
Research Paper

Factors affecting technical efficiency of small-holder coffee farming in the Krong Ana Watershed, Vietnam

Abstract: Coffee production is a major source of income for farmers in the Dak Lak province in Vietnam. Although Vietnam is one of the largest coffee producers in the world, research to improve the coffee industry is lacking, in particular, evaluating production efficiency in coffee farming could highlight factors that improve technical efficiency. The overall objective of this study is to estimate the technical efficiency of coffee production and determine which factors affect technical inefficiency of small holder coffee farmers in the Krong Ana Watershed of the Dak Lak province. Based on the stochastic production frontier, the estimated mean technical efficiency scores were 0.7466 and 0.6836 respectively for the Cu Kuin district and the three combined districts (Krong Ana, Krong Bong and Lak). Formal education of the household head, amount of financial credit obtained, ethnicity, coffee farming experience of the household head, and agricultural extension service used were key factors that can reduce technical inefficiency in coffee production.

Key words: Coffee production, Krong Ana Watershed, Technical efficiency, Stochastic production frontier.

1. Introduction

Coffee farming was first introduced to Vietnam by the French in the 1850's; however, following that introduction, coffee production remained relatively low. It was not until after the country's re-unification in 1975 and implementation of the national policy, involving setting "new economic zones" in the Central Highlands, that migrants from across the country began settling in the Central Highlands to establish coffee production in this area. After this occurrence, Vietnamese coffee production increased significantly and Vietnam soon became the fourth largest coffee exporter in the world in 1998 with a share of approximately 6.5% of the world's coffee production (de Fontenay & Leung 2002). This share continued to increase in subsequent years contributing 12.4% of the world's coffee production in crop year 2008/09 (ICO 2010). According to the International Coffee Organization (ICO), Vietnam had become the second largest coffee producer worldwide trailing only Brazil in the 2000/01 to 2008/09 period.

Coffee is the primary export crop for Vietnamese agriculture and plays an important role in the country's economy. This is especially true for the Central Highlands of Vietnam and its role in the world coffee market. The Dak Lak province has been the largest coffee producing province in Vietnam in terms of both coffee yield and planting area. Agricultural production in this

province has been dominated by coffee production (Business Portal)¹. The Krong Ana watershed, known for its large coffee plantations, lies along the Krong Ana River and includes parts of the Krong Bong, Lak, Cu Kuin, and Krong Ana districts within the Dak Lak province (see Figure 1).

Improving technical efficiency can result not only in efficient use of inputs or production resources, but also to increases in coffee production and subsequently, higher profits from coffee farming. For the major agricultural production activity in the Dak Lak province, improving technical efficiency in coffee production can have positive impacts on other business activities in the province. The objectives of this study are three-fold: (1) Estimate technical efficiency in coffee farming utilizing the stochastic production frontier methodology; (2) Identify factors contributing to technical inefficiency in coffee production, and (3) Evaluate the economic effects from increasing (decreasing) technical efficiency.

2. Background information

2.1 Factors affecting coffee production.

A number of studies have examined input factors affecting agricultural production in general and coffee production in particular e.g., Huang & Liu (1994), Alvarez & Arias (2004), Binam *et al.* (2004), Vedenov, Houston & Cardenas (2007), and Nchare (2007). More specifically, Nchare (2007) considered labor in person-days, fertilizers in physical units and pesticide costs as input factors for the coffee production function. Similar factors were evaluated for small food crop production in Cameroon (Kolawole & Ojo 2007). In addition, Illukpitiya & Yanagida (2004) showed that labor, and inorganic and organic fertilizers were primary input factors for paddy production in Sri Lanka. These factors were also employed by Chen *et al.* (2009) for Chinese farms and also by other studies (see Alvarez & Arias (2004); Binam *et al.* (2004); and Illukpitiya & Yanagida, (2010)).

Irrigation is another key factor, influencing coffee production in Vietnam (Tran and D'haeze 2005). However, previous studies suggest conflicting optimal strategies with varied water application amounts. For example, Cheesman *et al.* (2007) found that coffee smallholders in the Dak Lak province tend to over-irrigate by a factor between 2.2 and 5 times the dosage required to achieve most favorable water conditions for a coffee plantation in order to maximize coffee yield. D'haeze *et al.* (2003) recommended an optimal level of efficient water use to be around 1,000 cubic meters per hectare during the flowering stage of coffee production in the Center Highlands of Vietnam. Local authorities suggest that during the dry season, usually from November to April, irrigation application of 3,300 cubic meters per hectare is recommended for coffee plantations (Luu 2002).

