sigma_{12} & \sigma_{1u} \\ \sigma_{12} & \sigma^2_2 & \sigma_{2u} \\ \sigma_{1u} & \sigma_{2u} & 1 \end{bmatrix}$$

The likelihood function for this model is

$$L(\beta_1, \beta_2, \sigma^2_1, \sigma^2_2, \sigma_{1u}, \sigma_{2u})$$
$$= \Pi[f^{Z_i'\gamma}_{-\infty} g(y_{1i} - \beta_1' X_{1i}, u_i)du_i]^{I_i} [f^{\infty}_{Z_i'\gamma} f(y_{2i} - \beta_2' X_{2i}, u_i)du_i]^{1-I_i} \qquad (3)$$

where g and f are the bivariate normal density function of (u_{1i},u_i) and (u_{2i},u_i) respectively (Maddala, 1983). Maximization of likelihood function (3) can be obtained but is cumbersome. Lee (1976) proposes a two-stage method which is simpler for estimation as follows:

Since decision to use Jasmine or non-Jasmine rice depends on the criterion function, the expected values of the error terms in (1) and (2) can be expressed as

$$E(u_{1i} \mid u_i \leq Z_i'\gamma) = E(\sigma_{1u} u_i \mid u_i \leq Z_i'\gamma)$$
$$= -\sigma_{1u} \frac{\phi(Z_i'\gamma)}{\Phi(Z_i'\gamma)} \neq 0 \qquad (4)$$

and

$$E(u_{2i} \mid u_i \geq Z_i'\gamma) = E(\sigma_{2u} u_i \mid u_i \geq Z_i'\gamma)$$
$$= \sigma_{2u} \frac{\phi(Z_i'\gamma)}{1 - \Phi(Z_i'\gamma)} \neq 0 \qquad (5)$$

In (4) and (5) lower case phi-represents the standard normal density function and upper case phi represents the standard normal cumulative density function. Equations (4) and (5) demonstrate that the expected values of the error terms in the yield equations are no longer equal to zero. Least squares applied to (1) and (2) then yields biased parameter estimates. Lee (1976) suggests a two-stage method in estimating (1) and (2) by computing new variables W_{1i} and W_{2i} and adding W_{1i} to (1) and W_{2i} to (2) in order to eliminate the bias. Hence

$$y_i = X'_{1i}\beta_1 - \sigma_{1u}W_{1i} + \varepsilon_{1i} \quad \text{for} \quad I_i = 1 \tag{6}$$

$$y_i = X'_{2i}\beta_2 + \sigma_{2u}W_{2i} + \varepsilon_{2i} \quad \text{for} \quad I_i = 0 \tag{7}$$

where

$$W_{1i} = \frac{\phi(Z'_i\gamma)}{\Phi(Z'_i\gamma)}$$

$$W_{2i} = \frac{\phi(Z'_i\gamma)}{1 - \Phi(Z'_i\gamma)}$$

$\varepsilon_{1i}, \varepsilon_{2i}$ = new residuals with zero conditional means

However, the method proposed by Lee (1976) induces a heteroscedasticity problem in the variances of ε_{1i} and ε_{2i}. In estimating (6) and (7), weighted least squares (WLS) is used instead of ordinary least squares to provide efficient estimates of the parameters. The variance of ε_{1i} and ε_{2i} can be computed as

$$\text{var}\,(\varepsilon_{1i} \mid I_i = 1) = \sigma^2_1 - \sigma_{1u}W_{1i}(Z'_i\gamma + W_{1i}) \tag{8}$$

$$\text{var}\,(\varepsilon_{2i} \mid I_i = 1) = \sigma^2_2 + \sigma_{2u}W_{2i}(Z'_i\gamma + W_{2i}) \tag{9}$$

and

$$E\,(\varepsilon_{1i} \mid I_i = 1) = 0 \tag{10}$$

$$E\,(\varepsilon_{2i} \mid I_i = 0) = 0 \tag{11}$$

The estimates of σ^2_1 and σ^2_2 are obtained from

$$\hat{\sigma}^2_1 = \frac{1}{N_1}\sum_{i=1}^{N_1}[\hat{u}^2_{1i} + \hat{\sigma}^2_{1u}(Z'_i\hat{\gamma})\hat{W}_{1i}] \tag{12}$$

$$\hat{\sigma}^2_2 = \frac{1}{N_2}\sum_{i=1}^{N_2}[\hat{u}^2_{2i} + \hat{\sigma}^2_{2u}(Z'_i\hat{\gamma})\hat{W}_{2i}] \tag{13}$$

where N_1 = number of observations for which $I_i = 1$

N_2 = number of observations for which $I_i = 0$

$$u_{1i} = y_i - X'_{1i}\beta_1 \qquad \text{for} \qquad I_i = 1$$

$$u_{2i} = y_i - X'_{2i}\beta_2 \qquad \text{for} \qquad I_i = 0$$

(Maddala, 1983).

