CHAPTER VI

ANALYSES OF THE STOCHASTIC FRONTIER, DETERMINANTS OF TECHNICAL INEFFICIENCY AND ALLOCATIVE EFFICIENCY

This is a pivotal chapter of this study. It focuses on evaluating the empirical results of the stochastic frontier production function estimation of litchi yield, technical efficiency of the specific farms as well as determining factors influencing technical inefficiency. Empirical models, definition of variables and tests of multicollinearity and heteroscedasticity were conducted prior to estimation of frontier function and technical inefficiency model. In addition, analyses of input optimization are also presented in this section.

6.1 Empirical models and variables

6.1.1 Empirical model for the stochastic frontier production function

The empirical model to estimate the frontier production function of litchi yield was constructed in the Cobb-Douglas functional form as follows:

$$Y = \beta_0\, TAGE^{\beta 1} IRBEAR^{\beta 2}\, DENS^{\beta 3}\, LAB^{\beta 4}\, FER^{\beta 5}\, SPRAY^{\beta 6}\, e^{\beta 7D1+\beta 8D2}\, e^{v-u} \qquad (12)$$

or it can be written in the log form for individual farm as:

$$LnY_j = \beta_0 + \beta_1 Ln(TAGE_j) + \beta_2 Ln(IRBEAR_j) + \beta_3 Ln(DENS_j) + \beta_4 Ln(LAB_j) + \beta_5 Ln(FERT_j) + \beta_6 Ln(SPRAY_j) + \beta_7 D_{1j} + \beta_8 D_{2j} + v_j - u_j \qquad (13)$$

where,

Y_j = litchi productivity of farm j (kg sao^{-1})

TAGE = average litchi tree age (years)

IRBEAR = proportion of irregular bearing (percent)

DENS = density of tree (trees sao^{-1})

LAB = quantity of labor used in the production (mandays sao^{-1})

FERT = cost of chemical fertilizer applied (,000 VND sao^{-1})

SPRAY = cost of chemical spray (,000 VND sao^{-1})

D_1 = dummy for production environment, taking value of 1 if farm is located in the old alluvial soil area, and 0 if it is located in ferralitic soil area

D_2 = dummy for manure application, taking value of 1 if farm used liquid manure, and 0 if not

j subscript denotes farm j

β_i = coefficients of variables

$v_j - u_j$ = error terms, of which

v_j = two sided error terms representing random error of farm j

u_j = one sided-nonnegative error term, representing technical inefficiency of farm j

e = base of natural logarithm (=2.7183)

Ln = natural logarithm

1 sao = 360 m^2

6.1.2 Empirical model for assessing determinants of technical inefficiency

Despite the main factors of production shown explicitly in the production function, managerial capability is somehow implicitly involved in the frontier production function that relates to technical efficiency (Paudyal, 1996). In reality, managerial capability is not measurable; it is quite an important factor that influences efficient levels among the litchi farmers. Even all farmers use the same technology and same inputs, some farmers can produce more than the others due to their managerial capability or human capital.

In this study, farm-specific technical inefficiency was hypothesized to be influenced by age, number of years of litchi cultivation experience, education level, ethnic group and access to information via supervised credit program as specified by the following regression model:

$$TI_j = \alpha_0 + \alpha_1 AGE_j + \alpha_2 ETH_j + \alpha_3 EDU_j + \alpha_4 EXP_j + \alpha_5 FSIZE_j + \alpha_6 INFOCRE_j + \varepsilon_j \qquad (14)$$

where, j subscript denotes farm j

TI_j = technical inefficiency of farm j

AGE = age of household head

ETH = 1 if household head belongs to majority group (Kinh), and 0 otherwise

EDU = number of years attended in school of household head

EXP = number of years in litchi production experience of household head

FSIZE = farm size measured in sao

INFOCRE = dummy for information, taking value of 1 if household had access to information via supervised credit program, and 0 otherwise

ε = error terms

TI_j is calculated from TE_j of specific farms i.e. $TI_j = (1 - TE_j)$

6.1.3 Definition of variables in the models

Y (Litchi productivity of farm)

This variable was selected as the dependent variable. In the area, most of cultivated litchis (90 percent) belong to one cultivar, namely "Thieu-Thanhha", so the litchi outputs can be considered as a homogeneous one. Litchi yield of household was calculated by summing up fresh fruit weights harvested during the harvesting season 2002. In this study, Y was calculated in kilograms per sao of the productive litchi area only but not for litchi planted area. Commonly, litchi trees begin bearing fruit in the third or forth year after growing, since all commercial litchi trees grown in the area are air-layering trees.

LAB (Labor)

The application of animal power to litchi land was very rare because characteristic of topography in the study area is slightly steepy. The litchi farmers also did not apply machines such as pruning machines or tractors to litchi cultivation.

Labor sources employed to litchi orchards (only for the productive litchi area during a crop of production) consisted of family labor and hired labor. The labors used for the activities include breaking up the earth, weeding, pruning, fertilizing, irrigation, spraying and harvesting. Therefore, this variable was the summation of human labors used for the activities and was expressed as the number of man-days employed per sao (one man-day is equivalent to 8 hours working in a day). The positive effect of labor on litchi productivity was expected in the model.

FERT (Chemical fertilizer application)

Litchi is a perennial crop, so it has characteristics of long production cycle, very environmentally sensitive crop, different needs of fertilizer by different tree ages, health status of each tree, etc. that are different from annual crop. In terms of fertilizer application, litchi farmers in the study area followed recommendations of applying the mixed fertilizer formulas of N:P:K such as 5:7:6 or 5:10:3.