2.2 Factors affecting technical inefficiency

Since Farrell's benchmark study (1957), a plethora of empirical studies have evaluated production efficiency. Many studies such as Aigner *et al.* (1977), Battese (1992), Bravo-Ureta & Pinheiro (1993), Battese & Coelli (1995), Binam *et al.* (2004), Illukpitiya & Yanagida (2004) and Rios & Shively (2005) highlighted effects of common socio-economic variables such as age, education, experience, gender, etc. on technical efficiency.

The educational level of the household head, commonly measured by the number of years of schooling, is positively related to the technical efficiency (see for example, Illukpitiya & Yanagida (2004); Binam *et al.*, (2004); Kehinde *et al.* (2010) and Nchare (2007)). Access to credit positively and significantly affects technical efficiency of coffee production in Cameroon (Nchare 2007). Additionally, Illukpitiya & Yanagida (2010), and Kolawole & Ojo (2007) also found similar results from the effects of education and credit on technical inefficiency of agricultural production.

Illukpitiya & Yanagida (2004) showed that educational level, experience of the household head, age of the household head and extension contacts, had positive and significant impacts on technical efficiency. Binam *et al.* (2003) revealed statistically significant results that younger heads of households are more efficient than older heads of households in Côte d'Ivoire. In a subsequent study, Binam *et al.* (2004) also found that access to cash credit is likely to increase technical efficiency of farmers in the slash and burn agriculture zone of Cameroon, by providing funds to reduce capital constraints hindering agricultural households.

Agricultural production and farm specific characteristics vary amongst different ethnic households. D'haeze *et al.* (2005) found that in Vietnam, resource-rich households belong to the Kinh majority, while the ethnic minority is usually unable to participate in production activities involving high investment costs and encounters more difficulties in obtaining credit and loans. The study by Dang & Shively (2008) confirmed that Kinh farmers had significantly higher per capita incomes in 2004. Van de Walle & Gunewardena (2001) discovered that in Vietnam, the majority of highly efficient households were those households having higher levels of education, smaller family sizes and more non-farm economic opportunities. Data also showed that minority people are further constrained by living further from major roads and local commercial centers (Dang 2003). These differences suggest that ethnicity may be an important explanatory variable of coffee production efficiency.

Muhammad-Lawal *et al.* (2009) suggest that young people or children may not be able to contribute to agricultural production activities because they are likely to be in school. Thus, the ratio of the number of children to family size can represent the household's child dependency index that may affect technical inefficiency of agricultural production.

2.3. Theoretical Model

Since the seminal article on efficiency measurement by Farrell (1957), the basic stochastic frontier model was independently proposed by Aigner *et al.* (1977) and Meeusen & van den Broeck (1977). The efficient frontier can be considered as either the maximum level of output for a given set of inputs (an output orientation), or the minimum set of inputs required to produce a given set of output (an input orientation) (Tingley, Pascoe, and Cogan 2005).

Kumbhakar *et al.* (1991), Reifschneider & Stevenson (1991), Huang & Liu (1994) and Battese & Coelli (1995) adopted a single-stage approach in which explanatory variables are incorporated directly into the inefficiency error component. For this method, the variance of the inefficiency error component is hypothesized to be a function of firm specific factors. For this study, the following production model was chosen (see Battese & Coelli (1995)):

$$y_i = f(x_{ij}; \beta_j) \cdot \exp \{V_i - U_i\} \quad (\text{Eq.1})$$

Where y_i is the production of the i -th firm, $i = 1, \dots, n$; x_{ij} is a vector of j inputs, $j = 1 \dots m$ used by the i -th firm; β_j is a vector of parameters to be estimated; the random error, V_i captures the effects of statistical noise, which are assumed to be independently and identically distributed as $N(0, \sigma_v^2)$; U_i are non-negative random variables, associated with technical inefficiency in production, which are assumed to be independently and identically distributed exponential or half-normal variable [$U_i \sim (|N(0, \sigma_u^2)|)$]. The deterministic production function is written as: $f(x_i; \beta)$, while $[f(x_{ij}; \beta_j) \cdot \exp \{v_i\}]$ is the stochastic production frontier. Both exponential and half-normal distributions have been criticized for arbitrarily restricting the mean of technical inefficiency effects to zero and related consequences for estimated technical efficiency levels. A few authors have proposed alternative specifications for the technical inefficiency effects (see Stevenson (1980), and Battese & Coelli (1995)). Although there is generally no *a priori* justification for the choice of any particular distributional form for the technical inefficiency effects, the generalized truncated-normal distribution has been most frequently applied in empirical applications due to its computational simplicity. The model to measure technical inefficiency effects proposed by Battese & Coelli (1995) has become quite popular because of its computational ease as well as its ability to examine the effects of various firm-specific variables on technical efficiency in an econometrically consistent manner, as opposed to the two-step approach (Leung & Sharma 2001). The Battese & Coelli model (1995) also estimates variance parameters in terms of: $\sigma_y^2 = \sigma_v^2 + \sigma_u^2$ and the parameter, $\gamma = \sigma_u^2 / \sigma_y^2$, which takes on a value between zero and one.