However, there is no guarantee that $\hat{\sigma}^2_1$ and $\hat{\sigma}^2_2$ will always be positive. Lee and Trost (1978) suggested two methods in estimating $\hat{\sigma}^2_1$ and, $\hat{\sigma}^2_2$ one of which guarantees that the estimates of $\hat{\sigma}^2_1$ and $\hat{\sigma}^2_2$ will always be positive. Freemen et al., (1998) used this two-stage method for switching regression models in their study.

2. Switching Regression and Frontier Estimation

Since the objective of this study is to estimate the Jasmine and non-Jasmine rice production frontiers, not ordinary frontiers independent from criterion functions, equations (6) and (7) must, then, be modified to be the stochastic frontier functions. Because the error terms of (6) and (7) are heteroscedastic, the WLS method must therefore be used (Maddala, 1983; Freeman et al., 1998). The transformed equations (using WLS) from (6) and (7), respectively, are

Jasmine rice production function : $$y^*_{1i} = X^{*'}_{1i}\beta_1 - \sigma_{1u}W^*_{1i} + \varepsilon^*_{1i} \qquad (14)$$

Non-Jasmine rice production function : $$y^*_{2i} = X^{*'}_{2i}\beta_2 + \sigma_{2u}W^*_{2i} + \varepsilon^*_{2i} \qquad (15)$$

$$\varepsilon^*_{1i} \sim N(0,\sigma^2_{\varepsilon^*_1}),\ \varepsilon^*_{2i} \sim N(0,\sigma^2_{\varepsilon^*_2})$$

To estimate the production frontiers to measure the technical efficiency, equations (14) and (15) may be expressed as

Jasmine rice production frontier : $$y^*_{1i} = X^{*'}_{1i}\beta_1 - \sigma_{1u}W^*_{1i} + V_{1i} - \theta_{1i} \qquad (16)$$

Non-Jasmine rice production frontier : $$y^*_{2i} = X^{*'}_{2i}\beta_2 + \sigma_{2u}W^*_{2i} + V_{2i} - \theta_{2i} \qquad (17)$$

where $V_{1i} \sim N(0,\sigma^2_{V_1})$, $V_{2i} \sim N(0,\sigma^2_{V_2})$; θ is truncated normal

$$f(\theta) = \frac{2}{\sigma_\theta (2\pi)^{1/2}} \exp\left(\frac{-\theta^2}{2\sigma^2_\theta}\right) \qquad (\theta \geq 0) \qquad (18)$$

The term $-\theta$ is the one-sided error. This implies that each observation is on or below the frontier. $-\theta$ is called "technical inefficiency" (Maddala, 1983). The and are non-negative random variables and called technical inefficiency effects, which are assumed to be independently distributed such that θ_{1i} and θ_{2i} are defined by the truncation (at zero) of the normal distribution with means μ_{1i} and μ_{2i} and variances $\sigma^2_{\theta_1}$ and $\sigma^2_{\theta_2}$ (Seyoum et al., 1998). V is the usual two-sided error that represents the random shifts in the frontier due to favorable and unfavorable factors. It captures measurement error in y as well.

If θ and V are distributed independently, and from Weinstein's result (1964), We obtain

$$g(\varepsilon^*_1) = \frac{2}{\sigma}\phi\left(\frac{\varepsilon^*_1}{\sigma_{\varepsilon^*_1}}\right)\left[1-\Phi\left(\frac{\varepsilon^*_1\lambda_1}{\sigma_{\varepsilon^*_1}}\right)\right] \quad (19)$$

$$g(\varepsilon^*_2) = \frac{2}{\sigma}\phi\left(\frac{\varepsilon^*_2}{\sigma_{\varepsilon^*_2}}\right)\left[1-\Phi\left(\frac{\varepsilon^*_2\lambda_2}{\sigma_{\varepsilon^*_2}}\right)\right] \quad (20)$$

where $\sigma^{*}{}^{2}_{\varepsilon_1} = \sigma^2_{\theta_1} + \sigma^2_{V_1}$, $\lambda_1 = \sigma_{\theta_1} / \sigma_{V_1}$

$\sigma^{*}{}^{2}_{\varepsilon_2} = \sigma^2_{\theta_2} + \sigma^2_{V_2}$, $\lambda_2 = \sigma_{\theta_2} / \sigma_{V_2}$

$\phi(\cdot)$ and $\Phi(\cdot)$ = density function and distribution function of standard normal distribution respectively.

