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The Role of Knowledge in Sustainable Agriculture: Evidence from Rice Farms' Technical Efficiency in Hanoi, Vietnam

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Abstract: This paper examines the production efficiency of 2079 rice farms in Hanoi (Vietnam) in 2018 and the role of formal and informal knowledge on their efficiency. Our empirical results showed that, in general, Hanoi's rice farms performed quite well in 2018. The differences in the specific performance of each farm could be explained by the farmer's characteristics (age, education and gender of the head of household) as well as by certain external factors (support programs or distance to city center). We found that self-learning through experience did not obviously improve the farm's production efficiency whilst education and training were notably important. We further suggest that regional councils and agricultural support programs played an important role in helping farmers improve their efficiency and sustainability.

Keywords: production efficiency; stochastic frontier analysis; rice farm; knowledge; Vietnam

1. Introduction

The sustainable development goals (SDGs), initiated in 2015 by the United Nations, addressed the global challenges that we will face in our changing environment, including poverty, inequality, prosperity, healthy living and well-being. A sustainable agriculture sector is seen as a central food safety solution, as well as being essential to hunger and poverty eradication [1]. Within the agriculture sector, rice is a principal food staple consumed daily by more than half of the world's population [2]. It is therefore important to examine the efficiency and sustainability of rice farms.

Technical efficiency can be measured by data envelopment analysis (DEA) [3,4] and stochastic frontier analysis (SFA) [5,6] by comparing actual and best practice (or 'frontier') production. In this sense, farms that use fewer inputs to produce the most outputs form the efficient frontier, and inefficient farms can be defined as those not lying on this frontier. It is argued that if farmers can improve the technical efficiency of their use of inputs, including polluted ones such as pesticides or herbicides, they can simultaneously achieve both the economic (i.e., to produce more outputs) and sustainable (i.e., to pollute less) objectives [7,8].

In this sense, Vietnam is an interesting case study because its agriculture sector still accounts for more than 15% and 40% of the country's gross domestic product and labor force, respectively [9]. In particular, rice farms in Vietnam have developed rapidly in the last decades. Rice production doubled between 1994 and 2017, from 20,000 million tons to 44,963 million tons, while the paddy

area rose only slightly, about 1.1% per year [10]. Vietnamese rice yield increased from 2.99 tons/ha in 1990 to 5.66 tons/ha in 2012 [11] and 5.78 tons/ha in 2017, which is higher than that of other rice exporting countries like Thailand, India and Pakistan [12]. During this time, Vietnam also became a major rice export country, about 15% of the world's total export volume. The rice export value in 2018 is estimated at 6.15 million tons (the equivalent of a 3.2 billion USD turnover), up 6% in volume and 20% in value compared to 2017 [12]. It is therefore obvious that in quantity Vietnamese rice farms are doing well both domestically and globally. The remaining questions are, however, whether they also operate efficiently and what the determinants of this efficiency are, so that Vietnam can further speed up this move toward sustainable development.

In the new era of technological development, knowledge is an important resource [13,14]. This paper examines the impact of knowledge on the technical efficiency of rice farms in Vietnam with data collected from rice farms in the suburban areas of Hanoi, Vietnam in 2018. These rice farms have the advantage of being close to Hanoi, the capital of Vietnam, and so benefit from technological improvements, therefore knowledge is important to them. For example, our data shows that all farms have been implementing tillage or harvest automation techniques. In this sense, the role of knowledge in the effective implementation of the technologies has become more important than the technologies themselves.

This paper contributes to the literature in two important ways. First, in terms of methodology, it was the first attempt to examine the technical efficiency of rice farms using different SFA models. In particular, we used different assumptions pertaining to the distribution of the inefficiency term (half-normal, exponential and truncated-normal) and different assumptions about the relationship between explanatory variables and the inefficiency term (the random error function, inefficiency variance function and idiosyncratic error variance function) in our SFA models. Our conclusions and discussions, based on robust results, are thus more reliable. Second, in terms of the sampled data, this is also the first study of the technical efficiency of rice farms around Hanoi, the capital of Vietnam. This sample allowed us to examine a situation in which technology could be controlled to the extent that the impact of knowledge was more significant. In the following section, we examine relevant literature on rice farm efficiency. Section 3 presents the methodology and data used in this research. Section 4 discusses our empirical results and Section 5 describes our conclusions.