Technical efficiency is defined as the ratio of observed output to the maximum feasible output in an environment characterized by $\exp \{V_i\}$. Technical efficiency of the i^{th} producer can be described as:

$$TE_i = \frac{y_i}{f(x_{ij}; \beta_j) \cdot \exp \{V_i\}} = \exp \{-u_i\} \quad (\text{Eq.2})$$

where u_i are the non-negative random variables, called technical inefficiency effects. These u_i are assumed to be independently distributed and defined by the truncated normal distribution, with mean, μ_u , and variance σ_u^2 . u_i is defined by:

$$u_i = Z_i\delta + W_i \quad (\text{Eq.3})$$

where, W_i for $i = 1, \dots, n$ are random errors, defined by the truncation of the normal distribution with mean zero and variance, σ_w^2 . The point of truncation is $-Z_i\delta$ i.e., $W_i \geq -Z_i\delta$. The Z_i s are the firm-specific variables which may also include input variables in the stochastic production frontier, provided that the technical inefficiency effects are stochastic.

2.4. Data sources and empirical models

A questionnaire was developed to gather both farm level coffee production data as well as household demographic information for the 2008/9 crop year in the research site consisting of 4 districts, namely, Cu Kuin, Krong Ana, Krong Bong, and Lak, in Dak Lak province, Vietnam, which lies in the Krong Ana watershed (see Figure 1). The method of data collection adopted was in person interviews with a sample size of 198 coffee farms². This number³ consisted of 103, 70, 14, and 11 farms in the Cu Kuin, Krong Ana, Krong Bong and Lak districts respectively⁴.

A likely question for this study is whether the independent variables have different impacts for different districts of the population. If differences exist then the data for all districts cannot be pooled into one sample. To answer this question, the Chow test was performed to test the equivalence of two regressions. The results of the Chow test suggested that the sample should be split (Cu Kuin and the other districts). Accordingly, two separate regression models were specified for Cu Kuin and the three other districts.⁵

Common problems with regression estimation are multicollinearity and heteroskedasticity (especially in the case of spatial analysis). See Ho (2011) for more information about the results from multicollinearity and heteroskedasticity testing. For both types of violations, the test results confirm the absence of these problems.

3. Empirical Models

Following the stochastic production frontier model developed by Aigner *et al.* (1977) and Meeusen & van den Broeck (1977), the stochastic frontier coffee production function for this study is specified as:

$$\ln y_i = \beta_0 + \sum_{j=1}^6 \beta_j \ln x_{ij} + V_i - U_i \quad (\text{Eq.4})$$

Where subscript i refers to the i -th coffee farm in the sample; $\ln$ denotes natural logarithms; y is coffee output and x_j are input variables ($j = 1, 2 \dots 6$) defined and summarized in Table 1; β s are parameters to be estimated; V_i s are iid $N(0, \sigma_v^2)$ random variables; U_i s are independently distributed ($|N(Z_i\delta, \sigma_u^2)|$) technical inefficiency effects, which are, following Battese & Coelli (1995), further defined as follows:

$$U_i = \delta_0 + \sum_{m=1}^7 \delta_m Z_{im} + W_i \quad (\text{Eq.5})$$

Where the Z s represent farm-specific variables, δ s are unknown parameters to be estimated, and W_i is a random variable as defined in Equation 5.

The parameters for the stochastic production frontier model in Equation 4 and those for the technical inefficiency model in Equation 5 were also simultaneously estimated by employing the maximum-likelihood estimation (MLE) program, FRONTIER 4.1 (Coelli, 1996).

4. Results and Discussion

4.1 Analyses of Maximum Likelihood Estimates

The maximum-likelihood parameter estimates for the stochastic production frontier model and those for the technical inefficiency model for coffee production in the Cu Kuin district and the combined districts are described in Table 2. The γ -parameter associated with the variances in the stochastic production frontiers for the Cu Kuin model and the combined districts model are estimated to be 0.9999 and 0.8041 respectively. Although the γ -parameter cannot be interpreted as the proportion of the total variance explained by technical inefficiency effects, the relative contribution of the inefficiency effects to the total variance term (γ^*) are calculated based on the γ -parameter⁶. The relative contributions are 99.99% and 59.84% for the Cu Kuin model and the three districts model respectively. This means that almost 100% of the variance for the total residual is explained by the inefficiency effects for the Cu Kuin model and approximately 60% of the variance for the combined districts model.

