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RESEARCH ARTICLE

Technical efficiency and agricultural policy: evidence from the tea production in Vietnam

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Abstract The objective of this paper is to apply the stochastic production frontier methodology to a survey database collected in northern Vietnam. Our study finds that the average technical efficiency of tea production is only about 41 %. Among extension policy measures available to farmers, only training on production inputs has an improving impact on technical efficiency. Other features of policy have no significant effect, contrary to the expectation. The adoption of the oldest variety "Trung-Du" is not a source of inefficiency while the effects of other new varieties are insignificant. The results indicate that there is a great potential for improving production efficiency in the region of the study.

Keywords Technical efficiency · Agricultural extension policy · Stochastic frontier · Tea production · Tea variety · Vietnam

JEL classification C21 · D24 · Q12 · Q18

Introduction

Tea is globally one of the most popular and lowest cost beverages, next only to water. In recent years, tea has become an important crop in Vietnam. Tea production shows modest growth before the 1990s and a more rapid growth thereafter. Vietnam ranks fifth in the world in terms of tea output. Furthermore, the tea sector in Vietnam offers certain advantages. In particular, it may help fighting erosion and runoff in the mountains regions. It also helps to alleviate poverty in rural regions by increasing farmers' daily income.

The tea sector was ranked seventh over 20 main agricultural exporting sectors in Vietnam, and it accounts for about 200 million dollars in total export value in 2011 (GSO 2013). There are about 400,000 households taking part in tea cultivation, and the tea sector has employed about 1.5 million jobs per year. Vietnam has the potential to increase the share of tea value as it has a great domestic market with about 90 million inhabitants on the one hand and an important land area able to be converted to tea cultivation on the other hand. However, the tea sector surprisingly represents a modest part in the Vietnamese economy. It is known as relatively small compared to other agricultural sectors (only 0.2 % of the gross domestic product—GDP—and 7 % of the total agricultural GDP, much lower than other crops) (GSO 2013).

Tran et al. (2004), Tran (2008), and Nguyen et al. (2015) argued that the Vietnamese tea sector has some main weaknesses such as low and unstable quality of tea products, low productivity, preponderance of small producers, fragmentation of cultivation area, and irrational use of pesticides and fertilizers. Most of the tea cultivation area corresponds to the variety "Trung-Du" which gives a low quality, small leaves, and a low productivity. Actually, there are many varieties of tea in Vietnam such as Trung-Du, "PH1," "Bat-Tien," "LDP1," etc. However, some old varieties of tea like Trung-Du still represent the majority, and the strategy of Vietnam is to gradually adopt new tea varieties such as PH1, LDP1, and Bat-Tien, which are thought to have a higher productivity and a better quality than the variety Trung-Du. For instance, Cuong (2006) found that the productivity of traditional tea variety, Trung-Du, is about 4 tons per hectare, while that of PH1 is about 6.5 tons per hectare in a district of the province of

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Phu-Tho. Tran et al. (2004) found that the average productivity with new varieties reaches 12 tons per hectare in the province of Son La. In general, a common view is that old varieties give a lower productivity than new varieties (Do Van 2012).

In addition, agricultural policy is an activity which aims to improve the utilization of existing technologies and to develop managerial skills of farmers. It also aims to provide farmers with information on new technologies, new varieties, more efficient farming practices, links to markets and other players in the agricultural value chain, etc. (Owens et al. 2003; Dinar et al. 2007; Birner et al. 2009; Davis et al. 2012; Ragasa et al. 2013). In fact, agricultural policy is an important policy for agricultural development in Vietnam. It was designed in order to develop the agricultural sector by increasing its added value in a sustainable way. According to Decree 02/2010/ND-CP on agricultural extension (in Vietnamese) enacted in 2010 by the Vietnamese government, this policy essentially consists of information and training on production techniques, inputs, product quality, commercialization and sales, and agricultural markets. This Decree clearly indicates that information and training (both on the farm and off the farm, combination between theory and practice) are given by officials. Farmers do not need to pay any registration fee to participate to these activities. They only pay 50 % of their accommodation and transport fees. Small- and low-income farmers are totally exonerated from any fee. All other fees (for example, equipment, fertilizers, and pesticides used in training courses, communication expenditures) are mostly supported by public (central or local) funds, up to 100 % if extension activities arise in a poor and mountain region. Depending on the type of extension activity, it can be implemented over individuals or a group of individuals.

The tea sector can take advantage of this agricultural policy. Agricultural extension for this sector encompasses several features: (i) training courses or technical instruction on tea cultivation (land preparation, planting, etc.), (ii) training on modern techniques of application of fertilizer and pesticide, (iii) training on harvesting and conservation, (iv) provision of information on tea market (consulting activity, information on market demand, prices, sales contract, etc.), and (v) training on sale skills.

These measures of agricultural extension policy and the incentive to adopt new tea varieties are then expected to have improving effects on technical efficiency. Therefore, our study aims at assessing the impacts of these factors on technical efficiency in tea production in Vietnam. For this purpose, we apply the stochastic production frontier analysis to a survey data collected by ourselves. We particularly try to identify the role of agricultural policy and the heterogeneity related to different tea varieties. Our results are twofold. Firstly, we observe that tea production in this region suffers from a strong technical inefficiency. Secondly, the implementation of some agricultural policy activities and the adoption of certain new tea varieties so far do not seem to have the expected results on technical efficiency.