2. Literature Review

Technical efficiency is commonly assessed using frontier analysis techniques including data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Each technique has its own pros and cons, however, it is commonly accepted that SFA is applicable for large samples with hundreds of observations where hypothesis tests regarding efficiency measurements can be consequently performed. In addition, SFA also has the advantage of utilizing a production function form for its analysis and, therefore, is suitable for studies of the production processes of agriculture or manufacturing [15].

SFA has been used to analyze the efficiency of rubber farms [16], soybean farms [17], citrus farms [18], mixed organic farms [19], and, especially, rice farms [20–28]. In particular, Battese and Coelli [26] proposed a time-varying SFA model for panel data to analyze 38 paddy rice farmers from an Indian village between 1975 and 1985. The technical efficiency of the farms ranged from 0.821 in 1975–76 to 0.942 in 1984–85. The determinants of the differences were later examined by Battese and Coelli [27] via a single-step SFA approach. The authors found that the age of the primary decision maker in the farming operation (or the head of the farm) was found to be negatively associated with the farm's efficiency; meanwhile the years of formal schooling of the head of the farm and the age at the time of observation positively contributed to the improvement of efficiency.

Wadud and White [24] employed both DEA and SFA to examine the efficiency of rice farms in Bangladesh in 1997. The results from DEA and SFA were consistent, with an average SFA efficiency score of 0.7913 showing that those farms were slightly more than 20% inefficient. This (in)efficiency was found to be determined by the land fragmentation, the irrigation infrastructure and the environmental degradation.

A recent study by Seok, Moon, Kim and Reed [20] on Korean paddle rice farms did not focus on the efficiency itself but its determinants. The findings show that higher values of age, education, share of labor, share of land, share of non-farm revenue, share of income subsidy and debt rate have negative impacts on the farm's efficiency. Farms with a female as the head of household also tended to be less efficient while bigger family size helped improve efficiency.

There are a limited number of studies on Vietnamese rice farms and their efficiency. To the best of our knowledge, Kompas [23] conducted the first SFA study to address the technical efficiency of the Vietnamese rice sector, but using regional-level panel data. This study found that during the period 1991–1999 the average technical efficiency of the rice sector in Vietnam was only 0.592, due to the low-level impacts of the natural condition and the machinery used. Other studies found an average efficiency score of 0.634 in 2003 [22], 0.816 in 2006 [21,29], 0.630 in 2012 [30], 0.860 from 1985 to 2006 [31] or 0.810 from 2010 to 2015 [32]. Although some of those studies did examine determinants of rice production efficiency such as gender or age, not even one emphasized the impact of knowledge, especially formal versus informal, on efficiency and sustainability.

3. Methodology

3.1. SFA Models

In the frontier analysis approach, efficiency is measured by “comparing the observed performance of a firm with some postulated standard of perfect efficiency”, which lies on the efficient production frontier [33]. This production frontier was first estimated, using ordinary least square (OLS) regression, by Aigner and Chu [34], Afriat [35], and Richmond [36]. Aigner et al. [6] and Meeusen and van den Broeck [5] then simultaneously proposed an SFA approach that decomposed the OLS residuals (or random errors) into a ‘pure’ error component v_i and an inefficiency component u_i :

$$(\text{OLS}) : \ln Y_i = \beta_0 + \beta_j \ln X + \varepsilon_i, \quad (1)$$

$$(\text{SFA}) : \ln Y_i = \beta_0 + \beta_j \ln X + v_i - u_i, \quad (2)$$

where $\ln Y_i$ represents the logarithmic value of the dependent output of the farm i , $\ln X$ represents the vector of logarithmic values of the independent inputs used by farm i to produce the output Y_i , and β_j is the estimated coefficient.

