Farm size and nonparametric efficiency measurements for coffee farms in Vietnam

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Abstract

We study the efficiency of smallholder coffee farms in Vietnam. Data from a 2004 survey of farms in two districts in Dak Lak Province are used in a two-step analysis. In the first step, technical and cost efficiency measures are calculated using DEA. In the second step, Tobit regressions are used to identify factors correlated with technical and cost inefficiency. Results indicate that small farms were less efficient than large farms. Inefficiencies observed on small farms appear to be related, in part, to the scale of investments in irrigation infrastructure.

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1. Introduction

Coffee is one of the most important export commodities of Vietnam, providing between 6 and 10 percent of national export revenues, and employing approximately one million people. Vietnam is recognized as the second largest coffee exporter after Brazil and in recent years has become the world's largest exporter of Robusta coffee, supplying more than 40 percent of the world coffee market in 2001. With over 95% of output destined to export markets and an increasingly liberalized economy, the Vietnamese coffee sector has become closely tied to the world coffee trade (ICARD and Oxfam 2002).

Coffee was first planted in Vietnam at the end of the 19^{th} century. Between 1980 and 2000, planted coffee area in Vietnam increased 23-fold and output increased 83-fold. One of the main reasons for the rapid increase in area planted to coffee in Vietnam was state-sponsored migration to coffee growing areas and a rapid increase in world coffee prices, an increasing share of which was passed on to Vietnamese smallholders. The increase in coffee production has been extensive rather than intensive (ICARD and Oxfam 2002). Furthermore, an oversupply of coffee worldwide combined with elastic demand resulted in a considerable drop in coffee prices in the latter part of the 1990s, causing serious difficulties and adjustment for coffee producers (Ha and Shively 2004).

Given the important role of coffee in the Vietnamese economy and continued instability in world coffee prices, increasing the efficiency of existing coffee operations has become a high priority in Vietnam. The overall goal of this study is to measure the efficiency of smallholder farming operations, compare outcomes on small and large farms, and trace the possible sources of inefficiency to farm and farmer-specific variables. An improved understanding of these relationships can help farmers allocate resources more wisely and assist policy makers in designing agricultural programs to reach sector-specific goals.

2. Methodology

The measurement of productive efficiency has important implications for both economic theory and economic policy (Farrell 1957). Measuring productive efficiency allows one to test competing hypotheses regarding sources of efficiency or differentials in productivity (Farrell 1957; Lovell 1993). Moreover, such measurement enables us to quantify the potential increases in output that might be associated with an increase in efficiency (Farrell 1957). Efficiency measurement is typically implemented by either an econometric or mathematical programming approach. The latter, commonly referred to as Data Envelopment Analysis (DEA), is pursued here. DEA is a nonparametric method and has the advantage that it does not impose a functional form on the production function (Färe 1985, Lovell 1993, Ray 2004). However, this approach has two disadvantages: it does not allow direct hypothesis testing (Ray 2004) and derived measures of inefficiency are confounded with the effects of noise, measurement error, and exogenous shocks beyond the control of the production unit (Färe 1985, Lovell 1993, Ray 2004).

The economic literature on production efficiency typically distinguishes two types of efficiency: technical efficiency and allocative efficiency. The latter includes as components cost minimization, revenue maximization, and profit maximization. A technically efficient firm is one that produces the maximum output for a given amount of inputs, conditional on the production technology available to it. An allocatively efficient firm applies the optimal amount of inputs to produce the optimal mix of outputs given the production technology and the prices it faces. A firm that is both technically and allocatively efficient is said to be economically efficient (Papadas and Dahl 1991).

In 1964, Schultz proposed the “efficient but poor” hypothesis to examine the allocative behavior of producers within traditional poor agricultural communities. Schultz argued that “there are comparatively few significant inefficiencies in the allocation of the factors of production in traditional agriculture,” concluding that a “community is poor because the factors on which the economy is dependent are not capable of producing more under existing circumstances.” Not surprisingly, the inverse relationship between farm size and agricultural productivity has been one of the most closely considered findings in international agricultural development (Gilligan 1998).