The estimation method for production frontiers was suggested by Aigner et al., (1977). To measure average inefficiency, Aigner et al., (1977) suggested using $\lambda_2 = \sigma_\theta / \sigma_V$ and $E(-\theta) = -(2^{1/2}/\pi^{1/2})\sigma_u$. In case of the Cobb-Douglas, the production frontier may be expressed as

$$y = AK^{\alpha}L^{\beta}e^{-\theta}e^{v} \quad (21)$$

In this case the technical efficiency is

$$e^{-\theta} = y/(AK^{\alpha}L^{\beta}e^{v}) \quad (22)$$

where $-\theta$ is half normal. The mean of technical efficiency is, then, obtained as

$$E(e^{-\theta}) = 2\exp\left(\frac{\sigma^2_\theta}{2}\right)[1 - \phi(\sigma_\theta)] \quad \text{(Maddala, 1983)} \quad (23)$$

Jondrow et al., (1982) showed the method of estimation of individual farm inefficiency by showing that the expected value of θ for each observation could be obtained from conditional distribution of θ, given ε and with the normal distribution for V and half normal for θ. The expected value of inefficiency for each farm, given ε, can be obtained as

$$E(\theta \mid \varepsilon) = \frac{\sigma_\theta \sigma_V}{\sigma}\left[\frac{\phi(\varepsilon\lambda/\sigma)}{1-\Phi(\varepsilon\lambda/\sigma)} - \frac{\varepsilon\lambda}{\sigma}\right] \quad (24)$$

(Bravo—Ureta and Rieger, 1991; Wang et al., 1996)

However, since θ_{1i}´s and θ_{2i}´s are non-negative random variables which are assumed to be independently distributed such that θ_{1i}´s and θ_{2i}´s are defined by the truncation (at zero) of

normal distributions with mean μ_{1i} and μ_{2i} and variances, $\sigma^2_{\theta_1}$ and $\sigma^2_{\theta_2}$ respectively, Seyoum et al., (1998) defined each μ_i as a function of some explanatory variables

$$\mu_{1i} = \omega_{11} + \omega_{12}F_{2i} + K + \omega_m F_{mi} \quad (25)$$

$$\mu_{2i} = \omega_{21} + \omega_{22}F_{2i} + K + \omega_m F_{mi} \quad (26)$$

where F_2, K, F_n are explanatory variables.

Because we have heteroscedasticity in Jasmine and non-Jasmine rice production functions mentioned above, the transformed Jasmine and non-Jasmine rice production equations (14) and (15), then, are used. We, like Xu and Jeffrey (1998), then estimate the technical inefficiencies and regress them on Education, Age, Labor force and Male-labor ratio for both Jasmine and non-Jasmine rice as specified later in equations (29) and (30).

To estimate the criterion function by using the probit model, the following variables are included.

I_i and Z_i in this study are defined as follows :

I_i	=	1 if Jasmine rice, i.e., $Z_i'\gamma \geq u_i$
	=	0 otherwise
Z_i'	=	$[D_1, D_2, ATC, P^{JM}, (P^{JM})^2, P^{OT}, (P^{OT})^2, RATIOW]$
D_1	=	1 if the observation is from Phitsanulok province
	=	0 otherwise
D_2	=	1 if the observation is from Tung Gula Ronghai (the Northeastern area)
	=	0 otherwise
ATC	=	The farmers' attitude towards rice farming for commercialisation (scores)
P^{JM}	=	Jasmine rice price, faced by the i th farmer in 1998 (Baht/kg)
$(P^{JM})^2$	=	Square of P^{JM}
P^{OT}	=	Non-Jasmine rice price, faced by the i th farmer 1998 (Baht/kg)
$(P^{OT})^2$	=	Squares of P^{OT}
Ratio w	=	The ratio of irrigated area to the total area of rice production for the i^{th} farmer
γ	=	Vector of parameters