The remaining of the paper is organized as follows. The first section discusses the potential determinants of technical efficiency, including factors which are related to other crops but appear to be relevant to tea. The Data section describes the data we collected ourselves in Vietnam. Section 3 presents the stochastic production frontier model applied to our data. Section 4 reports estimation results and interpretation. Finally, the last section concludes the study.

Potential determinants of technical efficiency

The literature on stochastic production frontier is abundant. Researches on tea production are however relatively scarce, and results obtained from existing studies are very heterogeneous. We will limit our attention on studies concerning agriculture and, in particular, the tea sector. We believe that results obtained for other crops can be reasonably applied to tea. In this section, we first provide a review about the level of technical efficiency and then discuss its major determinants reported by existing studies.

Reviews of technical efficiency estimation in agriculture using stochastic production frontier can be found in Bravo-Ureta and Pinheiro (1993). In particular, this study reviewed the frontier works applied to farm level data collected in developing countries. About 30 studies from 14 different countries were examined. India was the country that has received the highest attention, and rice was the most studied agricultural product. The average technical efficiency computed from all the reviewed studies is about 72 %. This finding underlined that there is considerable room to increase agricultural output without additional inputs and given existing production technology. The variables frequently used in these studies are farmer's education and experience, access to credit, farm size, etc. These variables, except for farm size for which the effect is ambiguous, appear to have a positive and significant effect on technical efficiency.

Cuesta (2000) introduced a stochastic frontier model accommodating firm specific temporal variation in technical inefficiency for Spanish dairy farms. The observed mean technical efficiency is found to be decreasing over time from 85.7 % in 1987 to 77.5 % in 1991, whereas the mean for the entire period is 82.7 %. Results from the Battese and Coelli (1992) model (with a common pattern of efficiency change) indicated a decreasing technical efficiency of Spanish dairy farms as well, from 84.2 % in 1987 to 81.4 % in 1991. Besides, Dey et al. (2010) depicted the frequency distribution of the estimated technical efficiency on small-scale farms in Southern Malawi. The technical efficiency of the integrated aquaculture-agriculture farmers is 90 %, while it is only 65 % for non-integrated aquaculture-agriculture farmers.

Wadud and White (2000) applied a translog model to survey data on rice farmers in Bangladesh. Variables included in modeling technical efficiency are age of farmers, land fragmentation, year of schooling, irrigation infrastructure, and environmental degradation. In a meta-analysis of technical efficiency of agriculture in developing countries, Thiam et al. (2001) used a Cobb-Douglas production function and found that crop variety does not seem to significantly affect technical efficiency. Raphael (2008) found that technical efficiency of cassava farmers in south-eastern Nigeria is on average about 77 %. An additional finding is that farmer's education, experience, membership in a farmers' association, credit, household size, improved cassava variety, and farm size are significantly related to technical efficiency whereas age has no significant impact.[1] Hossain et al. (2012) estimated a translog production frontier for Bangladeshi rice crops and found that technical efficiency is around 50 %. Khai et al. (2008) and Khai and Yabe (2011) analyzed the efficiency of soybean production in Vietnam and reported that the average technical efficiency is around 82 %. These studies showed that the most important factors having positive impacts on technical efficiency are intensive labor in rice cultivation, irrigation, and education.

Regarding tea production, Basnayake and Gunaratne (2002) estimated that the average technical efficiency of small tea producers in Sri Lanka is approximately 65 %. The authors indicated that farmer's age, education level, occupation, and experience as well as crop variety can have significant effects on technical efficiency. Concerning tea production in Vietnam, Tran (2008) showed that organic tea production has a very high technical efficiency, about 99 %. In their work based on a sample of tea producers in the Moc-Chau district, Son-La province (a small tea-producing province in north-western Vietnam), Saigenji and Zeller (2009) showed that the mean technical efficiency is 60 %. They also observed that contracted farming reached significantly higher technical efficiency compared to non-contracted farming. More precisely, technical efficiency of farms having a contract with a state-owned firm, farms having a contract with a private firm or a cooperative, and those having no contract is on average 69, 58, and 47 %, respectively. Other variables affecting technical efficiency were also included, such as total land owned by the household, number of plots, age of tea tree weighted by area, distance to the collecting point of tea leaves, use of motorbike to collecting point, and poverty index.

Concerning the variable of interest in our study, namely, agricultural extension policy, although its effect is expected to have an intuitive sign, i.e., negative effect on technical inefficiency (or positive effect on technical efficiency), confronting with real data gives contrasted results. Seyoum et al. (1998), Ahmad et al. (2002), and Lindara et al. (2006) found that various measures of agricultural policy (access to policy services, training, number of contacts with agricultural policy officers, etc.) can help improve technical efficiency. More precisely, Seyoum et al. (1998) investigated technical efficiency in maize producers in eastern Ethiopia, by comparing farmers within the Sasakawa-Global 2000 project (which involves better farming practices) and farmers outside this project. The authors found that advice of policy workers are beneficial to farmers within the project whereas they do not help farmers outside the project to reduce technical inefficiency. Ahmad et al. (2002) studied the technical efficiency of wheat producers in Pakistan and showed that having contact with agricultural policy agents can help farmers raise their technical efficiency. Regarding the study of Lindara et al. (2006) on the spice-based agroforestry sector in Matale District, Sri Lanka, technical efficiency is shown to be increasing with the number of farm visits by policy officers and the farmer's participation to a training class.