In this study, we use the translog production function instead of the Cobb-Douglas functional form because the former is more reliable and flexible than the latter [37], and also because the latter is in fact subsumed by the former [38]. When one wants to study the determinants of (in)efficiency, traditionally, he or she will use a two-step approach in which SFA is used in the first step to estimate the technical efficiency and regression is used in the second step to analyze the relationship between the efficiency and its determinants. Extensive Monte-Carlo simulations as well as many empirical studies, see, for example, Reference [39], however, suggested that the single-step approach of Battese and Coelli [27] was more appropriate. In particular, when examining Indian farms, Battese and Coelli [27] proposed that the model of u_i (Equation (4)) could be estimated simultaneously alongside the main SFA model (Equation (3)) as follows:

$$\ln Y_i = \alpha_0 + \sum_{m=1}^5 \alpha_m \ln X_m + \frac{1}{2} \sum_{m=1}^5 \sum_{n=1}^5 \alpha_{mn} \ln X_m \ln X_n + v_i - u_i, \quad (3)$$

$$u_i = \delta_0 + \delta_k Z + \varepsilon_i, \quad (4)$$

where Z is a vector of explanatory variables for the inefficiency term u_i of farm i and ε_i is the residual. Notice that in this study we have five inputs so that in Equation (3) m and n run from 1 to 5.

We noted that while the random error term ε_i and the idiosyncratic term v_i were assumed to follow a normal distribution, the ‘pure’ inefficiency term u_i did not. Since efficiency runs from 0 to 1, u_i was bound between 0 and 1 and, therefore, could have a truncated-normal, half-normal or exponential

distribution. In addition, Wang [40] further argued that the explanatory variable Z affected not only the inefficiency term u_i but also the idiosyncratic error term v_i or the overall random error term ε_i . We consequently constructed five different models for the assumptions, as shown in Table 1.

Table 1. Different models employed in our study.

	Assumptions on the Distribution of u_i			Assumptions on Parameterization of Inefficiency		
	Truncated-Normal	Exponential	Half-Normal	ε_i^a	u_i^b	v_i^c
Model 1	x			x		
Model 2		x			x	
Model 3		x				x
Model 4			x		x	
Model 5			x			x

^a Explanatory variables were assumed to impact the error term ε_i of Equation (1), ^b explanatory variables were assumed to impact the inefficiency term u_i of Equation (3), ^c explanatory variables were assumed to impact the idiosyncratic term v_i of Equation (3).

The technical efficiency scores of the individual farms were consequently calculated using the inefficiency component u_i established by Battese and Coelli [41], among others, to be

$$TE_i = \exp(-u_i). \quad (5)$$

3.2. Data and Variable Selection

Our data were obtained from the Hanoi Agricultural Production Survey (HAPS) conducted by the Ministry of Agriculture and Rural Development in collaboration with the National Institute of Agricultural Planning and Projection (NIAPP). The survey was conducted in 2018 and is the most recent data of Hanoi's rice farms. It employed a multistage sampling technique to select respondents from farming households in the 12 suburban regions/wards of Hanoi. The survey covered 2562 rice farms in total; however, after accounting for missing data or outliers, we were left with 2079 cross-sectional observations. Some descriptive statistics of our data are presented in Table 2.

The five inputs presented in Table 2 are commonly used in the rice efficiency literature and include labor, land size, seeds, fertilizers and pesticides [24,29,31,32]. It was clear that different farms used different amounts of inputs to produce different outputs (see Table 2) and, therefore, it was important to analyze their efficiency (and determinants) to improve sustainability.

On average, a single farm needed 4.29 laborers working on 0.36 hectare of land and utilizing 1.68 kg of seeds, 166.82 kg of fertilizers and 0.20 kg of pesticides to produce 1.95 tons of rice. The representative farm also had a male head of house (i.e., gender = 0.36), 38.01 years old (the youngest farmer was 30 and the oldest was 50 years old), with an education level higher than a high school degree (i.e., education = 1.14). This was reasonable because the socio-economic conditions in these regions are high (since they are in suburban Hanoi) because studying is more affordable.