Although this variable could be separated into three variables under pure amounts of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O), it was not done. The reason is that most of respondents reported that they applied the mixed forms of N:P:K (5:7:6 and 5:10:3) to their litchi orchards. Because of this, there were very high correlations among the separated factors of N, P and K that caused the problem of multicollinearity. In the stochastic frontier analysis, we have to deal with a tradeoff between aggregating and omitting variables on the one hand, and multicollinearity on the other hand. Once multicollinearity exists, it brings about large variances of estimators and makes precise estimates difficult. Moreover, in reality some selected farmers did not apply the mixed fertilizer as well as all three kinds of single fertilizer (N, P and K). This led to the loss of some observations since the Cobb-Douglas form does not allow any value of variables in the observations to take value of zero. Alternatively, to deal with the problem of multicollinearity as well as the loss of observations, those kinds of above chemical fertilizer consisting of the mixed and separated fertilizer were aggregated into one variable, namely FERT. This variable was defined as total expense of chemical fertilizer applied to the productive litchi areas during a cropping season. It was measured in thousand VND per sao for each selected household. The average fertilizer prices in the market were applied to calculate cost of fertilizer i.e. Urea (46 percent N) was 2.45 thousand VND kg^{-1}; Superphosphate Lamthao (18 percent P_2O_2) was 0.85 thousand VND kg^{-1}; Kali Sulfate (58 percent K_2O) was 2.5 thousand VND kg^{-1} and the mixed forms of N: P: K (5:7:6 and 5:10:3) were 1.35 thousand VND kg^{-1} for every sample household in order to avert influence of price variation. The prices of those kinds of fertilizer were provided by the district officers as well as fertilizer shopkeepers. Since fertilizer prices in the study area during the crop year 2002 were quite stable, the fertilizer price differences in payment by litchi farmers were negligible.

SPRAY (Chemical spray)

This variable was used to express total amount of money that farmer spent for the purchase of chemical to spray for productive litchi areas only. Chemical sprays were used for preventing and curing pests and diseases, and keeping young fruits out of dropping. It was the summation of expenses per sao (thousand VND) of all sprays during a crop. The calculation of spray cost for this variable was applied in the same way of the fertilizer.

TAGE (Tree age)

Tree age was considered as an important factor affecting litchi yield. Normally, bearing capability of the mature tree is higher than the young and the old ones. Regarding tree age and bearing capability of litchi, up to now there has been no finding on litchi showing the life cycle of fruiting. Reportedly by local officers in the study area, even 30-year-old litchi trees being well-cared were still keeping an increasing trend of fruit yield. As mentioned in Chapter V, the farm average productive tree age was about 9.26 years. With the current age levels, litchi trees in the area were considered as on going in the growth period and were expected to be positively influencing litchi yield.

Average tree age was calculated for each litchi farm using weighted average (only for productive areas) by multiplying the number of productive trees for each tree age group in the farm by the age of the group, then summing up them and finally dividing by total number of productive trees in the households. The minimum tree age group that was considered to be productive is 4 years and the maximum tree age group was found to be 34 years in the surveyed farms.

$$\underset{\text{(years)}}{\text{Average tree age}} = \frac{\Sigma\,(\text{Number of productive trees in age group j x Age of group j})}{\text{Total number of tree of the farms}} \quad (j = 4 \text{ to } 34)$$

IRBEAR (Irregular bearing or alternative bearing)

Since irregular bearing or alternative bearing is a popular phenomenon of some kinds of fruit tree, especially litchi. A tree is not often bearing every year and not fully bearing, there may be a part of tree canopy bearing but not all. If previous year, a tree was heavy bearing, this year it may not bear fruit. This variable was measured only for the productive litchi areas of each household as percentage of the part of tree canopy that was unbearing. This variable was expected to have a negative impact on litchi yield, signifying that higher the proportion of irregular bearing lower the yield.

DENS (Tree density)

Tree density calculated for each litchi farm is defined as the number of litchi trees per sao. The cultivation practices in the study area indicated that about 10 years ago when litchi production was primarily developed, lots of the surveyed farmers cultivated litchi with a thin spacing due to the expensive prices of air-layering. In recent years, they have propagated by air-layering by themselves, so new young trees was added in the middle of mature trees to exploit land resource. However, awareness of appropriate tree density adjustment was very different among the surveyed farmers that could cause the competition on nutrient and light among the trees. Therefore, this variable was considered as a factor affecting litchi yield. The equation applied to calculate tree density is as follows:

$$\text{Litchi tree density (trees sao}^{-1}) = \frac{\text{Total litchi trees in the household}}{\text{Total area (m}^2)} \times 360 \text{ m}^2$$

Note: 1 sao = 360 m²

D1 (Soil structure)

Litchi does not require very specific soil type, although marked differences have been observed between cultivars. It can grow under a wide variety of soils including alluvial soils, loams, heavy clays, organic soils, calcareous soils and rock piles. However, they prefer fresh and alluvial soils, preferably containing a sufficient amount of organic matter essential for vegetative growth in early years. Too much organic matter, however, could be detrimental to flowering in the adult phase (Sauco and Menini, 1989). In the study area, litchis are being grown in two main soil types (e.g. old alluvial and ferralitic soils), so it was assumed that litchis growing in the old alluvial soil bear higher yield as compared to those growing in ferralitic soil. Hence soil structure was used as a dummy variable in the stochastic frontier function.

D2 (Liquid manure)

In practice, not all of the surveyed farms applied farm-yard manure to litchi orchards except for the farms that raised lots of pigs. Normally, the farmers who raised lots of swine built the tanks to store their manure under the liquid form and then watered this source to their litchi orchards regularly. Amount of manure applied to litchi orchard was very difficult to measure. For that reason, the second dummy variable (D2) was included in the stochastic frontier model to denote for the farmers who followed the method of watering liquid manure. These farmers were assumed to get better litchi yield than the others who did not follow this method.

FSIZE (Farm size)

The field survey showed that farm size among the sample varied greatly from 4 to 68 sao with an average of 20.56 sao. Hence, this variable was employed to measure effect of the change in farm size of each household on its technical inefficiency. The influence of farm size was assumed to be positive on technical inefficiency of litchi farmers. It means that when farm size increases it causes difficulties for farmers to organize and to manage their orchards since lacks of labor and capital. This variable was measured in sao of the litchi planted area.