On the contrary, some studies showed that agricultural policy features do not have any significant impact on technical efficiency and that, in some cases, they can worsen technical inefficiency. For example, in Raphael (2008), the variable for policy contact does not have any significant effect on technical efficiency for cassava production in Nigeria. Khai et al. (2008) found that training and supports from the government (on fertilizers, pesticides, and seeds) have no significant effect on soybean production technical efficiency in Vietnam. Khai and Yabe (2011) used an agricultural policy variable, which represents three main policies of the government (preferential credit, land provision, and agricultural promotion). This variable can be thought to encompass features of policy in Vietnam aiming at increasing the performance of the agricultural system. The authors observed that agricultural policy does not help farmers cultivate rice more efficiently.

The discussion so far suggests that technical efficiency of tea production in Vietnam is not high. Moreover, based on the literature review, we can make some hypotheses regarding the determinants of technical efficiency. Table 1 only reports

[1] There is a longstanding literature about the nexus between farm size and technical efficiency/productivity, relying on the concept of economies/diseconomies of scale. Empirical evidence on the issue is however relatively scarce and mixed (Bardhan 1973; Carter 1984; Bravo-Ureta and Rieger 1991; Bravo-Ureta and Pinheiro 1993; Ahmad and Bravo-Ureta 1996; Raphael 2008; Alvarez and Arias 2003). Including farm size simultaneously as an input factor and a determinant of technical efficiency can raise a serious problem of identification. In order to avoid this problem in our empirical specification, we do not consider farm size as a determinant of technical efficiency but only include this variable in the set of production inputs.

Table 1 Expected impacts of determinants of technical inefficiency of tea in Vietnam

Variables	Expected sign
Agricultural extension measures	–
Old variety of tea	+
New varieties of tea	–
Black tea	+/–
High income	–
High education	–
Ethnic minority	+

Notes: A negative expected sign means a reduction of technical inefficiency (i.e., improving effect on technical efficiency) while a positive sign corresponds to an increase of technical inefficiency (i.e., worsening effect on technical efficiency).

variables that are used in our final model specification.[2] More precisely, we expect improving effects on technical efficiency (or negative effects on inefficiency) for agricultural extension activities and the use of new tea varieties as indicated in the previous section. We also expect that high economic condition and high education level can favor the access to new production technology and to any information that can improve the production and hence reduce technical inefficiency. On the contrary, being part of a minority ethnic group can represent a lack of advantage compared to the majority ethnic group (known as Kinh). Indeed, minority ethnic groups have lower economic and social conditions compared to the majority Kinh ethnic group. This disadvantaged situation might lead to a lower productivity, represented by a positive effect on technical inefficiency.

Finally, the impact of conventional cultivation (black tea in our case) might be of either sign, positive or negative. While black tea and green tea can be obtained from the same varieties, their production process fundamentally differs after harvesting (more precisely, oxidation treatment for black tea). Furthermore, it is recognized that green tea has a higher economic value than black tea but its production is more labor intensive. Hence, even if the expected sign of black tea is generally ambiguous, estimating its effect on technical efficiency is still interesting thanks to its policy implication in the context of our data.

Data

The data used in this research were collected from field survey in three provinces (Tuyen-Quang, Phu-Tho, Thai-Nguyen) of Vietnam by the authors from January to May 2013. Tuyen-Quang and Phu-Tho are two provinces which mainly produce black tea whereas Thai-Nguyen is renowned for its green tea. Figure 1 indicates the geographical location of these provinces on the map of northern Vietnam. According to the Vietnam Tea Association (Vitas 2009), tea production in Vietnam is mostly concentrated in the North (about 60 % of total area of plantation), which includes the three provinces of the study (Tuyen-Quang, Phu-Tho, and Thai-Nguyen), and Central Highlands (about 20 %), the remaining being dispersed in other provinces (in particular in Central Vietnam). The survey corresponds to a broad research project on "Welfare, sustainable development, and tea cultivation in Vietnam" that we are currently conducting in Vietnam.[3]

The survey was carried out on a sample of households randomly selected from a household list of 10 different villages. Face-to-face interviews were conducted. The average duration for the whole questionnaire lasted 1 h and 13 min with a maximum of 2 h. It consists of a quantitative household survey. In total, 244 tea farm households were interviewed. They were asked to provide information on tea production in 2012 (tea varieties, quantity of production, use of fertilizers, use of pesticides, cultivation land area, labor, and activities of agricultural policy that they followed). The main questions were also related to important household socio-economic characteristics such as assets, social capital, income sources, education, etc.[4]

The definition of variables is given in Table 2. Because of missing values on certain variables, the final data used in estimations contain 240 households. Summary statistics of variables are reported in Table 3. In 2009 in Vietnam, about 70 % of households had a tea production area less than 0.2 ha (Vitas 2009). Our data, obtained from a random sampling procedure, correspond to a small and medium-size farm sample. The average land area in our sample (in 2012) is higher than 0.5 ha (more precisely, 5874.254 m^2). The discrepancy with Vitas' (2009) figures is due to the concentration policy promoted in recent years in Vietnam aiming at reducing the fragmentation of cultivation area. We observe in our data that

[2] The list of potential determinants of technical efficiency discussed above is larger than the list of variables in this table. There are several reasons for not including all of them in our final model specification. Firstly, our data do not cover some of them (experience in tea cultivation, credit). Secondly, there is a problem of missing values for some indicators (farmer's age, farms with contract). Finally, certain variables (such as household size and membership of professional and political associations) are not taken into account based on a statistical argument. Indeed, household size is correlated with labor, which is defined as total labor, including both family labor and hired labor. Concerning membership in professional and political associations, there exist several available indicators in the database (membership in the Communist party, Communist Youth, association of women, farmers' association, etc.). Including these indicators in the regressions does not change the results as none of them has a significant effect. As they are not the focus of our study, they were not included in the final specification.