In an early study, Carter (1984) analyzed the inverse relationship between farm size and farm productivity in India and found differences between small and large farms that could not be explained by factors correlated with farm size. Carter showed that small farms were technically inefficient and, in addition, that small farms allocated labor beyond the optimal level defined by profit maximization at market prices. Using panel data from rice farms in the Philippines, Shively and Zelek (2003) similarly argued that, from a profit maximization perspective, small farms over applied labor and under applied fertilizers and pesticides. Hoque (1988) found that smaller farms were more efficient than larger farms in allocating labor but that larger farms were more efficient in allocating biological and chemical inputs. In contrast, Adesina and Djato (1996) found small and large farms in Côte d'Ivoire to be equally efficient. They identified access to credit and use of modern varieties as factors correlated with agricultural profit.

Recent studies exploring the relationship of farm size and efficiency have used a two-step methodology. In the first step, efficiency measures are calculated. Then, efficiency measures are regressed on farm specific characteristics to identify sources of inefficiency (see, for example, Tadesse and Krishnamoorthy 1997; Gilligan 1998; Shafiq and Rehman 2000; Fletschner and Zepeda 2002; Nyemeck et al. 2003; Dhungana, Nuthall and Nartea 2004; Helfand and Levine 2004). Efficiency is typically found to be correlated with farm-specific attributes such as farm size, the farm manager's education, land titling, access to credit, employment opportunities, land quality, agro-ecological zone, and extension services.

Here we follow the traditional two-step analysis. In the first step, we calculate technical efficiency and cost efficiency measures using DEA. In the second step, we regress these measures of technical efficiency and cost efficiency on a set of farm- and farmer-specific characteristics that includes farm size, household head education, land tenure, access to credit, and characteristics of fixed- and variable-input irrigation infrastructure employed on the farm.

2.1 Efficiency Measures

In order to identify the technical efficiency of farms in our sample, we solve the following linear programming problem:

$$(1) \qquad \max_{y,\lambda^1,\ldots,\lambda^K} y$$

$$\text{s.t.:} \qquad \sum_{k=1}^{K} y^k \lambda^k \geq y$$

$$\sum_{k=1}^{K} x_n^k \lambda^k \leq x_n^0$$

$$\sum_{k=1}^{K} \lambda^k = 1$$

$$\lambda^k \geq 0$$

where y is an optimal level of output, y^k denotes the output of the k^{th} farm, x_n^k denotes the level of the n^{th} input used on farm k, x_n^0 is the n^{th} input used on the farm whose efficiency is being tested, and λ^k is the weight given to farm k in forming a convex combination of the input vectors. The resulting technical efficiency index is calculated as a ratio between the observed level of output (kilograms of coffee per hectare) on the farm being tested (y^0) and the optimal level of output (y). Technically efficient farms are those with an efficiency index equal to one. Technically inefficient farms are those with an index strictly lower than one.

Cost efficient farms (under the assumption of variable returns to scale) are identified by solving:

$$(2) \qquad \min_{x_1,\ldots,x_n,\lambda^1,\ldots,\lambda^K} \sum_{n=1}^{t} w_n^0 x_n$$

$$\text{s.t.:} \qquad \sum_{k=1}^{K} y^k \lambda^k \geq y$$

$$\sum_{k=1}^{K} x_n^k \lambda^k \leq x_n \text{ for } 1 \leq n \leq t$$

$$\sum_{k=1}^{K} x_n^k \lambda^k \leq x_n^0 \text{ for } n > t$$

$$\sum_{k=1}^{K} \lambda^k = 1$$

$$\lambda^k \geq 0$$

where w_n^0 is the cost of the *n* (*n*=1,…,t) input faced by the farms whose efficiency is being tested, λ^k is the weight given to farm *k* in forming a convex combination of the output or input vectors, x_n denotes the optimal amount of input *n* (*n*=1,…,t), y^k denotes the output of farm *k* (*k*=1,..,K), λ^k is the weight given to farm *k*, x_n^k denotes the level of input *n* for firm *k*, and x_n^0 is the amount of fixed input *n* on the firm whose efficiency is being tested.