The functional form of the production frontiers for Jasmine and non-Jasmine rice for this study with selectivity variables are specified respectively as

$$Y = AX_1^{\beta_1}X_2^{\beta_2}X_3^{\beta_3} e^{\sum_{j=1}^{7}\alpha_j D_j} e^{-\sigma_{1u}\left(\frac{\phi(Z_i'\gamma)}{\Phi(Z_i'\gamma)}\right)} e^{v_1-\theta_1} \quad (27)$$

and

$$Y = AX_1^{\beta_1}X_2^{\beta_2}X_3^{\beta_3} e^{\sum_{j=1}^{7}\alpha_j D_j} e^{-\sigma_{2u}\left(\frac{\phi(Z_i'\gamma)}{1-\Phi(Z_i'\gamma)}\right)} e^{v_2-\theta_2} \quad (28)$$

where

Y	=	Rice output (kg per rai ; 6.25 rai = 1 hectare)
X_1	=	Seed (kg per *rai*)
X_2	=	Chemical fertilizer (kg per rai)
X_3	=	Labor (man-hours per *rai*)
D1	=	1 if it is Phitsanulok province
	=	0 otherwise
D_2	=	1 if it is Tung Gula Ronghai (the Northeastern area)
	=	0 otherwise
D_3	=	1 if using other chemical substance
	=	0 otherwise
D_4	=	1 if it is transplanted rice
	=	0 otherwise
D_5	=	1 if it is irrigated area
	=	0 otherwise
D_6	=	1 if it had severe drought
	=	0 otherwise
D_7	=	1 if it had neck blast
	=	0 otherwise
$\frac{\phi(Z_i'\gamma)}{\Phi(Z_i'\gamma)}$	=	Selectivity variable for Jasmine rice equation
$\frac{\phi(Z_i'\gamma)}{1-\Phi(Z_i'\gamma)}$	=	Selectivity variable for non-Jasmine rice equation
α , β	=	Parameters

The functional forms of the inefficiency equations for Jasmine and non-Jasmine rice are as follows:

For Jasmine rice:
$$\theta_{1i} = \delta_{11} + \delta_{12}\,\text{Education}_{1i} + \delta_{13}\,\text{Age}_{1i} + \delta_{14}\,\text{Labor force}_{1i} + \delta_{15}\,\text{Male-labor ratio}_{1i} + t_{1i} \quad (29)$$

For non-Jasmine rice :
$$\theta_{2i} = \delta_{21} + \delta_{22}\,\text{Education}_{2i} + \delta_{23}\,\text{Age}_{2i} + \delta_{24}\,\text{Labor force}_{2i} + \delta_{25}\,\text{Male-labor ratio}_{2i} + t_{2i} \quad (30)$$

where δ´s and t´s were parameters and error terms respectively.

Education	=	average education (years) of the members in the household
Age	=	average age of the members in the household.
Labor force	=	labor force (adult persons) in the household
Male-labor ratio	=	male labor to total labor in the household

Like Xu and Jeffrey (1998), OLS procedures are used to estimate equations (29) and (30).

DATA COLLECTION

The data used in this study were collected for crop year 1999/2000 by interviewing farmers in three areas, i.e., Chiang Mai Province , Phitsanulok Province and Tung Gula Rong Hai, (TGR), the Northeastern area and major Jasmine rice production area of the country. The sample size was 489 observations comprising 112, 176 and 201 observations from the corresponding areas.

Three sets of variables were prepared for three models, i.e., probit variety-choice model, production frontier models and technical efficiency models. Some of the variables appear in more than one model. All variables are defined as follows:

The farmers' attitude towards rice farming for commercial reasons (ATC) is measured in terms of scores ranging from 5, the lowest degree of commercialization, to 25, the maximum degree. These scores were evaluated from five questions: (1) Does your production aim for sale before consumption? (2) Do you always think of how to maximize profit when you produce? (3) Do you always think of the return on borrowed money and whether it is worth doing? (4) Do you always set a target of yield per unit of land regardless of production cost? (5) Do you use your borrowed money (planned for production) for social purposes when necessary? Each question is scored 1 to 5 for least agreed to most agreed except for questions (4) and (5) where the scores run in the reverse order. The sum of the scores from the five questions represents the farmers' attitude variable. This variable is expected to be positively related to choosing Jasmine rice for production.

Prices of Jasmine rice (P^{JM}) and other rice (P^{OT}) are measured in nominal term (Baht/kg) with positive and negative relationship respectively to choosing Jasmine rice.

The production area dummy variables D_1 and D_2 represent Phitsanulok and TGR because the physical and biological environments differ from Chiang Mai. These area dummy variables not only reflect differences in the physical environment but also the marketing environment.

Other environmental variables included are (1) ratio of irrigated to non-irrigated area of rice production on each farm (RATIOW). The higher the ratio, the greater the probability of choosing Jasmine rice. (2) Dummy variables of being irrigated (D_5) and having severe drought (D_6) are expected to have respectively, positive and negative relationships with the production of rice.

Neck blast disease (D_7) is a dummy variable (since degree of severity of blast was not measured for non-Jasmine (only values for Jasmine were available)). It takes value 1 when the farmer indicated having observed disease in his field.