[3] Data and the survey questionnaire are available from the authors upon request.

[4] The households interviewed may simultaneously produce tea and other agricultural goods. Of course, we did make sure in our questionnaire that inputs are only related to tea production.

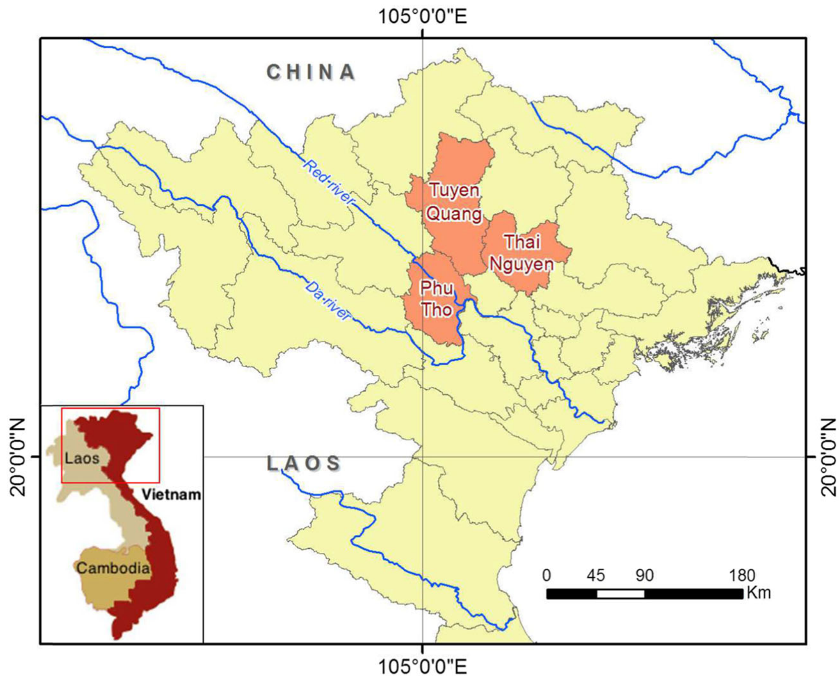

Fig. 1 Geographical location of the survey. Source: the authors, adapted from the Vietnam Ministry of Natural Resources and Environment

the average tea output is about 5 t/household, with a standard deviation of 8.48, and the range of production varies from about 0.02 t (or 20 kg) to 60 t (or 60,000 kg). Furthermore, while the General Statistics Office of Vietnam reported a productivity of Vietnam tea about 5–18 t/ha during the period 1961–2011 (GSO 2013), the figures for our sample are quite

Table 2 Definition of variables used

Variable name	Definition	Nature
Land	Land area used in tea production (in square meters)	Continuous
Labor	Total labor employed in tea production (in person-days)	Continuous
Production	Total tea production (in tons)	Continuous
Black tea	=1 if black tea production, 0 otherwise	Dummy
Tea varieties		
'Trung-Du'	Tea variety, trees of at least 5 years old (=1 if yes, 0 otherwise)	Dummy
'PH1'	Tea variety, trees of at least 5 years old (=1 if yes, 0 otherwise)	Dummy
'LDP1'	Tea variety, trees of at least 5 years old (=1 if yes, 0 otherwise)	Dummy
'Bat-Tien'	Tea variety, trees of at least 5 years old (=1 if yes, 0 otherwise)	Dummy
'Other'	Other tea variety, trees of at least 5 years old (=1 if yes, 0 otherwise)	Dummy
Fertilizers		
Organic fertilizers	=1 if use of organic fertilizers, 0 otherwise	Dummy
Chemical fertilizers	=1 if use of chemical fertilizers, 0 otherwise	Dummy
Extension policy		
Cultivation	Training on cultivation techniques (=1 if yes, 0 otherwise)	Dummy
Inputs	Training on fertilizers and pesticides (=1 if yes, 0 otherwise)	Dummy
Harvesting and conservation	Training on harvesting and conservation (=1 if yes, 0 otherwise)	Dummy
Information	Information on tea market (=1 if yes, 0 otherwise)	Dummy
Sale skills	training on sale skills (=1 if yes, 0 otherwise)	Dummy
High income	=1 if subjective perception of high income, 0 otherwise	Dummy
High education	=1 if household's head reached high school or above, 0 otherwise	Dummy
Ethnic minority	=1 if part of a minority ethnic group, 0 otherwise	Dummy

Table 3 Descriptive statistics of the sample

Variable	Mean	Std. Dev.	Min.	Max.	Obs.
Production (tons)	5.006	8.483	0.024	60	5.006
Land (square meters)	5874.254	6008.56	130	45,000	5874.254
Labor (person-days)	225.832	546.74	5	7863	225.832
Organic fertilizers	0.483	0.501	0	1	0.483
Chemical fertilizers	0.738	0.441	0	1	0.738
Black tea	0.433	0.497	0	1	0.433
Tea varieties					
'Trung-Du'	0.458	0.499	0	1	0.458
'PH1'	0.175	0.381	0	1	0.175
'LDP1'	0.217	0.413	0	1	0.217
'Bat-Tien'	0.192	0.394	0	1	0.192
'Other'	0.179	0.384	0	1	0.179
Extension policy measures					
Cultivation	0.717	0.452	0	1	0.717
Inputs	0.663	0.474	0	1	0.663
Harvesting and conservation	0.571	0.496	0	1	0.571
Information	0.258	0.439	0	1	0.258
Sale skills	0.221	0.416	0	1	0.221
High income	0.329	0.471	0	1	0.329
High education	0.329	0.471	0	1	0.329
Ethnic minority	0.108	0.311	0	1	0.108