The cost efficiency index is calculated as the ratio between the optimal cost ($w_n^0 x_n$) and the observed cost on the k^{th} farm being tested ($w_n^0 x_n^k$). Cost efficient farms are those with a cost efficiency index equal to one. Farms with an index less than one are characterized as cost inefficient. Technical efficiency and cost efficiency indexes are relative measures, in the sense that they are obtained by comparing each farm to farms within a reference category. Below we use farm size to construct our categories.

2.2 Sources of Inefficiency

Technical and allocative efficiency indexes obtained using DEA are separately regressed on farm specific characteristics in order to identify sources of technical and allocative inefficiency, respectively. Because efficiency measures range between 0 and 1, we employ a two-tailed Tobit model in place of OLS regression (Ray 2004). The Tobit model takes the following form:

(3) $$Index_k^* = \beta' X_k + u_k$$

where $Index_k^*$ is the value of the efficiency index obtained from DEA, β is a vector of unknown parameters, vector X_k contains independent variables hypothesized to be correlated with efficiency, and u_k is an error term that is independently and normally distributed with mean zero and common variance σ^2.

3. Data

Data for the study were collected from an agro-economic survey conducted in 2004. The study area covered two districts in Dak Lak Province: Buon Don District and Cu M'gar District. A total of 209 farmers, approximately equally distributed over the districts, were interviewed. The survey obtained data on land use, agricultural production, irrigation practices and management, input levels in agriculture, labor, processing and marketing of farm produce and use of credit.

All surveyed farms produced coffee of the Robusta variety. Characteristics of these farms are summarized in Table 1. The average area planted to coffee in the sample is 1.29 hectares. Farms were classified according to the area planted with coffee. A farm with planted coffee area of 1.5 hectares or less is classified as a “small” farm. In contrast, a farm with planted coffee area greater than 1.5 hectares is classified as a “large” farm. To compute cost efficiency indices, we include the variable inputs hired labor, fertilizer, herbicides and pesticides. Fertilizers considered are urea, NPK, phosphorous, potassium, ammonium sulphate, organic fertilizers and other fertilizers. Family labor is incorporated as fixed input.[1] Total coffee production costs, off-farm work and tenure were significantly higher on small farms (see Table 1). Data reported in Table 2 indicate that use of NPK, sulphate and family labor was significantly higher on small farms. Large farms used greater amounts of hired labor, although the difference is not statistically significant at standard test levels. Unit costs of inputs are reported in the final columns of Table 2.

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[1] Given that Robusta trees produce their first crop 3 to 4 years after planting and remain fruitful for 20 to 30 years, land is also considered a fixed input.

4. Results

4.1 Efficiency Results

Technical efficiency indices for small and large farms are reported in the top panel of Table 3. Technical efficiency indexes for large farms were, on average, larger than for small farms. In addition, a higher percentage of large farms were technically efficient. Nonetheless, large farms still had the potential to increase their output by almost 35%.

Cost efficiency indices for small and large farms are reported in the lower panel of Table 3. On average, large farms were more cost efficient than small farms. Cost efficiency indices indicate that large farms had the potential to reduce costs by 42% and small farms had the potential to reduce costs by 58%. In general, cost minimization indices were considerably lower than their corresponding technical efficiency indices.

4.2 Sources of Inefficiency

Results of the efficiency analysis point to greater inefficiency on small farms. This motivates us to ask why this might be the case? Are small coffee farms simply inefficient, or do special characteristics of these small farms lead to inefficiencies that might be overcome through improved policies? To address these questions we turn to an analysis of possible sources of inefficiency in the sample. We use the efficiency index measures as dependent variables in a series of regressions.