Following Battese and Coelli [27] and Seok, Moon, Kim and Reed [20], among others, we also examined the effects of some explanatory variables on the rice farm's technical efficiency. In this case, the characteristic determinants were gender, age and education. We further argue that while age can be a proxy for farming experience and skill [20,42], which is important in agriculture, education can be a proxy for technical knowledge and creativity [20,43]. Consequently, age can be seen as an informal type of knowledge and education as formal knowledge. Analysis of the influence of age and education is therefore equivalent to analysis of the influence of informal and formal knowledge on farm efficiency. For determinants related to the external environment, we examined the role of the local council or agricultural support programs, labeled guidance, the impact of the market on the farms, labeled trademark, and the impact of the technological spillover effect, measured in distance. The descriptive information of these variables is presented in Table 2 and the empirical results as well as the corresponding discussions are presented in the next section.

Table 2. Descriptions of Hanoi's rice farms.

Regions/Wards	Ba Vi	Chuong My	Dong Anh	Ung Hoa	Phu Xuyen	Me Linh	My Duc	Soc Son	Thach That	Thanh Oai	Thuong Tin	Average
Observations	216	174	8	204	223	139	199	336	257	58	265	
Variables for the production function												
Output (ton)	0.78	2.20	0.60	2.53	1.96	2.19	1.10	2.62	1.14	4.81	1.49	1.95
Labor (person)	4.49	4.13	3.88	2.43	3.78	5.13	4.73	5.04	4.63	4.66	4.33	4.29
Land size (ha)	0.14	0.38	0.20	0.47	0.34	0.35	0.20	0.55	0.22	0.89	0.28	0.36
Seed (kg)	1.71	1.65	2.86	1.76	1.66	1.39	1.37	1.28	1.84	1.79	1.18	1.68
Fertilizer (kg)	141.05	317.16	28.38	72.11	283.79	204.82	208.12	101.32	220.79	25.51	232.02	166.82
Pesticide (kg)	0.40	0.20	0.01	0.01	0.21	0.40	0.40	0.01	0.40	0.01	0.19	0.20
Determinants of technical inefficiency												
Gender	0.38	0.37	0.50	0.53	0.52	0.21	0.17	0.29	0.32	0.26	0.35	0.36
Age	37.60	38.21	35.13	38.43	38.65	38.09	38.34	38.45	38.96	37.43	38.82	38.01
Education	1.32	1.12	1.00	1.23	1.13	1.07	1.09	1.12	1.17	1.12	1.14	1.14
Guidance	1.00	1.00	0.88	0.99	0.99	0.99	1.00	1.00	1.00	0.86	1.00	0.97
Trademark	1.00	0.46	0.88	0.99	0.00	0.99	0.99	0.00	0.87	0.84	0.00	0.64
Distance (km)	51	26	15	36	33	19	41	26	35	20	22	29.45

Notes: Gender is a dummy variable equal to 1 if the head of the farm is a female and 0 otherwise; education is a category variable with a value of 1 if the head completed high school, 2 if the head completed an undergraduate degree and 3 for a higher education level; guidance is a dummy variable with a value of 1 if the farm has gotten guidance or training from the regional council or agricultural support programs, otherwise it is 0; trademark is a dummy variable with a value of 1 if the harvested rice is sold by the farm under a registered trademark and 0 otherwise; and distance measures the geographical distance between each region to the center of Hanoi.

4. Results and Discussions

4.1. Production Frontiers of Rice Farms in Hanoi

We first reported the estimated SFA frontiers in Table 3. Our general comment from the significant likelihood ratio (LR) test's values (see the model statistic results in Table 3) is that using the translog model for our analysis was justified since it fit our data better than the Cobb-Douglas model. In addition, the significance of δ_u and λ indicated the appropriateness and importance of examining the efficiency of the rice farms, see Reference [44] for more details. Specifically, our estimated frontier associated larger farms with more fertilizer use but less pesticide use. This partly indicated that Vietnamese farms are now more concerned about the quality and sustainability of their crops. Again, it supports the argument of References [7,8], saying that farms can improve their efficiency by minimizing the use of pesticides to achieve sustainable goals. The role of technological development is somehow reflected in the fact that farms using more labor underperformed compared to farms using more machines.

Table 3. SFA production frontiers of rice farms in Hanoi, Vietnam.