Notes: Number of observations: 240

comparable. In particular, our sample exhibits an average productivity of 6.67 t/ha and a standard deviation of 5.71 t/ha (its range comprised between 0.10 and 23.33 t/ha). Labor corresponds to total labor employed in tea production (planting, harvesting, etc.), including both family labor and hired labor. The average share of family labor in total labor is 57.5 %, the rest being hired labor. The average quantity of total labor is 225.8 person-days. All these figures indicate a large variability in production among the farmers, suggesting that our data include both small and large producers.

The final sample includes 136 green tea producers and 104 black tea producers. A dummy variable for black tea is then defined to check whether there exists a difference between black tea production and green tea production. Information of the use of fertilizers and pesticides is also reported. Because tea is a long-term cycle plant, we separate fertilizers into two groups, organic fertilizers and chemical fertilizers. The former group has a well-known role in fostering agricultural production whereas the latter, including chemical substances for tea trees and leaves, can degrade soil quality, which negatively affects tea production in the long run. The data show that most of the producers in our sample (177 households, 73.7 % of the sample) employ chemical fertilizers while, in a lesser extent, about a half of the sample (116 households, 48.3 % of the sample) use organic fertilizers. Moreover, as all the producers in our survey have recourse to pesticides, it is not informative to consider this variable in the analysis.

Regarding agricultural extension policy, a producer can follow different types of activity (the corresponding dummy variable will then take the value 1 when the farm has followed this activity until the year of study). Training on cultivation techniques is the most followed activity (172 producers, 71.7 % of the sample) and training on sale skills is the least one (53 producers, 22.1 %). Training on the use of pesticides and fertilizers (or inputs), training on harvesting and conservation, and information on the tea market (consulting activity, information on market demand, prices, sales contract, etc.) are followed by 159 (66.2 % of the sample), 137 (57.1 %), and 62 (25.8 %) producers, respectively. We observe that 39 farmers (16.3 %) do not participate to any of the five proposed extension activities while 12 producers (5 %) participate to all of the five activities. The numbers of producers who participate to 1, 2, 3, or 4 activities are 24, 43, 75, and 47, respectively (corresponding to 10, 17.9, 31.2, and 19.6 % of the sample). The most common situation is therefore participation in three activities. We finally remark that our study does not cover other aspects of extension policy (as investigated in the literature) such as contact with policy officers, credit access, agricultural promotion policy, etc.

Our analysis also includes dummies corresponding to household characteristics like high income (= 1 if the household's head thinks that (s)he belongs to the high-income group, 0 otherwise), high education (= 1 if the household's head has a high school degree or above, 0 otherwise), and ethnic minority (= 1 if the household belongs to an ethnic minority, 0 otherwise). The data contain 81 (self-perceived) high-income households, 79 households with high education, and 26 households belonging to an ethnic minority group.

Tea varieties are classified into 5 categories: Trung-Du (the oldest variety), PH1, LDP1, Bat-Tien, and the remaining types (category Other). As a tea tree only starts giving a significant production if it is at least 5 years old, these varieties are consequently defined over tea trees aged 5 years or more. Table 4 gives the distribution of the data according to tea varieties. We note that some farmers cultivate several tea varieties at the same time. The oldest variety Trung-Du is cultivated by 110 households, about 45.8 % of the data sample. Other varieties are adopted in a much lower extent, less than a half of the Trung-Du proportion.

Table 4 Sample distribution according to tea varieties used

Tea varieties	Frequency		Percent	
	No: 0	Yes: 1	No: 0	Yes: 1
'Trung-Du'	130	110	54.17	45.83
'PH1'	198	42	82.50	17.50
'LDP1'	188	52	78.33	21.67
'Bat-Tien'	194	46	80.83	19.17
'Other'	197	43	82.08	17.92

Notes: Number of observations: 240

A stochastic production frontier for tea production

The purpose of this section is to briefly describe a model of stochastic production frontier that can be applied to our Vietnamese data. The concept was introduced by Aigner et al. (1977) and Meeusen and van Den Broeck (1977). Recent reviews of the frontier literature can be found in Bauer (1990), Kumbhakar and Lovell (2003), Ozkan et al. (2009), Kompas et al. (2012), and Jiang and Sharp (2015).

We assume that output y_i of farmer i, $i = 1, 2, \ldots, n$ is subject to random shocks v_i and a degree of technical efficiency $\omega_i \in (0, 1]$:

$$y_i = f(x_i;\beta)\omega_i exp(v_i), i = 1, 2, \ldots, n, \quad (1)$$

where x_i is a $K \times 1$ vector of inputs, β a $K \times 1$ vector of parameters to be estimated.