To begin the regression discussion we note that one of the explanatory variables of interest is access to credit, which is arguably an endogenous variable. In recognition of this likelihood, we instrument the credit variable using a probit model. Results from this probit regression are reported in Table 4. The dependent variable for the probit model is a binary indicator for formal or informal access to credit (1 if the producer had access to credit; 0 otherwise). Explanatory variables in the model include a village dummy (1= Eapok or Eatul; 0=other), residency (in years), non-agricultural assets (total value of radio, television, video, bicycle and motorcycle), and a binary variable for house material (1= wood; 0= brick). Results indicate that the village of residence and housing material are positively and significantly correlated with access to credit. The first of these results likely indicates better proximity to lenders in a sub-set of the study villages. In the second case, we conclude that quality of housing signals credit worthiness. Ethnicity, years of residency, and non-housing assets are not strongly correlated with credit in the sample.

Equipped with our instrumental variable for credit, we employ two sets of Tobit models to study sources of inefficiency.[2] Results for the technical efficiency scores (models 1A and 1B) are reported in the first two columns of Table 5. Results for the cost efficiency scores (models 2A and 2B) are reported in the final two columns of Table 5. In each case model A is a short regression and model B is a long regression that includes interaction terms between farm size and other key variables. Explanatory variables for the short regressions (models 1A and 2A) include a dummy variable for farm size (1= small; 0=large), education of household head (in years), an indicator of farm ownership (measured as the proportion of farm area with title), the instrumental variable for credit,

[2] Maddala (1983) indicates that Tobit estimates are inconsistent when error terms have unequal variances (i.e. heteroskedasticity). Accordingly, we test for heteroskedasticity using likelihood-ratio and Wald tests. Results are inconclusive at standard test levels and so we proceed with Tobit estimation under the assumption of homoskedasticity.

the number of water pumps used on the farm for irrigation (in units), and the total length of irrigation pipeline (in meters). The long regressions (models 1B and 2B) add to the short regressions five interaction terms between farm size and education, tenure, credit, pump, and length of irrigation pipe.

In line with results from the DEA analysis, results from Model 1A indicate that small farms are technically inefficient. Efficiency appears to decline with the length of irrigation pipe employed on the farm, suggesting decreasing returns to the scale of the irrigation system. In contrast, the number of irrigation pumps is correlated with higher levels of technical efficiency. Access to credit is associated with higher technical efficiency but the correlation is statistically weak. Land ownership and education are not strongly correlated with technical efficiency in the sample.

The results of Model 1A seem to suggest that small farms are less efficient than large farms, even after controlling for factors generally believed to influence smallholder performance. To examine why this might be the case, we add to our regressors a set of terms constructed by interacting the binary indicator for "small farm" with other key variables (education, tenure, credit, pump, and length of irrigation pipe). Results for Model 1B suggest that technical inefficiency is not correlated with being "small" *per se*, but rather with two factors: being small and having a higher education level (perhaps indicating better off-farm options and reduced farm management intensity), and being small and employing relatively longer irrigation pipelines. In addition, the finding that irrigation pumps contribute to technical efficiency, regardless of farm size, remains robust to inclusion of interaction terms. Several patterns revealed here, e.g. insignificant roles for credit and land ownership and a mixed role for education are consistent with patterns from a study of coffee farms in Côte d'Ivoire (Nyemeck et al. 2003).

Tobit models for cost efficiency are presented in the final columns of Table 5. Results from model 2A confirm that cost inefficiency was greater on small farms and on farms with longer irrigation pipes. Access to credit is generally correlated with cost inefficiency, but not at statistically significant levels.

To further assess the role of farm size in explaining cost inefficiencies, Model 2B includes our list of interaction terms. The results underscore a positive association between education and cost efficiency, although efficiency falls with higher levels of education on small farms. In addition, smaller farms suffered from greater cost inefficiency when employing relatively lengthy irrigation pipes. Access to credit is correlated with higher cost efficiency indices but the pattern is statistically weak.