Variable	Coefficient	Standard Error
Production frontier		
Constant	1.600 ***	0.317
Labor	−0.385 **	0.194
Land	1.629 ***	0.109
Seed	−0.193	0.137
Fertilizer	0.193 **	0.077
Pesticide	−0.163 ***	0.032
(Labor) ²	−0.029	0.075
(Land) ²	0.210 ***	0.026
(Seed) ²	−0.051	0.080
(Fertilizer) ²	−0.037 ***	0.013
(Pesticide) ²	−0.028 ***	0.005
Labor × Land	−0.141 ***	0.028
Labor × Seed	0.068	0.046
Labor × Fertilizer	0.043	0.027
Labor × Pesticide	−0.012 **	0.005
Land × Seed	0.035	0.024
Land × Fertilizer	−0.081 ***	0.015
Land × Pesticide	0.010 ***	0.004
Seed × Fertilizer	0.041 **	0.018
Seed × Pesticide	−0.004	0.005
Fertilizer × Pesticide	0.026 ***	0.005
Model statistics		
δ_u	1.094 ***	0.108
δ_v	0.215 ***	0.004
λ	5.095 ***	0.108
LR statistic	223.420 ***	

Notes: LR—likelihood ratio; *, ** and *** indicate significant differences at $p < 0.01$, $p < 0.05$ and $p < 0.001$ respectively.

4.2. Knowledge and other Determinants of Hanoi's Rice Farm Efficiency

To calculate the technical efficiency of Hanoi's rice farms in 2018 we used Equation (5), shown in Section 3.1. Table 4 presents the summary statistics of the different efficiency scores based on different assumptions of the distribution and association of the explanatory variables, including formal and informal knowledge, on the inefficiency or idiosyncratic terms of Equation (3). We concluded generally that the average efficiency score was relatively high, from 0.948 in Model 4 to 0.977 in Model 5, suggesting that the rice farms examined performed quite well in 2018. However, the large range

between the maximum and minimum values of the efficiency scores in each model (e.g., from 0.154 to 0.992 for Model 1) indicates the existence of external variables affecting the scores.

Table 4. Production efficiency of rice farms in Hanoi.

	Mean	Standard Deviation	Minimum	Maximum
Model 1	0.960	0.059	0.154	0.992
Model 2	0.964	0.051	0.106	0.995
Model 3	0.966	0.008	0.136	0.998
Model 4	0.948	0.070	0.067	0.994
Model 5	0.977	0.022	0.222	0.997

Consequently, the influence of explanatory variables on the farm's technical (in)efficiency was examined following Equation (4), the single-step SFA approach [27]. Those results are presented in Table 5, where a negative association with the farm's inefficiency should be interpreted as a positive relationship with its efficiency, and vice versa.

Firstly, according to Table 5, we found that gender tended to have a negative impact on inefficiency. This suggests that farms with female heads performed better than those with males as the head. This finding was consistent with the situation of rice farms in Nigeria [45], the Philippines [46] and Vietnam [21,29], where it is argued that women engage more intensively in agriculture than men. We further argue that, as our sampled farms are situated in the suburbs of Hanoi, a large proportion of males in good health and with knowledge/education have migrated into the city center to seek jobs. It is therefore reasonable for females to be more involved (and better equipped) to operate the farms.

Secondly, a farmer's age or informal knowledge had a positive contribution to technical efficiency but this result was not very clear. Only two models showed significant statistics (Models 1 and 5), one model showed insignificant statistics (Model 2), and two models showed opposing but insignificant statistics (Models 3 and 4). This finding, nevertheless, is in line with Huynh and Yabe [29] and Fuwa, Edmonds and Banik [42], but contradicts the results of Seok, Moon, Kim and Reed [20] and Trong and Napisintuwong [30]. Previous studies of the relationship between a farmers age and their efficiency, such as that of Liu and Zhuang [47] and Li and Sicular [48] found that technical efficiency increases until the (head) farmer is about 40–45 years old. In this sense, our findings were reasonable since the heads of Hanoi's rice farms were generally young—the average age was only about 38 years old, as indicated in Table 2.

Table 5. Determinants of rice farm inefficiency.