AGE (Age of household head)

The older farmer was expected to be better aware of litchi cultivation than the younger one. The survey indicated that the elder farmer had better ability of resource management and utilization than the younger ones, even they worked very diligently and carefully, since almost all the household heads were in the age of working. Hence, this variable was employed in the model to capture effect of age of the household head on technical inefficiency. Therefore, it was expected to have a negative impact on technical inefficiency.

EDU (Education level of household head)

This variable was measured as the years of schooling attainment of household heads. He or she was the household head since he or she was a person who played a pivotal role in the family and had power to make decisions. The education level reflects the abilities of household heads in resource utilization and adoption of new scientific advances. It was assumed that the higher education that a household head had the lower technical inefficiency of litchi production he or she obtained.

EXP (Experience of household head in litchi production)

This variable was used to present the years that household heads experienced in litchi cultivation. This criterion was used widely to many empirical researches relating to production function and technical efficiency and it showed that contribution of farming experience is significant to the increase in technical efficiency of agricultural production. The experience of household head thus was included in the technical inefficiency model and expected to have a negative influence on technical inefficiency of litchi production.

INFOCRE (Access to information via supervised credit program)

This variable was included in the model to capture influences of access to information via the supervised credit program by litchi farmers in the study area on technical inefficiency of litchi production. From the field survey, it was found that the litchi farmers who had the access got better understandings of litchi cultivation than the others. They responded that they got the useful knowledge of litchi cultivation techniques such as irrigation, pruning and training, fertilizing, and pest and disease control from the bank staff via the materials that they were introduced such as "Experiences of Litchi Cultivation in Lucngan", "Litchi Cultivation Techniques in Upland and Hill", and as well as advertisements for new advances for litchi production and the usage i.e. mixed fertilizer and chemical sprays when they came to the bank.

In practice, the borrowers also expressed that they were worried about the amount of money they owed to the bank, so they were very concerned about the efficiency of resource utilization with an expectation of achieving a bumper crop and good litchi prices. Almost all the borrowers tried to access and learn about knowledge of methods of fertilizer application (i.e. amount and on timing of application as well as proper application), irrigation, pruning techniques, air-layering, etc. Hence, access to credit included in the technical inefficiency model served as a dummy variable and expected to have a negative influence on technical inefficiency of litchi farm.

ETH (Ethnic group)

Although litchi cultivation has a very long history in Vietnam, it has really developed for about 10 years. Litchi was primarily planted in Lucngan district, Bacgiang province by the Kinh people migrating from Thanhha district, Haiduong province in the 1960s. Nowadays, litchi affirms its position in the local economy and is widely grown in the province not only by the Kinh people but also by ethnic minority groups such as Tay, Nung, Sandiu, Caolan, etc. With regards to social context in litchi production, ethnic criterion was considered as a factor affecting litchi production in terms of human resource. Since Kinh group is the ethnic majority, it was considered to have better awareness of litchi cultivation practices than the others. Therefore, it was employed to the model as a dummy variable, taking value of 1 for the Kinh households and 0 otherwise.

6.2 Descriptive Statistics of the variables

The simple descriptive statistics of mean, standard deviation (SD), maximum, minimum and coefficient of variation (CV) of the variables included in the stochastic frontier production function and technical inefficiency model are presented in Table 18.

Table 18 Descriptive statistics of the variables included in the stochastic frontier function and technical inefficiency model

Variable	Unit	Mean	SD	Minimum	Maximum	CV (%)
			Stochastic frontier model			
Y	kg sao^{-1}	392.71	170.38	107.14	833.33	43.39
TAGE	years	9.26	2.03	5.00	15.08	21.95
IRBEAR	percent	17.90	8.88	2.00	40.00	49.61
DENS	trees sao^{-1}	11.03	4.02	3.33	20.00	36.41
LAB	mandays sao^{-1}	13.47	8.19	4.20	40.50	60.80
FERT	,000 VND sao^{-1}	129.70	84.07	8.25	409.12	64.82
SPR	,000 VND sao^{-1}	35.87	31.18	10.0	135.00	86.92
D1	dummy	0.337	0.476	0.00	1.00	141.3
D2	dummy	0.287	0.455	0.00	1.00	158.54
			Technical inefficiency model			
AGE	years	43.16	10.24	21.00	73.00	23.72
ETH	dummy	0.575	0.497	0.00	1.00	86.43
EDU	years	6.85	2.28	2.00	10.00	33.31
EXP	years	14.47	5.05	5.00	34.00	34.86
FSIZE	sao	20.56	14.07	4.00	68.00	68.43
INFOCRE	dummy	0.525	0.502	0.00	1.00	95.62

Source: Survey and calculation, 2002

It was found that, the factors that had high coefficients of variation were farm size, labor, fertilizer, and spray with coefficients of variation (CV) of over 60 percent (except for dummy variables). Especially, CV of chemical spray was 87 percent. Irregular bearing and litchi yield had medium CVs of about 49.6 and 43.4 percent, respectively. Low coefficients of variation were found in tree age, tree density, education, experience and age of household heads, which were less than 36.4 percent.

Test of multicollinearity

Multicollinearity is a phenomenon that violates one of the assumptions of the classical linear regression model that is no correlation among the regressors included in the regression model. In other words, each X variable included in the model has a separate or independent influence on dependent variable, Y. If multicollinearity exists in the model, it makes hard to get coefficient estimates with small variance, and causes t scores of one or more coefficients of regression tend to be statistically insignificant (Gujarati, 1995). Therefore, it is necessary to detect its existence in the model. The simple way to test multicollinearity is to establish and to examine the correlation matrix for the independent variables (Sriboonchitta, 1983). If some of the pairwise correlations among explanatory variables in the multiple regression are high, say, in excess of 0.8. There is a possibility that some serious collinearity exist (Gujarati, 1999). However, the author also suggested that depending on the purpose of the study that it can be accepted, even high collinearity the R square and estimators are statistically significant.