Input variables include seed (X_1), chemical fertilizer (X_2), labor (X_3) and other chemical inputs usually consisting of insecticides, fungicides and herbicides (D_3) taking the value of 1 if the farmer used these other chemical inputs and 0 otherwise. Except for the D_3, all variables were measured per area (*rai*) and expected to have positive relationships to production output. As for other chemicals of which farmers usually applied (mostly as defensive measures) positive signs are expected. It is not possible to measure the quantity of chemical used because farmers applied various kinds of chemical that come in different forms (liquid or powder).

Machine time, especially tractor time spent on land preparation, was not included in the production model since most farmers paid for hired tractor services at approximately the same rate per unit of land. The working time per unit of land in terms of the equivalent standard horse power tractor would then be approximately equal for all observations. This is because the contract is based on the same amount of service, i.e., finished ploughing.

Household characteristics are hypothesised to affect technical efficiency namely, average age and education of the household members (years), labor force (adult persons) and the ratio of male labor to total labor.

Table 3. Descriptive statistics of variables for a probit criterion function.

Variable	N	Minimum	Maximum	Mean	SD
I	489	0.00000	1.00000	0.57669	0.49459
D_1	489	0.00000	1.00000	0.35992	0.48047
D_2	489	0.00000	1.00000	0.41104	0.49253
ATC	489	10.00000	25.00000	16.72597	2.76293
P^{JM}	489	4.20000	11.25000	7.36707	1.30899
$(P^{JM})^2$	489	17.64000	126.56300	55.98360	20.13395
P^{OT}	489	2.94000	10.00000	5.04902	0.91990
$(P^{OT})^2$	489	8.64360	100.00000	27.38511	11.18330
Ratiow	489	0.00000	1.00000	0.27223	0.32746

Source: Survey

Table 4. Descriptive statistics of variables for Jasmine rice production function.

Variable	N	Minimum	Maximum	Mean	SD
(ln Y)	282	11.66672	921.59881	354.70531	185.35869
(ln X_1)	282	2.00000	70.39977	16.56432	11.77531
(ln X_2)	282	0.90000	68.25018	13.21683	7.98064
(ln X_3)	282	1.20000	84.40022	20.91309	15.75100
(D_1)	282	0.00000	1.00000	0.26596	0.44263
(D_2)	282	0.00000	1.00000	0.52837	0.50008
(D_3)	282	0.00000	1.00000	0.76241	0.42636
(D_4)	282	0.00000	1.00000	0.41489	0.49358
(D_5)	282	0.00000	1.00000	0.26241	0.44073
(D_6)	282	0.00000	1.00000	0.18794	0.39136
(D_7)	282	0.00000	1.00000	0.74468	0.43682
Selectivity Variable	282	0.14298	1.13717	0.61098	0.27047

Source: Survey

Table 5. Descriptive statistics of variables for non-Jasmine rice production.

Variable	N	Minimum	Maximum	Mean	SD
$(Y)^b$	207	16.00002	1,050.00478	431.00815	188.36119
$(X_1)^b$	207	1.95440	58.82342	15.169591	10.16220
$(X_2)^b$	207	1.72000	40.00000	12.44645	7.07310
$(X_3)^b$	207	1.06667	81.81822	21.78613	16.80959
$(D_1)^b$	207	0.00000	1.00000	0.48792	0.50107
$(D_2)^b$	207	0.00000	1.00000	0.25121	0.43476
$(D_3)^b$	207	0.00000	1.00000	0.83575	0.37140
$(D_4)^b$	207	0.00000	1.00000	0.51691	0.50093
$(D_5)^b$	207	0.00000	1.00000	0.28502	0.45252
$(D_6)^b$	207	0.00000	1.00000	0.10628	0.30894
$(D_7)^b$	207	0.00000	1.00000	0.68600	0.46525
$\frac{\phi(\hat{\alpha}_i Z_i)^a}{1-\Phi(\hat{\alpha}_i Z_i)}$	207	0.43918	1.65978	0.83235	0.25815

Source: [a] Calculation
[b] Survey

Table 6. Descriptive statistics of variables for inefficiency equation for Jasmine rice.

Variable	N	Minimum	Maximum	Mean	SD
Technical Inefficiency[a] effects	282	0.06522	3.01465	0.57321	0.43518
Education[b]	282	0.00000	14.00000	4.83379	1.64226
Age[b]	282	25.50000	72.50000	43.46493	8.88551
Labor[b] force	282	1.00000	8.00000	2.56383	1.16801
Male-labor ratio[b]	282	0.00000	1.00000	0.51858	0.16341

Source: [a] Calculation
[b] Survey

Table 7. Descriptive statistics of variables for inefficiency equation for non-Jasmine rice.