A likelihood ratio test was performed to test the null hypothesis whether a Cobb- Douglas stochastic production function or the traditional average production function (OLS) should be chosen for this study. The null hypothesis assumes all parameters in the stochastic production function are zero. The likelihood ratio test results are 72.16 and 5.14 for the Cu Kuin model and the combined districts model respectively. Both values exceed the critical Chi-square value of 2.71 at the 95% confidence level. Thus, the traditional average production function is not an appropriate representation of the sample data.

Table 2: here

The second test examines the null hypothesis that technical inefficiency effects are not present, i.e., $H_0: \gamma = 0$. This null hypothesis was rejected on statistical grounds for both models (Cu Kuin and the three districts). These latter results attest to the importance of accounting for technical inefficiency effects in coffee production for the Krong Ana watershed. The former results confirm the stochastic nature of coffee production in the study sites.

4.2 Stochastic production frontier

As expected, the slope coefficients of the stochastic production frontier for both Cu Kuin and the three combined districts models were positive. For both models, four of the six explanatory variables had statistically significant effects on coffee output. However

for the Cu Kuin district model, labor and inorganic fertilizer costs had insignificant effects while for the combined districts model, pesticide expenditures and the amount of water applied were insignificant. In the case of labor and inorganic fertilizer costs, variability in usage of these inputs (e.g., standard deviation and/or coefficient of variation) is higher in the three combined districts model than the Cu Kuin model. For labor, this variability can probably be explained by the more difficult topographic conditions in the combined districts requiring more labor in coffee production. Farmers in the combined districts tend to spend more on fertilizers than the Cu Kuin district because of lower soil quality.

On the other hand, the models' results for expenditures on pesticides and irrigation water application are not easily interpreted. Perhaps, the higher density of coffee plantations in Cu Kuin may enable farmers to better control the spread of pests than in the three combined districts. In the case of irrigation, the average amount of water applied in the Cu Kuin district is significantly higher than that in the three combined districts. Lack of rainfall data makes explanation of these irrigation differences difficult to explain.

Regarding factors affecting coffee production, should farmers invest more on each factor (input)? Table 3 describes the relationship between changes in benefits (revenues) and changes in costs with respect to each corresponding input factor. This analysis assumes that changes in an input factor will not affect other factors of production (i.e., *ceteris paribus* assumption)

Table 3: here

Fertilizers are key inputs in coffee farming. The three combined districts model has a larger estimated coefficient (0.1741) for inorganic fertilizer expenditures than the Cu Kuin model. Given the price of coffee output and fertilizer costs, the effect of inorganic fertilizer expenditure on revenue from coffee output was estimated. Accordingly, if farmers (on average) in this sub-region could spend 1% more on inorganic fertilizer (equal to 128,045 VND⁷), coffee output would increase by 0.1741% (equal to 130,065 VND⁸). Given these estimates, it would be economical on average for farmers in the combined districts area to invest more on fertilizer. However, for the Cu Kuin region, the effect of inorganic fertilizers on coffee production is not statistically significant.

Similarly, a 1% increase in organic fertilizer (18,892 VND for the Cu Kuin district, and 27,193 VND for the three other districts) would increase coffee output for Cu Kuin by 0.0105% (9,536 VND in terms of additional revenue) and by 0.0071% for the three other districts (5,304 VND). Therefore, in both sub-regions, (on average) the additional application of organic fertilizers would not be economical.

Similar calculations suggest that on average farmers in the Cu Kuin district could be cost effective by investing more on pesticides and applying more irrigation water. By increasing expenditures on pesticides by 1%, coffee output would increase 0.1294% for the Cu Kuin district. This suggests that if farmers spent an additional 7,386 VND on pesticides, they would receive (on average) an additional revenue of 117,520 VND. Likewise, if farmers in the Cu Kuin district could apply 1% more irrigation water (about

17.44 cubic meters), coffee output would increase by 0.3157% (286,716 VND). For the other three districts, there is no statistically significant effect for either additional expenditures on pesticides or increased quantity of irrigation water applied to coffee production. Therefore, based on this evidence, recommendations can only be made for farmers in the Cu Kuin district regarding pesticide and irrigation water application.

However, applying more pesticides and/or extracting more water may have negative impacts on coffee production and the surrounding environment as well. Thus, for sustainable development in coffee production, application of chemical fertilizers, pesticides, and irrigation water should be carefully considered. Application of more chemicals can directly damage the environment. Sustainable coffee production is now considered to be a more suitable strategy for future development, e.g., sustainable coffee growing standards are being implemented in Dak Lak such as UTZ⁹ and 4C¹⁰ for which agreements enable farmers to obtain a five to ten percent premium over current coffee prices (M4P, 2011)¹¹.