Data in Tables 19 and 20 showed the correlation matrices of the explanatory and dependent variables in the models. It was found that correlation between the pairs of explanatory variables were less than 0.5 in both the stochastic frontier and technical inefficiency but one correlation of labor to irregular bearing (0.58). Since the variables included in the model play a critical role, and have a strictly theoretical relation in generating litchi yield, the remedy for multicollinearity can be worse than do nothing. In general, correlations between the pairs the explanatory variables in the two models were acceptable, meaning that the explanatory variables in the models were considered to be free from severe multicollinearity.

Table 19 Correlation matrix for listed variables in the stochastic frontier model

	LnY	LnTAGE	LnIRR	LnDENS	LnLAB	LnFERT	LnSPR	D1	D2
LnY	1.00								
LnTAGE	.3640	1.00							
LnIRR	-.5927	-.1729	1.00						
LnDENS	.3028	-.2206	-.2820	1.00					
LnLAB	.7621	.1818	-.5822	.4973	1.00				
LnFERT	.5398	.2668	-.3367	.3144	.4562	1.00			
LnSPR	.5740	.1866	-.2839	.1196	.4935	.4741	1.00		
D1	.4514	.3271	-.2885	-.1176	.1641	.2111	.3393	1.00	
D2	.3893	.2358	-.2180	.0471	.2460	.1704	.1539	.2475	1.00

Source: Survey, 2002 and calculation by LIMDEP 7.0

Table 20 Correlation matrix for listed variables in the technical inefficiency model

	TI	AGE	ETH	EDU	EXP	FSIZES	INFOCRE
TI	1.0000						
AGE	-0.46513	1.0000					
ETH	-0.54177	.37162	1.0000				
EDU	-0.10344	.03329	.17138	1.0000			
EXP	-0.23935	.44388	.35875	.04457	1.0000		
FSIZES	0.66537	-.22749	-.27081	.12812	-.10575	1.0000	
INFOCRE	-0.27581	-.07830	.04304	.32319	-.06464	.10780	1.0000

Source: Survey, 2002 and calculation by LIMDEP 7.0

Test of heteroscedasticity

A classical assumption of the linear regression model is that the disturbances u_i are homoscedastic, meaning that they all have the same variance, δ^2. But in reality not always this assumption is fulfilled, if so the variances of ui equal δ_i^2, indicating that it is varying from observation to observation. Hence heteroscedasticity exists in the model (Gujarati, 1999). If this occurs in the model, then OLS estimators are no longer BLUE (best linear unbiased Estimator). Therefore, the t-tests are not reliable; it can lead drawing misleading conclusions.

There are some methods of test for the existence of heteroscedaticity. In this study, the Breusch-Pagan-Godfrey test was applied because this one has been applied popularly in many researches and the sample size of the study is large enough. Under the support of LIMDEP 7.0 or follow the procedures of this test (see Gujarati 1995) to come up with the value of χ^2 = 12.164 with 8 degrees of freedom (see Appendix 5). From the chi-square table for 8 degrees of freedom, the 10, 5 and 1 percent critical χ^2 values were found to be greater than the computed χ^2. Thus, the hypothesis of homoscedastic variance in the model is not rejected.

6.3 Estimation of the stochastic frontier, technical efficiency scores and determinants of technical inefficiency in litchi yield

The results presented in Table 21 of the maximum-likelihood estimates for all the parameters of the stochastic frontier function and inefficiency model, as defined by Eq.(13) and Eq.(14), are simultaneously obtained using the program, FRONTIER Version 4.1c (Coelli, 1996), which estimates the variance parameters as follows:

$$\delta^2_\varepsilon = \delta^2_u + \delta^2_v$$

$$\gamma = \delta^2_u / \delta^2_\varepsilon$$

Table 21 Estimates of the stochastic Cobb-Douglas frontier production function and technical inefficiency model for litchi yield using FRONTIER 4.1

Estimator	Coefficient	t-ratio
Stochastic frontier model		
Ln(CONSTANT)	5.03529	13.279***
Ln(TAGE)	0.23428	1.962**
Ln(IRBEAR)	-0.09672	-2.549***
Ln(DENS)	-0.00564	-0.082ns
Ln(LAB)	0.16432	2.520***
Ln(FERT)	0.07056	2.123**
Ln(SPRAY)	0.04051	1.214ns
D1(SOIL)	0.09299	1.720*
D2(MANURE)	0.11096	2.301**
Technical inefficiency model		
Constant	0.60770	3.161***
AGE	-0.00973	-2.010**
ETH	-0.17127	-2.081**
EDU	-0.00198	-0.133*ns*
EXP	0.00203	0.240*ns*
FSIZE	0.01215	4.753***
INFOCRE	-0.19656	-2.818***
Sigma-squared ($\delta^2_\varepsilon = \delta^2_u + \delta^2_v$)	0.04234	3.836***
Gamma ($\gamma = \delta^2_u / \delta^2_\varepsilon$)	0.73706	2.831***
Log-likelihood	26.06659	
R-squared (OLS)	0.76400	
Adjusted R-squared (OLS)	0.73740	
Model test: $F_{(8, 71)}$ (OLS)	23.73	($F^{0.01}_{tab.}$ =2.78)

*Notes: ***, **, * denote for 0.01, 0.05 and 0.10 levels of significance, respectively; ns means not significant*

6.3.1 Stochastic frontier production function

The estimation of the stochastic frontier production function for litchi yield of the selected farms representing for litchi farms in the province was done based upon the cross sectional data gathered from the sample farms. The results presented in

Table 21 indicated that coefficients of the variables have correct signs. The factors that had statistically significant effects on litchi productivity were tree age, irregular bearing, labor used, fertilizer, regional dummy, and dummy of liquid manure irrigation.