Variable	N	Minimum	Maximum	Mean	SD
Technical Inefficiency[a] effects	207	0.07324	2.56455	0.53187	0.42223
Education[b]	207	0.00000	12.00000	4.60343	1.69665
Age[b]	207	25.50000	72.50000	43.84739	8.98214
Labor[b] force	207	1.00000	8.00000	2.52657	1.10516
Male-labor ratio[b]	207	0.00000	1.00000	0.50826	0.16413

Source: [a] Calculation
[b] Survey

EMPIRICAL RESULTS

The accuracy of prediction using the estimated probit criterion function by maximum likelihood method was 65.85%. There were three significant variables: D_2, RATIOW and ATC at 1%, 5% and 10% levels of significance (Table 8). Surprisingly, all price variables were insignificant. The ratio of irrigated area to the total area of rice production, and Tung Gula Ronghai dummy variables were highly significant in a positive relationship to selection of growing Jasmine rice. Also, the farmers' attitude towards rice farming for commercialization is significant but at the lower level of 10%.

Using the estimated probit criterion function, we estimated the Jasmine and non-Jasmine rice production frontiers with maximum likelihood estimation. The parameter estimates for Jasmine and non-Jasmine rice production frontiers are shown in Tables 7 and 8, respectively. The estimates of the parameters for Jasmine rice production frontier have the expected signs.

All of the estimated coefficients of the variables in the production frontier including $\sigma^2_{\varepsilon 1}$ and λ_1 for Jasmine rice were significantly different from zero at least at 10% level of significance except the estimated coefficients of X_1, D_1, D_3 and D_4, which were seed, Phitsanulok province, other chemical substance, and transplanting rice variables, respectively. That $\lambda_1 = \sigma_{\theta_1}/\sigma_{v_1}$ was significant (at 1% level of significance) implied that the Jasmine rice production frontier did exist. And that the selectivity variable was significant (at 10% level of significance) confirmed that the Jasmine rice production function with self-selectivity used in this study was correct.

Table 8. Estimates of parameters of a probit criterion function by maximum likelihood method.

Variable	Coefficient	Standard-error	t-Statistic	Prob
Constant	-1.61513	1.69673	-0.952	0.3411
D_1	-0.04842	0.16622	-0.291	0.7708
D_2	0.84065	0.17921	4.691****	0.0000
ATC	0.03862	0.02323	1.662**	0.0964
P^{JM}	0.29800	0.43228	0.689	0.4906
$(P^{JM})^2$	-0.02494	0.02794	-0.893	0.3720
P^{OT}	-0.11191	0.16077	-0.696	0.4864
$(P^{OT})^2$	0.01600	0.01327	1.206	0.2277
RATIOW	0.71067	0.20129	3.531****	0.0004
Accuracy of Prediction = 65.85 percent				
McFadden R^2 = 0.093741				

Source : Calculation

Note : McFadden $R^2 = 1 - \frac{\text{Log} - \text{likelihood}}{\text{Re stricted} - \text{L}}$

: **** Significant at 1 percent level

: *** Significant at 5 percent level

: ** Significant at 10 percent level

Table 9. Estimates of parameters of Jasmine rice production frontier.

Variable	Coefficient	t-ratio
Production Function		
Constant A 5.99861	19.284****	
InX_1	0.05933	1.160
InX_2	0.18902	3.970****
InX_3	0.11929	3.164****
D_1	0.02883	0.470
D_2	-0.12051	-0.777
D_3	-0.54057	-3.250****
D_4	-0.00658	-0.058
D_5	0.33818	3.023****
D_6	-0.43274	-6.259****
D_7	-0.20306	-3.271****
Selectivity Variable*	-0.38486	-1.948**
Variance Parameters		
$\sigma^2_{\varepsilon_1}$	0.76968	22.428****
λ_1	3.76162	4.915****

Source : Calculation with Limdep Version 7.0

Note : Selectivity Variable* = $\frac{\phi(\hat{\alpha}_i Z_i)}{\Phi(\hat{\alpha}_i Z_i)}$

: $\lambda_1 = \frac{\sigma_{\theta_1}}{\sigma_{v_1}}$

: $\sigma_{\varepsilon 1} = \sqrt{\sigma^2_{\theta_1} + \sigma^2_{v_1}}$

: **** Significant at 1 percent level

: *** Significant at 5 percent level

: ** Significant at 10 percent level

: All variables were weighted by var $(\varepsilon_{1i} \mid I = 1)$

Table 10. Estimates of parameters of non-Jasmine rice production frontier.