By assuming $\omega_i = \exp(-u_i)$ with $u_i \geq 0$, we obtain[5]

$$y_i = f(x_i;\beta)exp(v_i - u_i), i = 1, 2, \ldots, n, \quad (2)$$

Applying log transformation to Eq. (2), we get

$$\ln y_i = \ln f(x_i;\beta) + v_i - u_i. \quad (3)$$

We observe that v_i corresponds to the usual regression error term, i.e., independently and identically distributed with $N(0, \sigma_v^2)$, which captures random variation in output due to factors beyond the control of producers. The error term corresponding to technical inefficiency in production, u_i, is assumed to be independently distributed with $N^+(\mu, \sigma_u^2)$ with truncation point at 0. The condition $u_i \geq 0$ ensures that all observations lie on or beneath the production frontier.

An estimation for u_i is given by (see Jondrow et al. 1982)

$$E\{u_i|v_i - u_i\} = \tilde{\mu}_i + \tilde{\sigma}\left\{\frac{\phi\left(-\tilde{\mu}_i/\tilde{\sigma}\right)}{\Phi\left(\tilde{\mu}_i/\tilde{\sigma}\right)}\right\}, \quad (4)$$

where $\tilde{\mu}_i = \left[-(v_i - u_i)\sigma_u^2 + \mu\sigma_v^2\right] / \sigma^2$, $\tilde{\sigma} = \sigma_v\sigma_u/\sigma$, $\sigma = \left(\sigma_v^2 + \sigma_u^2\right)^{1/2}$, and $\phi(.)$ and $\Phi(.)$ are respectively the density and the cumulative distribution function of the standard normal distribution. A $(1-\alpha)\%$ confidence interval of the conditional distribution $u_i|(v_i - u_i)$ is given by

$$LB_i = \tilde{\mu}_i + \tilde{\sigma}\Phi^{-1}\left[1 - (1-\alpha/2)\Phi\left(\tilde{\mu}_i/\tilde{\sigma}\right)\right], \quad (5)$$

$$UB_i = \tilde{\mu}_i + \tilde{\sigma}\Phi^{-1}\left[1 - (\alpha/2)\Phi\left(\tilde{\mu}_i/\tilde{\sigma}\right)\right], \quad (6)$$

where LB_i and UB_i correspond to the lower bound and the upper bound, respectively (see Horrace and Schmidt 1996 and Greene 2008).

The degree of technical efficiency can be estimated by the following conditional expectation

$$TE_i \equiv E\{exp(-u_i)|v_i - u_i\} = \left\{\frac{\Phi\left(\tilde{\mu}_i/\tilde{\sigma}\right) - \tilde{\sigma}}{\Phi\left(\tilde{\mu}_i/\tilde{\sigma}\right)}\right\} exp\left\{-\tilde{\mu}_i + \frac{1}{2}\tilde{\sigma}^2\right\}, \quad (7)$$

where $v_i - u_i = \ln y_i - \ln f(x_i;\beta)$ from Eq. (3). The $(1-\alpha)\%$ confidence interval for technical efficiency TE_i can be computed as $\{\exp(-UB_i), \exp(-LB_i)\}$.

In order to compute the technical efficiency score, we need to estimate parameters from model (3), and this

[5] It should be noted that by definition ω_i and u_i move in the opposite directions: ω_i represents a measure of technical efficiency while u_i corresponds to technical inefficiency. The producer achieves the optimal output when ω_i reaches the highest value ($\omega_i = 1$) while u_i is at its lowest value ($u = 0$). On the contrary, when u_i tends to infinity, ω_i tends to 0, the production is totally technically inefficient.

can be performed by maximum likelihood. The log-likelihood of this model is

$$\ln L = \sum_{i=1}^{n} \left\{ -\frac{1}{2}\ln(2\pi) - \ln\sigma - \ln\Phi\left(\frac{\mu}{\sigma\sqrt{\rho}}\right) + \ln\Phi\left\{\frac{(1-\rho)\mu - \rho(v_i - u_i)}{\{\sigma^2\rho(1-\rho)\}^{1/2}}\right\} - \frac{1}{2}\left\{\frac{(v_i-u_i)+\mu}{\sigma}\right\}^2 \right\}, \quad (8)$$

where $\rho = \sigma_u^2/\sigma^2$.

For the estimation, we need to specify the functional form for $f(x_i;\beta)$. Usually, it corresponds to the Cobb-Douglas or translog function. Moreover, as in Battese and Coelli (1995) and afterward in Kompas et al. (2012), instead of the homogeneity in the distribution of technical efficiency ($u_i \cong N^+(\mu, \sigma_u^2)$), we can specify a conditional mean model for u_i as

$$u_i = z_i'\delta + \eta_i, \quad (9)$$

where z_i' is a $J \times 1$ vector of explanatory variables, δ is the associated vector of unknown coefficients, and η_i is distributed with$N^+(0, \sigma_u^2)$ with truncation point at 0. In this case, we replace μ in the previous expressions by $z_i'\delta$. The absence of technical inefficiency is characterized by $\rho = \delta = 0$. This test may be implemented by a likelihood-ratio test whose specific critical values can be found in Kodde and Palm (1987).[6]

In the next section, we apply this stochastic frontier model to our data on Vietnam's tea production. We do specify the production function a priori but will test two specifications, Cobb-Douglas and translog. The dependent variable, y, corresponds to the quantity of tea production (measured in tons). Inputs included in x are the quantity of labor (measured in persons-days) and the land area (measured in square meters). Dummies for the uses of organic fertilizers and chemical fertilizers are also added in the production function part of the frontier to capture the other inputs' use. Potential factors determining technical efficiency, which are included in z, are five dummy variables representing the agricultural extension measures available to agricultural producers in Vietnam, five dummy variables capturing tea varieties (Trung-Du, PH1, LDP, Bat-Tien, and Other), a dummy for black tea, a dummy for farmer's high income, a dummy for farmer's high education, and a dummy for farmer's belonging to an ethnic minority (see Table 2 for the definition of variables).