The coefficient of variable tree age was statistically significant at 0.05 level of significance and had value of 0.234. This is an important factor that influenced significantly litchi productivity of the litchi farms. It can be explained that an increase in 1 percent of litchi tree age could lead to an increase in litchi productivity by 0.234 percent. From this result, one can make a prediction for the supply capacity of litchi in the following season. Assuming that others factors are constant, given the average tree age of 9.26 years in 2002, for the following year the trees will increase one year old more, so this will result in an increase in the productivity about 2.53 percent or equivalent to an increase in litchi yield (at mean level) of 9.9 kg sao^{-1} (275 kg ha^{-1}) (excluding yield of new productive trees). Assuming litchi yield as a function of its tree age, its current production is on the second stage of production function, since its marginal physical product (MPP) is less than average physical product (APP). Given this point, a farm planning can be made for the increase in input applications and for the following year.

Irregular bearing was found to have a negative and significant influence at the 0.01 statistically significant level on litchi yield with a coefficient (or an elasticity) of -0.097. It means that on the average, an increase in one percent of the observed value (17.9) of irregular bearing (ignore the measurement of this variable) could lead to a decrease in litchi yield by 0.097 percent. Assuming that keeping other variables constant, for the following season (2003) if the observed level of irregular bearing (17.9 percent) increases to, let say, 25 percent (the annual average level as estimated by local officers) or 40 percent as occurred in 2001, then the litchi yield will decrease to 15 kg sao^{-1} (417 kg ha^{-1}) or 47 kg sao^{-1} (1,305 kg ha^{-1}), respectively (at mean level). These predictions implied the considerable impact of this phenomenon on performance of litchi farmers. If farmers are informed about litchi cultivation techniques they can prevent losses caused by irregular bearing via techniques such as pruning, training, on timing of irrigation, and fertilizing to create symmetric tree shapes and successful blossoming that can avoid the irregularity of weather condition.

Human labor had a positive impact on litchi productivity at the 0.01 statistically significant level with a coefficient of 0.164. It can be interpreted that an increase in one additional percent of labor could lead to an increases in litchi yield by 0.164 percent. Considering at mean levels, if farmer employs one more manday per sao of the productive litchi orchard he or she will get 4.8 kg sao^{-1} more, assuming that other factors are constant. In general, farmers in the area used simple technology for litchi production, to date human labor is mainly used. This finding indicated that litchi farms in the province could employ more labor for their farms from their abundant source if they want to enhance litchi yield. However, when farmers need to hire more labor due to lack of family labors, it is necessary to consider the wage of hired labor with its marginal value of product. This issue will be discussed in the Section 6.4. In recent years, litchi production has developed rapidly not only in the province but in other provinces, so the price of litchi fruit had a very fast going down trend.

Coefficient of fertilizer application with a value of 0.071 was also found to be positive in sign and statistically significant at 0.05 level of significance. This tells us that total expense of chemical fertilizer spent for litchi orchards had a positive effect on litchi yield. If farmers apply one additional percent of fertilizer expense with a proper rate of mixed fertilizer could lead to an increase in output by 0.071 percent. Keeping other factors constant and considering at mean level, an increase in one additional thousand VND of fertilizer cost per sao could raise litchi yield by 0.215 kg sao^{-1}. Lately years, litchi farmers have been copping with the situation of low output prices of litchi fruit, so they have to take into account of opportunity cost, whether they should invest these resources more or not. Similarly to the way of explanation for labor used, we need to consider the marginal value of product of fertilizer and its price, otherwise profit from litchi production of farmers will decrease. This issue is discussed in the Section 6.4.

Regarding the density of litchi tree, from the results of MLE, it was found to have a negative effect but statistically insignificant on litchi yield. This implies that, a negative effect of this variable on litchi yield was negligible and competitions in the population began happening. Current tree density of the surveyed farms is becoming denser (11 trees sao^{-1} at average age of 9.26 years) because most of litchi trees now are in the growth period, their canopies have a bigger trend. It will induce a decrease in litchi output in the next crops if farmers do not have an appropriate adjustment in litchi tree density and tree canopy.

The findings showed that coefficient of chemical spray had a positive sign but was not statistically significant, meaning that effect of the input on litchi yield was negligible, since farmers used this input inefficiently. Results from the field survey also showed that practice of chemical spray was very different among the households. Lots of farms suffered from severe pests since the diagnostics were not precise and they had to spray not only for prevention but for curing. Expenses of chemical spray among the sample survey varied greatly with a large CV (87 percent). The maximum use of this input per sao was nearly 13.5 times higher than the minimum one. The number of sprays varied among the households even some farms had 8 sprays, while some others had only 2-3 times of spray. This proved a shortage of technical knowledge of pest and disease management of the litchi farmers.

The coefficient of environmental dummy variable (D1) that reflects litchi cultivation in different soil structures was the 0.1 statistically significant level and had a value of 0.093. It can be explained that on the average, farmers cultivating litchi in the alluvial soil area had a yield of 1.1 times (or 39 kg sao^{-1}) higher than those cultivating in the ferralitic soil area (keeping other factors constant). This can be explained by the difference in soil quality. Most of litchi trees in Bacgiang province were cultivated in two basic soil types, ferralitic hills and old alluvial soil located on the left bank of Lucnam river. In terms of quality, ferralitic soil seems to be poorer in nutrition than old alluvial soil.

Coefficient of dummy variable (D2) was the 0.01 statistically significant level and had a value of 0.111, signifying that if other factors are kept constant, the farmers who raised lots of pigs and followed the method of watering liquid manure to litchi trees, had a productivity of 1.117 times higher than those who did not follow this method. This is equivalent to a difference of 46 kg sao^{-1} on the average. The findings showed that farmers who followed this way regularly had high litchi yield and technical efficiency scores even when they applied low levels of chemical fertilizer, and this method can reduce land degradation.

The R-square in OLS regression was statistically significant at the 0.01 statistically significant level and had a value of 0.764, which implies that 76.4 percent of total variation in ln of output can be explained by the ln of variables existing in the model. The rest, 23.6 percent can be associated by the factors outside the model.