Variable	Coefficient	t-ratio
Production Function		
Constant A	5.31212	10.900****
InX_1	0.03011	0.328
InX_2	0.17821	3.213****
InX_3	0.02447	0.377
D_1	0.20496	2.131***
D_2	0.18363	0.843
D_3	-0.21863	-1.079
D_4	0.23801	1.987***
D_5	0.43708	2.465***
D_6	-0.30281	-3.003****
D_7	-0.04000	-0.536
Selectivity Variable*	0.22087	1.080
Variance Parameters		
$\sigma^2_{\varepsilon_2}$	0.74023	16.294****
λ_2	3.89922	2.853****

Source : Calculation with Limdep Version 7.0

Note : Selectivity Variable* = $\dfrac{\phi(\hat{\alpha}_i Z_i)}{1 - \Phi(\hat{\alpha}_i Z_i)}$

: $\lambda_2 = \dfrac{\sigma_{\theta_2}}{\sigma_{v_2}}$

: $\sigma_{\varepsilon 2} = \sqrt{\sigma^2_{\theta_2} + \sigma^2_{v_2}}$

: **** Significant at 1 percent level

: *** Significant at 5 percent level

: ** Significant at 10 percent level

: All variables were weighted by var $(\varepsilon_{2i} \mid I = 1)$

Likewise, all of the estimates in the production frontier as well as $\sigma^2_{\varepsilon_2}$ and $\lambda_2 = \sigma_{\theta_2}/\sigma_{v_2}$, except the estimates of InX_1, InX_3, D_1, D_2, D_7 and selectivity variable, for non-Jasmine rice were significantly different from zero at least at 5% level of significance. Because of the significance of λ_2, it was explicit that the production frontier for non-Jasmine rice was present.

The production elasticities with respect to chemical fertilizer and labor for Jasmine and non-Jasmine rice were 0.18902, 0.11929, 0.17821 and 0.02447 respectively. However, the production elasticity with respect to labor in the non-Jasmine rice production frontier was not significant. Neck blast disease, on average, reduced the output of Jasmine rice in the 1999/2000 production year significantly while the blast did not reduce the non-Jasmine rice production significantly in the same year. Drought had, on average, a greater negative effect on the production of both Jasmine and non-Jasmine rice than the neck blast.

The average technical efficiency for Jasmine and non-Jasmine rice were 60.72 and 62.81 percents respectively (Tables 9 and 10). In three areas, Chiang Mai, Phitsanulok and Tung Gula Ronghai, the technical efficiencies in Chiang Mai and Phitsanulok were almost the same at 64.28 and 64.68% respectively for Jasmine rice. The efficiencies of these two areas were higher than Tung Gula Ronghai by approximately 13% (Table 11).

For non-Jasmine rice, the technical efficiency in Chiang Mai was highest at 66.92% which was followed by Phitsanulok at 63.13%. Tung Gula Ronghai showed, again, the lowest efficiency at 57.95% (Table 12). The distributions of technical efficiencies of Jasmine and non-Jasmine rice are presented in Figure 1.

The results of the analysis of factors affecting technical inefficiency for Jasmine and non-Jasmine rice are displayed in Tables 11 and 12, respectively. The only significant factors were male-labor ratio and labor force (at 5 and 10% levels of significance respectively) for Jasmine rice. The sign of the estimated coefficient of male-labor ratio was negative. This implies that the higher the proportion of male labors to total labor, the lower the technical inefficiency. The estimated coefficient of labor force had a positive sign which implies that the greater the labor force of the farm household, the greater the technical inefficiency. For non-Jasmine rice, all of the parameter estimates in the inefficiency equation were not significant.

Table 11. Technical efficiency for Jasmine rice.

Technical efficiency	Chiang Mai (% of farmers)	Phitsanulok (% of farmers)	Tung Gula Raonghai (% of farmers)	Total (% of farmers)
Very low (0.0000–0.2000)	0.0	0.0	5.4	2.8
Low (0.2001–0.4000)	6.9	9.3	22.1	15.6
Moderate (0.4001–0.6000)	27.6	24.0	23.5	24.5
High (0.6001–0.8000)	48.3	54.7	28.9	39.7
Very high (0.8001–1.0000)	17.2	12.0	20.1	17.4
Total	100.0	100.0	100.0	100.0
Average technical efficiency	**0.6428**	**0.6468**	**0.5139**	**0.6072**

Source: Calculation

Table 12. Technical efficiency for non-Jasmine rice.