5. Conclusions

This paper used a two step methodology to examine the efficiency of coffee farms in Vietnam. In the first step, technical and cost efficiency measures were calculated using a DEA approach. In the second step, farm specific characteristics were used in a series of Tobit regressions to explore factors correlated with inefficiency, especially on small farms. Results indicate lower technical and cost efficiency on small farms. Inefficiencies observed on these small farms may be due primarily to factors other than farm size *per se*. As the length of irrigation pipelines increases, efficiency falls, especially on small farms. Higher education levels on small farms also appear to reduce efficiency, perhaps because education increases opportunities for off-farm work and thereby reduces on-farm management intensity. Access to credit and security of tenure were not found to be significant factors in explaining efficiency in the sample.

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Table 1. Characteristics of coffee farms, Dak Lak Province, 2004

	Small Farms (0 - 1.5 ha)	*Large Farms* (> 1.5 ha)	*All Farms*
Year first planted coffee	1992	1991	1991
	(4.7)	(5.1)	(4.9)
Area planted to coffee (ha)	0.81*	2.41*	1.29
	(0.35)	(0.69)	(0.87)
Yield (kg/ha)	2,763	2,666	2734
	(1,160)	(1,430)	(1,244)
Sales price (D/kg)	9,500	9,295	9,438
	(775)	(1,085)	(883)
Total coffee production cost (1,000 D/ha)	7,654*	6,470*	7,298
	(4,124)	(3,809)	(4,060)
Income (1,000 D)	37,700*	65,600*	46,086
	(24,100)	(42,000)	(33,108)
Income per capita (1,000 D)	7,518*	11,400*	8,684
	(5,409)	(9,830)	(7,237)
Off-farm income (1,000 D)	5,223	2,758	4,480
	(10,931)	(5,450)	(9,666)
Off-farm work (% with off-farm income)	44.5*	38.1*	42.6
	(49.9)	(49.0)	(49.6)
Household size (number)	5.5*	6.7*	5.9
	(1.8)	(2.1)	(2.0)
Age of household head (years)	45.1	45.4	45.2
	(11.8)	(10.7)	(11.5)
Female headed household (%)	17.8	17.5	17.7
	(38.4)	(38.3)	(38.3)
Education of household head (years)	7.2	6.4	7.0
	(3.5)	(4.0)	(3.7)
Tenure (% of farm area with title)	86.8*	78.3*	84.3
	(27.5)	(30.6)	(28.7)
Credit (% with access to credit)	41.8	47.6	43.5
	(49.5)	(50.3)	(49.7)
Pump ownership (% with pump)	73.3	82.5	76.1
	(44.4)	(38.3)	(42.8)
Irrigation pipe (length in meters)	186.8*	296.8*	220.0
	(149.4)	(148.1)	(157.0)
Livestock (% with pigs or cows)	38.4	39.7	38.8
	(48.8)	(49.3)	(48.8)
Number of observations	146	63	209

Note: standard deviations in parentheses. * indicates means are significantly different in paired t-test at 10% test level. In 2004 $1US= 15,787 D