Estimation of stochastic frontier function using maximum likelihood estimation (MLE) method differs from the ordinary least squares (OLS) by the inclusion of error term, U_{it}. If all firms produce fully efficiently, meaning that firms have not any percent of technical inefficiency so one sided-none negative error component does not exist (U_{it}= 0) but symmetric error term (V_{it}), the OLS yields consistent estimates of all production frontier parameters.

However, if inefficiency is present (U_{it}>0), the OLS estimation is bias for constant term, whereas the remaining parameters are still consistent (Knittel, 2002). Besides yielding unbiased estimate of the intercept, stochastic frontier analysis has at least two advantages over OLS. First, stochastic frontier analysis allows one to obtain estimates of the mean level of inefficiency present in the data. OLS is incapable of this because a measurement of mean level of inefficiency requires a consistent estimate of the intercept as well as the distributional properties of both the two-sided error term and the "inefficiency" error term. Second, stochastic frontier analysis allows one to obtain estimates of the variance in inefficiency, which would allow policy makers to measure the extent to which efficiency levels vary among firms.

To investigate whether a stochastic frontier production function does exist or not, it is required by testing the significance of the γ (gamma) parameter that the $\gamma = \delta^2_u / \delta^2_\varepsilon$, measures the total variation in output from the frontier which is attributed to technical efficiency. If the null hypothesis, that γ equals zero or effect of technical inefficiency is not statistically significant, is not rejected, this indicates that σ^2_u is zero. Hence that the U_t term should be removed from the model, leaving a specification with parameters that can be consistently estimated using the OLS. It should be noted that any likelihood ratio test statistic involving a null hypothesis, which includes the restriction that γ is zero does not have a chi-square distribution because the restriction defines a point on the boundary of the parameter space (Coelli, 1996).

The results in Table 21 also showed that the value of γ for the stochastic frontier model was statistically different from zero at 0.01 level of significance (asymptotic t-statistic = 2.83), implying that there exists a significant difference between the two (OLS and MLE) production function estimates. For that, the difference between observed and frontier value was dominated by technical inefficiency. This proved that the stochastic frontier production function does exist so it allows us to estimate technical efficiencies for each specific farm. The γ had a value of 0.737, which implies that 73.7 percent of the discrepancies between the observed values of output and the frontier outputs in the study area unexplained by the model was due to technical inefficiencies. Hence, only 26.3 percent of total variation in output was attributed to random effects causing by the factors outside of the model.

The computed variance ratio parameter $\lambda = \delta_u/\delta_v$ in the model was 1.6743. The λ value was greater than unity indicated that the one-sided error (u_i) dominates the symmetric error (v_i). This implies that a greater part of the residual variation in the litchi yield was associated with the variation in technical inefficiency rather than with measurement error, which was associated with uncontrollable factors, related to the production process.

6.3.2 Determinants of technical inefficiency

The shortfall of realized output as mentioned earlier from the frontier is primarily due to factors that were within the control of litchi farmers in the sample survey that relate to managerial capability. Although, managerial capability is not measurable, it is quite an important factor that influences efficient levels among the litchi farmers. In this study, technical efficiency of the specific farm was assumed to be influenced by the characteristics of household head i.e. age, litchi cultivation experience, education level, and ethnic group and access to information via the supervised credit program, and farm size. The results of the estimates of the explanatory variables in the technical inefficiency model were presented in Table 21.

The factors that had significant impact on technical inefficiency were found to be age of household head, ethnic characteristic, credit access and farm size. The negative coefficient of an explanatory variable implies that inefficiency level decreases as its absolute value increases, or it is equivalent to an increase in the efficiency level. On the contrary, the positive ones show the positive influences on technical inefficiency.

The FSIZE (farm size) had a positive coefficient, signifying that technical efficiency decreases as farm size increases. This can be explained by the limitation of resources for the production process such as labor and capital that farmers had to face when they expand their farm scale.

The dummy variable ETH (ethnic group) had a negative impact on technical inefficiency, which implies that the farmers who belong to ethnic minority groups on the average achieved lower technical efficiency than those who are ethnic majority (as implied for Kinh people).

For the dummy variable INFOCRE (access to information via the credit program), the result indicated that the farmers who had access to the credit program obtained lower technical inefficiency than the others who did not have access. This proved the role of the supervised credit program in assisting the knowledge of litchi cultivation and introducing new scientific advances to litchi growers.

The coefficient of variable AGE (age of household head) was statistically significant and had a negative sign showing that elder household head obtained lower technical inefficiency scores than the younger one. Seemingly, this is a contrary to theory but it can be explained. The reason is that ages of almost all the household heads were in the working age. Mostly, they were less than 50 years old, so the elder ones are still active, and have very rich farming experiences as well as resource management capability, while the young farmers, who became the household head not long, lack farm management experiences.

The effects of the two variables, EDU (education) and EXP (experience) were not statistically significant. It means that these two variables had negligible effects on technical inefficiency, even as the variable EXP (experience) had a wrong sign. The reason that can explain the insignificance of the EDU is that this variable had a small CV. It means that the deviation of education level of the household heads was low. For the EXP in the case of litchi farmers, the years of litchi cultivation that they experienced was partly attributed to litchi tree ages but not all because some household heads inherited litchi orchards from their parents or bought them from other owners. The variation in the years of the experience among the household heads was also small because litchi production has actually developed in the area not long (for about 10 years lately), this led to its insignificant effect on technical inefficiency.

6.3.3 Evaluation of technical efficiency scores

The technical efficiency ratio, that is the ratio of actual to potential output, was calculated for each of the 80 litchi farms in the survey sites. Figure 13 shows the frequency distribution of production-unit-specific technical efficiency for each farm appeared in the sample. Predicted technical efficiencies ranged from a minimum of 34.1 percent to a maximum of 95.5 percent with a mean value of being 74.7 percent and a standard deviation of 16 percent. Although, 22.5 percent of the sampled farms that had very high efficiency scores that are 90 percent or greater, 17.5 percent of those farms had very low technical efficiencies that are below 60 percent.