Technical efficiency	Chiang Mai (% of farmers)	Phitsanulok (% of farmers)	Tung Gula Raonghai (% of farmers)	Total (% of farmers)
Very low (0.0000–0.2000)	0.0	1.0	13.5	3.9
Low (0.2001–0.4000)	0.0	6.9	9.6	5.8
Moderate (0.4001–0.6000)	27.8	30.7	17.3	26.6
High (0.6001–0.8000)	55.6	44.6	34.6	44.9
Very high (0.8001–1.0000)	16.7	16.8	25.0	18.8
Total	100.0	100.0	100.0	100.0
Average technical efficiency	**0.6692**	**0.6313**	**0.5795**	**0.6281**

Source: Calculation

Table 13. Estimated coefficients of inefficiency equation for Jasmine rice.

Variable	Coefficient	t-ratio
Constant	0.44207	2.157***
Education	0.00392	0.254
Age	0.00381	1.271
Labor force	0.04234	1.782**
Male-labor Ratio	-0.31304	-2.320***
$R^2 = 0.026821$	$adjR^2 = 0.01277$	F-test = 1.91

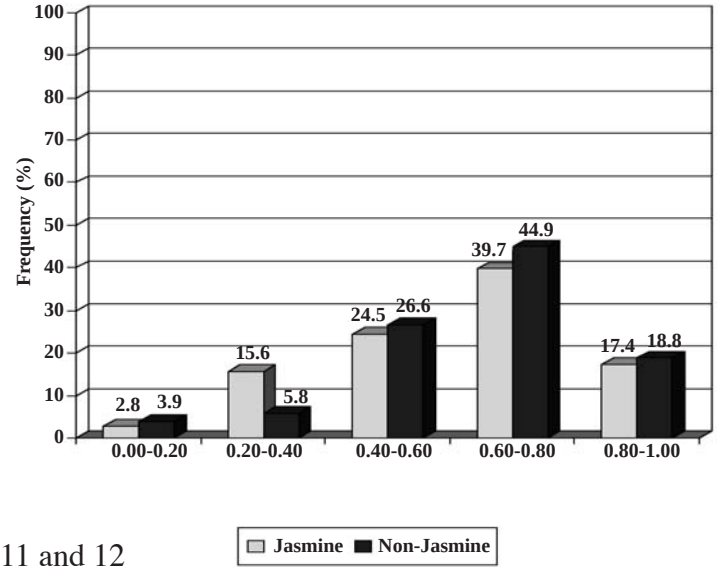
Source : Calculation from Limdep Version 7.0
Note : *** Significant at 5 percent level
** Significant at 10 percent level
: Heteroscedasticity occurred and it was corrected.

Table 14. Estimated coefficients of inefficiency equation for non-Jasmine rice.

Variable	Coefficient	t-ratio
Constant	0.68112	2.727****
Education	-0.00321	-0.211
Age	-0.00226	-0.765
Labor force	0.04136	-1.571
Male-labor Ratio	-0.27486	-1.309
$R^2 = 0.025768$	$adjR^2 = 0.00648$	F-test = 1.34

Source : Calculation from Limdep Version 7.0
Note : **** Significant at 1 percent level
: Heteroscedasticity occurred and it was corrected.

Figure 1. Distributions of technical efficiencies of Jasmine rice and non-Jasmine rice.



Source: Tables 11 and 12

POLICY IMPLICATIONS

The percents of the output reduction due to the drought were 35.13 and 26.13 while reductions due to the neck blast were substantially lower at 18.38 and insignificantly different from zero for Jasmine and non-Jasmine rice respectively, in the 1999/2000 production year. This implies that the effect of drought severity was more intense than that of the neck blast. Irrigation policy for Jasmine rice production area should receive more attention relative to neck blast. It also implies that developing a drought-resistant Jasmine rice variety would be advisable. The average technical efficiency for Jasmine rice was just 60.72%. Thus, substantial yield gains in Jasmine rice could be made by improving technical efficiency. Unfortunately, the inefficiency equation for Jasmine rice estimated in this study could not explain the relationship between the inefficiency and factors affecting the inefficiency at a satisfactory degree. Further research on the determinants of technical efficiency for Jasmine rice is highly recommended.

CONCLUSION

To improve Jasmine rice yield per *rai*, irrigation policy for Jasmine rice production area, Jasmine rice drought-and neck-blast resistant variety development and technical efficiency improvement are strongly recommended. The maximum gains are 39.28, 35.13 and 18.38 percent for each improvement of technical efficiency, drought and neck blast resistance respectively. Since the determinants explaining the inefficiency equation for Jasmine rice investigated in this study are dubious, further research on this issue is needed. However, since the observed data used in this study were not sampled randomly from the population due to the farmers' decision on the selectivity of growing Jasmine rice or non-Jasmine rice, then the stochastic production frontier method of estimation to investigate the technical efficiency had to be modified to include a self-selectivity variable to eliminate biases of the estimated parameters.

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