[6] The usual critical values of the likelihood-ratio statistic cannot be used here because the distribution of the test statistic under the null hypothesis ($H_0: \rho = \delta = 0$) is not well defined.

Estimation results

Statistical tests of the model

In this section, we report estimation results and tests on the production function as well as results on the determinants of technical inefficiency. Estimation is performed by maximum likelihood. As the sample size is moderate, we use the bootstrap standard errors instead of the usual ones in order to obtain a more robust inference.[7]

We firstly use the likelihood-ratio test to choose which production function specification is the most suitable for modeling tea production in our sample. The two production functions tested are Cobb-Douglas (null hypothesis) and translog (alternative hypothesis). The test statistic is 22.00, which is higher than the critical value of the chi-square distribution with 6 degrees of freedom at the 5 % level (12.592), leading to the rejection of the Cobb-Douglas function in favor of the translog specification.

Using the translog model, we test for the absence of technical inefficiency, which corresponds to the null hypothesis $H_0: \rho = \delta = 0$. The distribution of the likelihood-ratio test statistic is not standard under the null hypothesis. We can however use the adequate critical values provided by Kodde and Palm (1987). As the computed value of the test statistic is 425.777, much higher than the 5 % critical value of the chi-square distribution with 16 degrees of freedom under the null hypothesis (26.296), we can reject the null hypothesis and conclude that technical inefficiency exists in our sample.

The final test is related to the joint significance of determinants of technical inefficiency. The likelihood-ratio statistic follows a chi-square distribution with 14 degrees of freedom under the null hypothesis $H_0: \delta = 0$ (except the intercept). The computed value of the statistic is 122.87, much larger than the 1 % critical value of 23.685, implying that the determinants included in the model are jointly significant. In other words, the determinants considered here can provide a good explanation for technical (in)efficiency in our sample.

Estimation results: production function

Table 5 shows the coefficients of the translog frontier production model. Two inputs, namely, land and organic fertilizers, have significant positive effects on the production. The elasticity of land is 0.430, a result which is consistent with Madau (2007) and Kompas et al. (2012). The elasticity of organic fertilizers is quite high, 1.463, and statistically

[7] We use the sampling procedure with replacement (firstly with 200 and then with 1000 replications for sensitivity check, but both sets of results were very similar) to compute bootstrap standard errors, in order to prevent a possible inconsistency in statistical inference often met with the usual standard errors in small or moderate samples. Estimation results reported in Tables 5 and 6 correspond to 200 replications.

Table 5 Estimation of the production function for tea production, translog model

Variables	Coefficient	Boot. Std. Err.
lnLand	0.430*	0.247
lnLabor	−0.302	0.352
Organic fertilizers	1.463**	0.692
Chemical fertilizers	−1.209	0.802
lnLand × lnLabor	0.054	0.047
Organic fertilizers × lnLand	−0.099	0.094
Organic fertilizers × lnLabor	−0.119	0.088
Chemical fertilizers × Organic fertilizers	−0.079	0.156
Chemical fertilizers × lnLabor	0.094	0.086
Chemical fertilizers × lnLand	0.095	0.079
Intercept	−2.394	2.153

Notes: Number of observations: 240

*Significance at the 10 % level; **Significance at the 5 % level

significant. This finding is in contrast with the results of Dey et al. (2010) who found a significant and negative elasticity (−1.406). Regarding the effect of chemical fertilizers, it is not significant. This result is not surprising because tea is a long-term cycle plant and its production can be improved by using organic fertilizers. On the contrary, while chemical fertilizers might have a positive effect in the short run, their use are not recommended because of their degrading impact on soil quality which negatively affects the tea production in the long run.

Estimation results thus show that only land and organic fertilizers can increase production, while chemical fertilizers, labor, and all interaction terms are not significant.[8] The insignificant effect of labor seems at first glance counter-intuitive. While labor was found to have a significant positive impact on agricultural production in several existing works (see Sect. 2), some previous studies obtained a result very similar to ours, such as Cuesta (2000) for Spanish dairy farms and Madau (2007) for Italian cereal farms. It can also be noted that Hossain et al. (2012) estimated a translog production frontier for Bangladeshi rice data where labor input was not included. Estimation results imply that tea production in the region of the study is more sensitive to a change in the cultivation area and the use of organic fertilizers than a change in labor. In fact, the source of labor force is mainly members of the household, the size of which takes of course a certain time to adjust. Therefore, if a farmer aims at raising his/her production, the first input (s)he wants to adjust should be (organic) fertilizers instead of labor.

[8] Although the interaction terms are individually not significant, their joint effects are statistically significant as shown above by the likelihood-ratio test, leading to the choice of the translog production specification to the detriment of the Cobb-Douglas one.