Technical inefficiency meanwhile represents the degree of failure to produce the maximum output from a given level of inputs. One percent technical inefficiency means that the litchi farmers could have produced one percent more output from existing level of inputs. Jondrow *et al.* (1982) used (1 -TEi) to predict the technical inefficiency of the i^{th} firm.

Following Jondrow *et al.* (1982), the technical inefficiency for the litchi farmers was computed and it ranged from between 4.49 (=1- 0.9551) and 65.89 percent (=1-0.3411). This signifies that there exists an extent of 4.5 to 65.9 percent of potential for increasing output of the litchi farmers from the existing level of their resource used. Therefore, there exists a big potential for expansion in the output by adopting the technology of the best-practiced litchi farmers incorporate with optimal resource allocation.

In this analysis the results showed that on average there is 23.27 percent (=1-0.7473) technical inefficiency in the selected households. This means that actual litchi output is 23.27 percent less than the maximum output, which can be achieved from the existing level of inputs used. In case, mean levels of technical efficiencies show a high degree of technical and management ability, Battese (1992) noted that very high levels of technical efficiencies indicated that increasing production would require new innovations or a higher level of technology to be introduced.

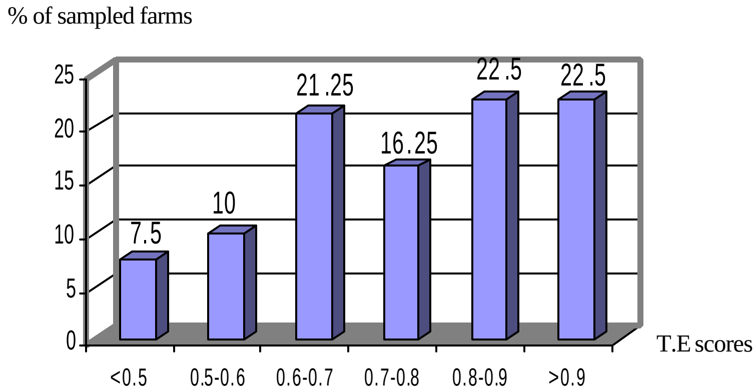

Figure 13 Frequency distribution of predicted technical efficiencies

For in-depth analyses, the mean difference of technical efficiency is compared between groups of litchi farmers based upon criteria that were attributed to them such as credit access, ethnic and farm sizes. Mean differences of technical efficiency of the farmer groups were tested using t-test (Appendix 4). The results are presented in Table 22.

With regards to human capital, the farmers belonging to ethnic minorities obtained a mean value of technical efficiency of 64.7 percent that was significantly lower than that of the ethnic majority group (Kinh people) at 82.1 percent. The findings showed that the farmers who had access to information via supervised credit program, achieved mean value of technical efficiency (78.9 percent) that was significantly higher than that of farmers without the access (70.1 percent).

Especially, mean values of technical efficiency were various in terms of farm sizes (land holding). The findings show that, there had a decreasing trend in technical efficiency as farm sizes increase. In this study, farm size was classified into three levels, small size (<0.5 ha), medium size (0.5-1.0 ha) and large size (>1.0 ha) with the obtained levels of technical efficiency were 86.1, 72.8 and 56.1 percent, respectively. These differences were statistically significant at 0.01 level of significance.

Table 22 Comparisons of mean difference of technical efficiency of each farm group

	Access to information via credit program***		Ethnic***		Farm sizes*** (ha)		
	With	Without	Kinh	Ethnic	<0.5	0.5-1	>1 ha
Mean TE	78.9	70.1	82.1	64.7	86.1	72.8	56.1
% farms	52.5	47.5	57.5	42.5	41.2	37.5	21.3

*Notes: *** denotes for 1%, 5% levels of significance, respectively*

6.4 Optimization of input utilization

Perhaps, profit maximization is the desired goal of any firm. This objective does not exclude the litchi farmers in Vietnam. In terms of micro-economic theory, the optimal level of input usage obtains at the point that marginal value of product of an input (MVP_{Xi}) must be equal to its price (P_{Xi}). In other words, at this level of input use (X* in Figure 14) the firm gets maximum profit. Therefore, once marginal value of product of an input remains greater than its price, producer still get more benefit ($X' < X^*$) if his/her resources are available to employ more. On the contrary, he/she gets loss of profit if employs the additional units of input Xi further from the optimal level of X^*. Of course, it is assumed that the relationship input-output followed the Law of Diminishing Returns to Scale and is considered in the static condition of inputs and output prices.

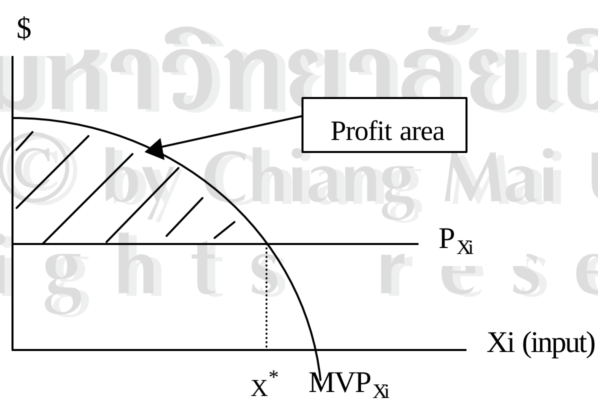

Figure 14 Relationship between marginal value of product and input price

In the Cobb-Douglas function form, the coefficients estimated show the partial elasticity of each input (E_i), it can be expressed as

$$E_i = \frac{\%\text{ change in output}}{\%\text{ change in input i}} = \frac{\delta Y/Y}{\delta X_i / X_i} = \frac{\delta Y/ \delta X_i}{Y/ X_i} = \frac{MPP_{Xi}}{APP_{Xi}}$$

or, $MPP_{Xi} = E_i .Y/ X_i$,

so, $MVP_{Xi} = P_y.E_i.Y/ X_i$ (15)

Given the estimates of the stochastic Cobb-Douglas frontier function incorporate with using the mean values of output, input levels and their prices, the marginal values of product with respect to the purchased inputs that had a statistically significant effect on litchi yield (including labor and fertilizer) are computed based upon Eq.(15). The results are shown in Table 23.