4.3 Technical Efficiency

As shown in Table 4, the distributions of technical efficiency scores in the two sub-regions are different. In the combined districts region, the distribution tends to be nearly rectangular i.e, equal from lower to higher intervals, while in the Cu Kuin district, technical efficiency scores decrease for farms in the upper intervals. It is noticeable that the Cu Kuin district has a smaller percentage on farms in the lower technical efficiency intervals as compared to the combined districts. This is probably due to differences in topographic conditions and soil quality which are more favorable for coffee farming in Cu Kuin than for the combined districts.

Table 4: here

4.4 Analyses for technical inefficiency models

As shown in Table 2, ethnicity, availability of extension services, and the child dependency index have statistically significant effects on technical inefficiency for coffee farmers in the Cu Kuin district. On the other hand, the MLE results for the combined districts show that most of the selected explanatory variables except extension services and age of household head significantly affect technical inefficiency. These results indicate that factors significantly affecting technical inefficiency vary by area or location. The MLE results show that the average technical efficiency score for farmers in the Cu Kuin district is 74.66%, which is significantly higher than 68.76%, the average technical efficiency score for the three combined districts (from a pairwise t-test with $t = 2.84$). This is consistent with average coffee yield per hectare being significantly higher for Cu Kuin than for the three other districts (from a pairwise t-test with $t = 5.05$).

Of interest is the estimated coefficient for formal education of the household head which has an estimated negative sign in both models. However, the educational variable is statistically significant only for the three districts model. This result suggests that

increasing formal education in the combined districts model tends to significantly reduce technical inefficiency. Similar results were found by Phillips & Marble (1986), Seyoum *et al.* (1998), Weir & Knight (2000), Nchare (2007) and Illukpitiya & Yanagida (2010). However, in the Cu Kuin district, the effect of education on technical efficiency is statistically insignificant. This difference in estimated results can be explained as the Cu Kuin district having a statistically higher average education level than the combined districts (from a pairwise t-test with $t = 3.14$). These results help explain why the actual coffee output of farmers from Cu Kuin is closer to its stochastic frontier on average than those from the combined districts.

In an integrated world, education is a key factor for success. More than four decades ago, Welch (1970) suggested that educated workers are better able to gather and utilize information that is useful for involved decision making. He explained that workers not only improve their standard of work, but also contribute to production by effectively allotting the firm's resources. This also involves allocating their time efficiently among different responsibilities which can significantly affect worker productivity.

The ethnicity factor is another variable in the inefficiency model, where model results differ by area. In the combined districts model, the coefficient on ethnicity is negative and significant which means that as the ethnicity factor changes favoring the majority, coffee production becomes less technically inefficient. On the other hand, the influence of this factor on technical inefficiency levels is positive and statistically significant for the Cu Kuin model. This suggests that as a change in the ethnicity factor favoring the majority, coffee production becomes more technically inefficient. In the Cu Kuin district, though minority farmers are less productive than majority farmers (a t-test for pairwise comparison of coffee yields per hectare between majority farmers and minority farmers is 4.14), minority farmers used less inputs for all factors of production (e.g., inorganic fertilizer expenditure ($t = -3.86$), organic fertilizer expenditure ($t = -2.22$), labor ($t = -2.05$), and the amount of irrigation water ($t = -2.52$)). This may explain why minority farmers, as compared to majority farmers in the Cu Kuin district, may be relatively more efficient than shown simply by comparing yields per hectare. On the other hand, for the combined districts, majority farmers had a statistically lower coffee yield ($t = 4.30$) and these farmers used more inputs for several factors of production, e.g., expenditure on inorganic fertilizers ($t = 6.13$), expenditure on organic fertilizers ($t = 2.34$) and amount of irrigation water ($t = 4.17$). These conflicting results do not satisfactorily explain the effects of ethnicity on technical inefficiency in the two sub-regions. It is likely that multiple effects should be investigated to illustrate the effects of ethnicity.

The amount of credit loaned negatively and significantly affects technical inefficiency in the Krong Ana, Krong Bong and Lak districts (combined districts). This can be explained as loaned credit helps to mitigate financial problems that farmers may face during the production period by enabling them to purchase more of the needed inputs. This is similar to the results obtained by Nchare (2007) for the analysis of factors affecting the technical efficiency in Arabica coffee production in Cameroon (also, see Obwona (2006)). However, the effect of loaned credit on technical inefficiency levels for the Cu Kuin model is statistically

insignificant. Farmers in the combined districts were able to obtain higher loanable amounts as compared to those in the Cu Kuin district ($t = 4.32$).

For the combined districts, the MLE results suggest that more farming experience reduces technical inefficiency in coffee production. This result is similar to findings by Illukpitiya & Yanagida (2010) for agriculture production in Sri Lanka. However, there is insufficient evidence to conclude that this relationship also holds for coffee production in the Cu Kuin district. Comparing both sub-regions, farmers from the combined districts have significantly less experience in coffee farming than farmers from Cu Kuin ($t = 3.50$).