Table 2. Inputs used in coffee production

	Input Levels		*Input Costs*	
Input	*Small Farms* (0 - 1.5 ha)	*Large Farms* (> 1.5 ha)	*Small Farms* (0 - 1.5 ha)	*Large Farms* (> 1.5 ha)
Urea (kg/ha)	323.36	268.76	3,271.64†	2,707.36†
	(502.83)	(457.85)	(1,460.95)	(1,046.82)
NPK (kg/ha)	1,387.64*	1,016.52*	3,016.98	2,672.17
	(1,292.54)	(994.87)	(2,902.48)	(936.06)
Phosphorus (kg/ha)	188.61	178.16	3,349.36	3,822.69
	(345.17)	(331.98)	(1,540.26)	(1,424.88)
Sulphate (kg/ha)	196.90*	87.06*	1,884.07†	1,766.72†
	(353.02)	(257.15)	(558.95)	(412.06)
Potassium (kg/ha)	186.17	208.73	2,641.56	2,225.39
	(420.58)	(399.45)	(2,743.52)	(1,040.15)
Organic fertilizer (kg/ha)	172.95	233.33	609.35	648.50
	(536.37)	(644.58)	(221.78)	(282.49)
Other fertilizer (kg/ha)	106.37	103.17	2,113.15	2,145.31
	(432.08)	(484.92)	(317.24)	(223.66)
Herbicide (kg/ha)	0.31	0.09	59,403.82†	49,674.82†
	(2.53)	(0.63)	(17,914.05)	(12,368.22)
Pesticide (kg/ha)	4.54	4.99	66,708.10†	48,613.96†
	(4.86)	(5.37)	(51,998.93)	(22,634.65)
Hired labor (days/ha)	55.53	72.56	24,321.92†	22,126.98†
	(68.95)	(70.02)	(3,421.91)	(3,066.43)
Family labor (days/ha)	172.08*	142.00*	–	–
	(80.72)	(83.38)		
Number of observations	146	63	146	63

Note: * and † indicate means are significantly different in paired t-test at 10% test level.

Table 3. Technical efficiency index for coffee farms[1]

	Small Farms (0 - 1.5 ha)	*Large Farms* (> 1.5 ha)
Technical efficiency		
average level	0.82	0.89
standard deviation	0.24	0.19
% efficient	49.3	65.1
Cost efficiency		
average level	0.42	0.58
standard deviation	0.30	0.31
% efficient	10.3	19.1
Number of observations	146	63

Table 4. Probit model for access to credit

Independent Variable	*Coefficient Estimate*
Constant	-0.9051* (0.2709)
Village dummy (1=Eapok or Eatul; 0= other)	0.5018* (0.2243)
Ethnicity (1= Kinh; 0= other)	-0.2206 (0.2748)
Residency (years)	0.0043 (0.0067)
Assets (value in million D)	0.0062 (0.0051)
House material (1= wood; 0= brick)	0.4691* (0.2105)
Correct predictions	61%
Number of observations	209

Note: standard errors in parentheses. * indicates coefficient estimate is significantly different from zero at 10% test level.

Table 5. Tobit models for efficiency

	Technical Efficiency		Cost Efficiency	
Independent Variable	*Model 1A*	*Model 1B*	*Model 2A*	*Model 2B*
Constant	1.0917 (0.1762)	0.5418 (0.3632)	0.7158* (0.1292)	0.3174 (0.2282)
Small (1= small; 0=large)	-0.1479* (0.0750)	0.4682 (0.4069)	-0.2202* (0.0561)	0.2947 (0.2661)
Education (years)	-0.0044 (0.0088)	0.0257 (0.0167)	-0.0014 (0.0065)	0.0203* (0.0111)
Tenure (% of area with title)	-0.0703 (0.1153)	-0.2941 (0.2061)	0.0654 (0.0851)	-0.0064 (0.1425)
Credit (instrumental variable)	0.1845 (0.2319)	0.4362 (0.4751)	-0.2233 (0.1746)	0.1510 (0.3294)
Pump (number)	0.1523* (0.0616)	0.3268* (0.1158)	0.0683 (0.0454)	0.0701 (0.0698)
Irrigation pipe (length in meters)	-0.0004* (0.0002)	0.0006 (0.0004)	-0.0004* (0.0002)	0.0001 (0.0003)
Small*Education		-0.0417* (0.0198)		-0.0324* (0.0136)
Small*Tenure		0.3344 (0.2463)		0.1133 (0.1750)
Small*Credit		-0.2440 (0.5427)		-0.4770 (0.3862)
Small*Pump		-0.2132 (0.1387)		0.0112 (0.0907)
Small*Irrigation pipe		-0.0012* (0.0005)		-0.0007* (0.0004)
Number of observations		209		

Note: standard errors in parentheses. * indicates coefficient estimate is significantly different from zero at 90% confidence level.