Table 23 Optimal relationship of input utilization

Input	Elasticity, $\hat{E}_i$	Mean inputs	Mean output	Output price, P_y	MPP_x	VMP_x	Input price, P_x	MVP_{Xi}/P_{Xi}
Fertilizer	0.071	129.70	392.7	3.4	0.254	0.731	1.00*	0.731
Labor	0.164	13.47	392.7	3.4	5.107	16.256	15.00	1.084

Notes: - (*) Since chemical fertilizer was measured in terms of value (MPP_{Fert} equals MVP_{Fert}), it price turns out to be unity.

- Price of labor and fertilizer were based on the average prices on the local market.
- Price of labor was wage paid for hired labor by 15 thousand VND manday^{-1}.
- Price of litchi fruit was determined as the average litchi price (3.4 thousand VND kg^{-1}) in harvesting season 2002, based on evaluation of local officers.

A comparison between VMP_{Xi} and P_{Xi} in Table 23 for each input indicated that the VMP of fertilizer was smaller than its price, meaning that on the average, litchi farmers applied a fertilizer level that exceeded the optimal point of allocative efficiency. VMP of fertilizer was 0.731, implying that an increase in one thousand

VND of fertilizer application (at mean level) could lead to the loss of profit by 0.269 thousand VND. It is suggested that at the output price of 3.4 thousand VND kg^{-1}, fertilizer application should be reduced. It could be applied more if and only if the price of litchi is greater than 4.7 thousand VND kg^{-1}, since at this price MVP of fertilizer equals its price.

Regarding labor used, the marginal value of product of labor was 16.26 thousand VND was higher than the wage price, 15.00 thousand VND. It means that at the observed price of output, an increase in one additional manday of hired labor in litchi farms (at mean level) would raise litchi farmer profit by 1.256 thousand VND more. Therefore, human labor should be employed more from hired labor or family labor if available to take care of litchi orchards i.e. weeding, pruning, training and fertilizing in order to enhance litchi yield as well as farmer income.

For more detail, to investigate the actual level of allocative efficiency obtained by individual litchi farms, the ratios of MVP_{Xi}/P_{Xi} were computed for the inputs i.e. labor and fertilizer for each farm appeared in the sample survey based on actual level of those inputs used and output achieved by each farm (Appendices 6 and 7). Distributions of the ratios computed for labor to fertilizer inputs are illustrated in Figures 15 and 16, respectively.

The frequency distribution of MVP_{lab}/P_{lab} ratios for labor among the sample farms was found to be highly concentrated around the optimal value of 1.0 (meaning that $MVP_{lab} = P_{lab}$). Meanwhile, the distribution of these ratios of fertilizer seems to be scattered from the optimal point. This implies that allocative efficiency of labor use among the sample surveys was higher than the fertilizer use.

The results also indicated that, 30 percent of the observed farms operating around the allocative efficiency point of labor had the MVP_{lab}/P_{lab} ratios falling into the range of 0.8 to1.2. Meanwhile, this figure of fertilizer application accounted for 21 percent. About 74 percent of the selected farms overused fertilizer that caused the decrease in their profits, since marginal values of product of fertilizer of those farms were less than its price, while this figure of labor use was 32 percent. None of the farm had fully allocative efficiency in terms of labor and fertilizer utilization.

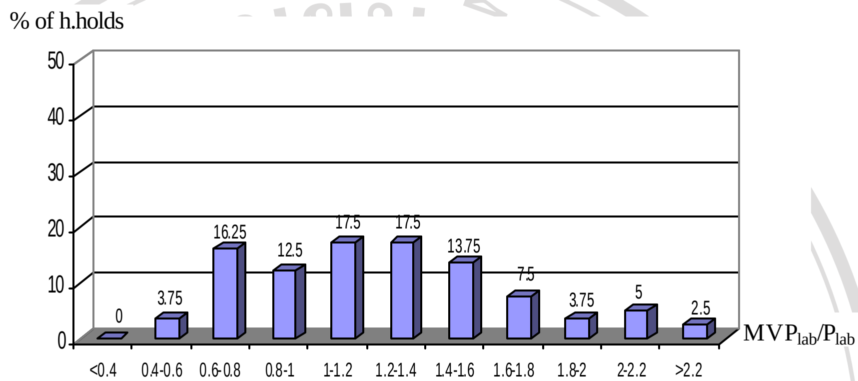

Figure 15 Distribution of MVP_{Lab}/P_{Lab} ratio for labor use

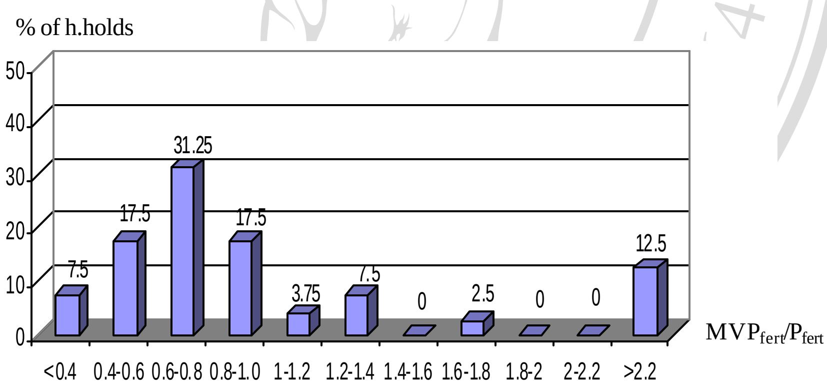

Figure 16 Distribution of MVP_{fert}/P_{fert} ratio for fertilizer use