Last, for both models, the MLE results suggest that the child dependency index positively and significantly affects technical inefficiency. It is likely that farm households with a larger child dependency index will have more household expenses for children e.g., school fees, books, clothes, medicine, etc. These children are also not expected to work on the family's coffee farm. This is perhaps one of the problems that households have to deal with thereby reducing technical efficiency. Similar results were found by Muhammad-Lawal *et al.* (2009), indicating that the young household members may not be able to contribute to labor supply since they are often pre-occupied with school during peak periods of agricultural production activities.

5. Conclusions and Policy Recommendations

Based on the stochastic production frontier, the estimated mean technical efficiency scores were 0.7466 and 0.6836 respectively for the Cu Kuin district and the combined districts. Formal education of the household head, amount of financial credit obtained, ethnicity, coffee farming experience of the household head and agricultural extension services used were key factors that can increase technical efficiency.

In regards to the Cu Kuin district, greater availability of extension services can reduce technical inefficiency. The provincial centre for agriculture extension has played an important role in agricultural development. Extension activities can increase coffee production in the Dak Lak province by providing services to farmers e.g., farm workshops where farmers participate and share information, farmers' tours of highly productive farms, demonstrations of new seed varieties, fertilizer application trials, etc. In 2010, the provincial centre for agricultural extension planned 13 extension programs with 46 on farm experiments (including crops such as rice, rubber, avocado, pepper, and coffee). The centre has also implemented a few foreign investment projects for rural development in the province (Thuan Nguyen, 2011)¹². Other programs have started in the province, including Good Agricultural Practices (GAP) for Robusta coffee, using the Farmer Field School methodology, and farmers can apply the so-called Farmer Field Book (FFB), supported by GTZ¹³, (GTZ, 2009). Also, there are a few collaborative programs between the centre for extension, district extension stations and research institutions in the province. Therefore, policies with governmental involvement should be considered: (1) to enhance activities of agricultural extension; (2) to promote intensive collaboration among institutions,

governmental extension departments and farmer associations to implement coffee farming experiments and best management practices (in terms of techniques and optimal applications of fertilizers, pesticides, irrigated water); and (3) to provide adequate funding and human resources to strengthen extension activities.

For the combined districts region, more formal education for the household head is associated with higher technical efficiency. A recent study by Tao Yang (2004) reported that in China, middle and high schooled educated families systematically make better input decisions than primary schooled educated families (also see Nchare (2007) and Kehinde *et al.* (2010)). Therefore, providing basic education services (i.e., extending coverage of formal education, basic use of computers and the Internet etc.) may help farmers to update and effectively utilize information related to coffee production and decisions involving investment in factors of production and marketing of coffee output. For long term strategies, education is usually an important stepping stone for a growing economy.

In addition, Tao Yang (2004) suggested that as a result of allocative effects, education significantly contributed to sustained income growth. In Vietnam, the provincial government has attempted to increase benefits to coffee farmers through education. For instance, the Buon Ma Thuot Coffee Exchange Centre, founded in 2008, directly interacts with coffee producers and coffee processing and exporting companies. The exchange centre introduces modern production and marketing approaches to coffee farmers. This example illustrates the role of education in terms of reducing inefficiency.

Also for the combined districts region, estimated results show that increased credit availability can reduce technical inefficiency by providing credit services that help coffee producers overcome financial constraints and thereby improve efficiency. It is also important that this financial support be used effectively. The extension service can work with credit lenders to suggest effective strategies for using and managing capital in coffee production.

Acknowledgements:

The funding for this field research was provided by the Professional Enhancement Fund of the International Fellowship Program and the Graduate Student Organization of University of Hawai'i at Manoa. We deeply acknowledge their support.

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Table 1: Descriptive Statistics