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Gender	−0.128	−0.165	−0.207 ***	−0.201 ***	−2.265 **
Age	−0.036 ***	−0.025	0.002	0.001	−0.337 **
Education	−0.364 ***	−0.117	−0.517 ***	−0.659 ***	−0.008
Guidance	−0.288	−1.205	−0.815 ***	−1.707 ***	−1.282
Distance	−0.313 ***	−0.200 ***	−0.185 ***	−0.190 ***	−1.900 ***
Trademark	−0.411 ***	0.922 ***	0.587 ***	0.555 ***	−1.869 **
Constant	8.002 ***	1.829	2.655 ***	3.943 ***	44.997 ***

Notes: *, ** and *** indicate significant differences at $p < 0.01$, $p < 0.05$ and $p < 0.001$ respectively.

Thirdly, formal knowledge, i.e., education, clearly improved the farm's production efficiency, in line with the rice efficiency literature [30,49]. This finding was consistent across five models, especially in terms of sign or direction, suggesting that the role of formal knowledge is clearer than that of informal knowledge. We also found a positive impact of agricultural support programs (i.e., guidance) on technical efficiency and, consequently, concluded that with the rapid development of technology, self-learning through experience is not sufficient. Education and supplementary guidance/training are

better a better resource to help farmers improve their efficiency and sustainability. We further suggest that regional councils and agricultural support programs can play an important role in this case.

Fourthly, the farms further from Hanoi tended to perform better than their counterparts. This was contradictory to the spillover effect hypothesis, stating that farms closer to Hanoi's city center benefit more from technological development in the city and should therefore perform better. We argue that this is not the case for our farmers since the distance is not significant, only between 15 and 51 km. Consequently, technological conditions at the sampled farms were similar, as discussed in the introduction, and the spillover effect was not significant. In contrast, we found that this finding might relate to the fact that in regions/wards close to Hanoi, people are more engaged in industrial or urban works rather than agricultural works, so that farmers' efficiency is hindered on those farms.

Meanwhile, the impact of trademark on technical efficiency was inconclusive, suggesting that more data, such as prices or profit/profitability, are needed to examine the impact of the market on rice farmers. If more data on (input) prices can be collected, a cost SFA or profit SFA study would be a positive contribution. We, however, leave this issue for future research.

5. Conclusions

This paper examined the production efficiency of 2079 rice farms in Hanoi (Vietnam) in 2018. We chose rice farms in suburban Hanoi because they may benefit from technological improvement and, therefore, knowledge may be more important to them. To understand the role of both formal and informal knowledge on rice farm efficiency, we used a single-step SFA approach [27] to estimate a production frontier for the sampled farms. We then analyzed the association of knowledge (and other explanatory variables) to (in)efficiency. The empirical results were compared and contrasted across five models so that the derived discussions and conclusions were robust and reliable.

Our empirical results showed that, in general, Hanoi's rice farms performed relatively well and close to the production frontier with the average efficiency score ranging from 0.948 to 0.977, depending on the SFA model. The differences in the specific performance of each farm can be explained by the farmer's characteristics as well as other external factors. In particular, our findings suggested that farms with female heads tended to outperform those with a male as the head because women are more engaged with agriculture [46] and because a large proportion of the male population with good health and knowledge has migrated into the city center to seek jobs. Formal knowledge, indicated by the level of education of the head of the farm, had a significant and positive impact on efficiency. Meanwhile, the role of informal knowledge or self-taught experience, indicated by the age of the head of the farm, on production efficiency was also positive, but unclear. We concluded that with the rapid development of technology, self-learning through experience was not sufficient, while education and training were a better mechanism for farmers to improve their efficiency and sustainability. We further suggest that the regional councils or agricultural support programs can play an important role in helping farmers improve their efficiency and sustainability.

We have only examined the technical efficiency of Hanoi's rice farms using the production frontier. It would be interesting and useful if more data on input and output prices could be collected so that a cost frontier or profit frontier could be used to provide a comprehensive view on the farms. The scope of this study could also be extended to incorporate larger areas/regions, different types of farms, and larger sets of socio-economic explanatory variables. We leave those for future research.

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