Parameter	Variable	Description	Cu Kuin district					Three combined districts				
			N	Mean	Std Dev	Min	Max	N	Mean	Std Dev	Min	Max
Input/ output production												
β1	Cfyield	Coffee yield (in tons per hectare)	103	2.84	0.56	0.73	4.00	95	2.33	0.83	0.50	4.29
	Labor	Labor (man-days per hectare)	103	198.81	45.64	102.50	340.00	95	194.29	56.82	106.67	425.00
β2	ValueInorF	Cost of inorganic fertilizer (million VNDs per hectare)	103	11.52	2.72	1.31	18.00	95	12.80	6.38	1.00	32.80
β3	ValueOrF	Cost of organic fertilizer (million VNDs per hectare)	103	1.89	1.13	-	10.88	95	2.72	2.60	0.00	12.00
β4	ValuePes	Cost of pesticide (million VNDs per hectare)	103	0.74	0.24	0.03	1.50	95	0.75	0.64	0.00	3.33
β5	Irrigamount	Amount of water applied (thousand cubic meters s per hectare)	103	1.74	0.29	0.46	2.48	95	1.60	0.60	0.40	4.00
β6	Cofage	Age of coffee trees (in year)	103	16.67	3.99	3.00	23.00	95	13.45	4.99	3.00	25.00
Farm-specific												
δ1	Hage	Age of household head	103	45.44	4.35	35.00	56.00	95	45.34	9.85	24.00	74.00
δ2	Edu	Number of years of formal education of the household head	103	9.01	3.16	2.00	16.00	95	7.59	3.19	1.00	15.00
δ3	Eth	Dummy variable of ethnicity (if Vietnamese Kinh = 1 or otherwise 0)	103	0.83	0.37	0.00	1.00	95	0.83	0.38	0.00	1.00
δ4	Ext	Extension services (yes = 1 or otherwise 0)	103	0.88	0.47	0.00	4.00	95	0.65	0.60	0.00	4.00
δ5	Creditm	Amount of credit loaned from banks and credit organizations (in million VND)	103	9.99	11.58	0.00	57.14	95	22.42	26.60	0.00	125.00
δ6	Nofexperience	Number of years of experience in coffee farming by the household head	103	17.41	4.18	0.00	24.00	95	15.12	4.97	0.00	25.00
δ7	Depindex	Child dependency index (number of children divide by family size)	103	0.16	0.19	0.00	1.00	95	0.32	0.15	0.00	0.60

UNDER PEER REVIEW

Table 2: MLE of stochastic production frontier and technical inefficiency models

Label	Para- meter	Cu Kuin district			Three combined districts		
		Coeff- icient	S.E	t-ratio	Coeff- icient	S.E	t-ratio
Production frontier							
Constant	β0	-0.1991	-0.4129	0.4822	-0.5168	-0.5616	0.9203
Ln (Labor)	β1	0.1094	0.0730	1.4991	0.1872	0.0985	1.9009*
Ln (Inorf)	β2	0.0729	0.0515	1.4148	0.1741	0.0496	3.5056**
Ln (Orf)	β3	0.0105	0.0026	3.9834**	0.0071	0.0025	2.8482**
Ln (Pes)	β4	0.1294	0.0417	3.1023**	0.0018	0.0043	0.4159
Ln (Water)	β5	0.3157	0.1003	3.1466**	0.0232	0.0983	0.2358
Ln (Cfage)	β6	0.2359	0.0657	3.5923**	0.1320	0.0684	1.9290**
Technical inefficiency model							
Constant	δ0	0.1204	0.2907	0.4143	1.0200	0.3329	3.0640**
AgeHH	δ1	-0.0007	0.0071	- 0.0929	-0.0019	0.0039	-0.4771
Edu	δ2	-0.0137	0.0100	-1.3639	-0.0349	0.0174	-2.0098**
Eth	δ3	0.1463	0.0762	1.9208**	-0.2945	0.1316	-2.2382**
Ext	δ4	-0.0991	0.0477	-2.0794**	0.0598	0.0637	0.9389
Cre	δ5	0.0010	0.0017	0.5544	-0.0049	0.0024	-2.0344**
Exp	δ6	0.0106	0.0089	1.1936	-0.0223	0.0101	-2.2065**
Cdpindex	δ7	0.5975	0.1116	5.3537**	0.9458	0.3470	2.7258**
Variance of parameters							
sigma-squared	σ ²	0.0179	0.0034	5.18**	0.0753	0.0170	4.44**
Gamma	γ	0.9999	0.0063	159.23**	0.8041	0.1378	5.83**
Log (likelihood)		72.1552			5.1341		
Mean of exp (Ui)		0.7466			0.6876		

* Significant at 10% level;

** Significant at 5% level.

Table 3. Change in revenue as the inputs increase by 1%

Factors	Cu Kuin			3 combined districts		
	Change in revenue (VND)	Change in input	Sig ^a	Change in revenue (VND)	Change in Input	Sig ^a
Labor	99,356	1.99		139,852	1.94	*
Inorganic fertilizer	66,207	115,200		130,065	128,045	*
Organic fertilizer	9,536	18,892	*	5,304	27,193	*
Pesticide	117,520	7,386	*	1,345	7,518	
Irrigation water	286,716	0.01744	*	17,332	0.01597	
Age of coffee tree	214,242	0.17	*	98,614	0.13	*

^a indicates 95% significance level of the MLE regression model

Table 4. Frequency distributions of technical efficiency estimates

Categories	Cu Kuin		3 combined districts	
	Farms	Percentage	Farms	Percentage
TE ≤ 40%	0	0.00%	4	4.21%
40% < TE ≤ 50%	1	0.97%	13	13.68%
50% < TE ≤ 60%	14	13.59%	16	16.84%
60% < TE ≤ 70%	19	18.45%	13	13.68%
70% < TE ≤ 80%	39	37.86%	18	18.95%
80% < TE ≤ 90%	19	18.45%	20	21.05%
TE > 90%	11	10.68%	11	11.58%
Total	103	100.00%	95	100.00%
Max	0.9992		0.9478	
Min	0.4822		0.3071	
Mean*	0.7466		0.6876	
Std	0.1188		0.1712	

Note: These efficiency scores for the two sub-regions are not strictly comparable because the two models have two different corresponding stochastic frontiers.

* Results of a pair-wise comparison show that the mean efficiency levels of the two sub-regions are statistically different ($t = 5.28$).

Figure 1/ Krong Ana Watershed, Vietnam



Note: Since 2007, Krong Ana district has been divided into 2 districts (Krong Ana and Cu Kuin)

¹ Business and Investment Information Portal Dak Lak. Coffee production in Dak Lak province, available at <http://www.daklakdpi.gov.vn/Default.aspx?tabid=261> (accessed on March 10, 2010).

² Based on the sampling formula proposed by Johnson & Bhattacharyya (2006) and a pre-test survey of 48 coffee farms in the research site. In the case of missing data, the actual sample size accounted for this possibility by including an additional 10% of coffee farms.

³ The total number of farms in the sample was 203, but there were 5 farms with missing data. Thus, the total observed farms were 198.

⁴ Each district is considered as a stratum, the sub-sample size of each stratum was equal to the total sample size multiplied by the proportion of population of each stratum in the 4 strata. However, the total number of farms in the 4 strata was not available. Thus, this proportion was replaced by the proportion of coffee planting area in each stratum.

⁵ Chow test results: Cu Kuin vs Krong Ana ($F = 2.40$, $p = 0.0231$); Cu Kuin vs Krong Bong + Lak ($F = 3.05$, $p = 0.0056$); Krong Ana vs Krong Bong + Lak ($F = 1.80$, $p = 0.09$); Cu Kuin vs Krong Ana + Krong Bong + Lak ($F = 2.18$, $p = 0.0430$).

⁶ The parameter γ is not equal to the ratio of the variance of the technical inefficiency effects to the total residual variance because the variance of u_i is equal to $[(\pi-2)/\pi] \cdot \sigma^2$ instead of σ^2 . The relative contribution of the inefficiency effect to the total variance, γ^* , is equal to $\gamma / [\gamma + (1-\gamma)\pi/(\pi-2)]$ (Battese & Coelli, 1988).

⁷ Since the mean inorganic fertilizer expenditure for the three combined districts was 12,804,500 VND, 1% of this number is equal to 128,045 VND.

⁸ Given that the coffee price at the end of crop year 2008/09 (December 2009) was about 32,000,000 VND per ton and the mean coffee yield in this sub-region was 2.33 tons per hectare, the additional revenue is equal to $0.1741\% \cdot 2.3346 \cdot 32,000,000 \approx 130,065$ VND.

⁹ UTZ means “good” in Mayan language, UTZ CERTIFIED's mission is to set the world standard for socially and environmentally responsible coffee production and sourcing. The UTZ CERTIFIED program answers two important questions: (1) where does the coffee come from? and (2) How was it produced? (Available at: <http://www.utzcertified.org/index.php?pageID=110> (retrieved on June 12th, 2011)).

¹⁰ The term 4C stands for Common Code of the Coffee Community. The main pillars of 4C are a code of conduct, rules of participation for trade and industry, support mechanisms for coffee farmers, a verification system and the participatory governance structure (see <http://www.4c-coffeeassociation.org/en/> (retrieved on June 12th, 2011)).

¹¹ Making markets work better for the poor. Research in Dak Lak to Understand the Constraints and Potential of Agricultural Contracting (available at <http://www.markets4poor.org/node/482> (retrieved on June 12th, 2011)).

¹² Thuan Nguyen (2011). Dak Lak Agriculture Extension: the bridge between famers and technology development. Dak Lak Online (available at <http://baodaklak.vn/channel/3483/201103/Khuyen-nong-dak-Lak-Cau-noi-giua-nong-dan-voi-tien-bo-khoa-hoc-ky-thuat-1985320/> (retrieved on May 24, 2011)).

¹³ GTZ stands for Gesellschaft für Technische Zusammenarbeit (translated as German Technical Cooperation). In Vietnam, on behalf of the German Federal Ministry for Economic Cooperation and Development, the GTZ has assisted Vietnamese policy makers in their efforts to reduce poverty and to effectively continue the reform process for the purpose of sustainable development of the country since 1993.