Table 6 Determinants of technical inefficiency in tea production, translog model

Variables	Coefficient	Bootstrap standard error
Extension policy		
Cultivation	0.122	0.153
Inputs	−0.242*	0.142
Harvesting and conservation	0.114	0.108
Information	0.130	0.147
Sale skills	−0.047	0.120
Tea varieties		
'Trung-Du'	−0.261**	0.107
'PH1'	−0.002	0.366
'LDP1'	−0.144	0.112
'Bat-Tien'	−0.214*	0.112
'Other'	−0.369**	0.176
Black tea	−2.805	3.422
High income	−0.016	0.110
High education	−0.009	0.083
Ethnic minority	0.093	0.115
Intercept	2.663**	0.397
$\ln(\sigma^2)$	−1.493**	0.329
Inverse logit of ρ	0.622	9.192
σ_u^2	0.146	0.472
σ_v^2	0.079	0.470
σ^2	0.225	0.074
ρ	0.651	2.089

Notes: Number of observations: 240

*Significance at the 10 % level; **Significance at the 5 % level

Estimation results: determinants of technical inefficiency

Table 6 reports estimation results relative to the determinants of technical inefficiency associated to the translog production function. Among five categories of agricultural extension policy, training on the use of inputs (fertilizers and pesticides) is the only significant one, with a negative effect suggesting improvement of technical efficiency. The existing literature, which does not distinguish various training activities and information provision as the five-category scheme in our analysis, provides contradictory results as reviewed in Sect. 2. Here, only training on the use of fertilizers and pesticides can help reduce technical inefficiency while other policy practices have no significant role. Agricultural extension policy is implemented in every agricultural sector in Vietnam (following Decree 02/2010/ND-CP of the Vietnamese government). Concerning tea production in particular, the result implies that policy should be targeted on training relative to the use of pesticides and fertilizers. This training could be provided in its existing form to tea producers as it can help reduce technical inefficiency. Other kinds of training and information (training on cultivation techniques, harvesting and conservation, sale skills, and information on the tea market) have no significant role in their current form. This finding is different from that obtained by Khai et al. (2008) and Khai and Yabe (2011) who indicated that government's support (on pesticides, fertilizers, and seeds) has no impact on technical efficiency of soybean and rice production. Dey et al. (2010) also mentioned that extension service does not have any significant effect on farm output.

Furthermore, there is a heterogeneity concerning the cultivated varieties. Indeed, among the five groups of tea varieties considered here, varieties Trung-Du, Bat-Tien, and Other have significant impacts on technical efficiency. The effects of Trung-Du, Bat-Tien, and Other varieties group are negative on technical inefficiency and precisely −0.261, −0.214, and −0.369, respectively. These figures show that adopting the oldest variety (Trund-Du) is not really a disadvantage contrary to what was expected and that only some of the new varieties can lead to an increase in technical efficiency (Bat-Tien and Other). Two well-known new varieties, PH1 and LDP1, have no effect on technical efficiency of tea production in our sample. This heterogeneity suggests that tea producers should be cautious about adopting new varieties. In particular, the oldest variety Trung-Du still remains technically efficient. This result seems to contradict with the current recommendation about the non-adoption of the Trung-Du variety by some actors of the profession and Vietnamese institutions (Tran et al. 2004). Indeed, a tea plant is ready for production when it is sufficiently aged (typically more than 5 years old) and the maximum production can be reached when it attains 30 years old. Estimation results show that under the current conditions, the old variety Trung-Du still has a relatively high performance compared to new varieties like PH1 and LDP1. This means that farmers might take advantage of their longer experience with Trung-Du than with other varieties. Our study then recommends that under the current situation farmers should choose the old variety Trung-Du, or, among new tea varieties, Bat-Tien or other types. While new varieties, including PH1 and LDP1, have proven their higher yield and higher quality than Trung-Du in many investigations (Do Van 2012), how this advantage can be translated into field production depends on field conditions and on the farmer's adaptation with respect to these varieties.

Results also show that there is no statistical difference between black tea production and green tea production as the coefficient of this variable is insignificant. This finding is in contradiction with Tran (2008) who found that green tea production in Vietnam has a very high technical efficiency (namely 99.8 %). One explanation for our result is that while the conventional (black) tea has a lower economic value than green tea, it can take advantage of a longer experienced production as it is the case in our sample. Hence, our finding suggests that, under the current conditions, there is no technical efficiency gap between these two types of production.

Table 7 Summary statistics for technical efficiency

Variables	Mean	Std. Dev.	Min.	Max.	Obs.
Technical efficiency	0.412	0.362	0.014	0.929	240
u_i	1.445	1.114	0.076	4.301	240

Notes: Number of observations: 240

Finally, household's characteristics such as (self-perceived) high income, high education of the household's head, and being part of a minority ethnic group have no significant effect on technical efficiency. Thus, farmer's characteristics do influence production efficiency as much as tea varieties or extension policy variables do.

Technical efficiency distribution

The distribution of technical efficiency for our data is summarized in Table 7. The results point out that technical efficiency is very low for our data. The average value of technical efficiency is about 41.2 %, and the range is very large, varying from 1.4 to 92.9 %. Our results are not really in contradiction with those estimated by previous frontier studies on the tea sector in Vietnam or elsewhere. For example, regarding the Vietnam tea production, while the overall average level of technical efficiency computed from the study of Tran (2008) is very high, around 99 % for organic tea, the value obtained by Saigenji and Zeller (2009) is much lower, ranging from 47 to 69 % in average for tea producers with and without a farming contract, respectively. For small tea producers in Sri-Lanka, Basnayake and Gunaratne (2002) obtained an average level of technical efficiency around 65 %. Furthermore, our efficiency calculation is not too far from the finding of

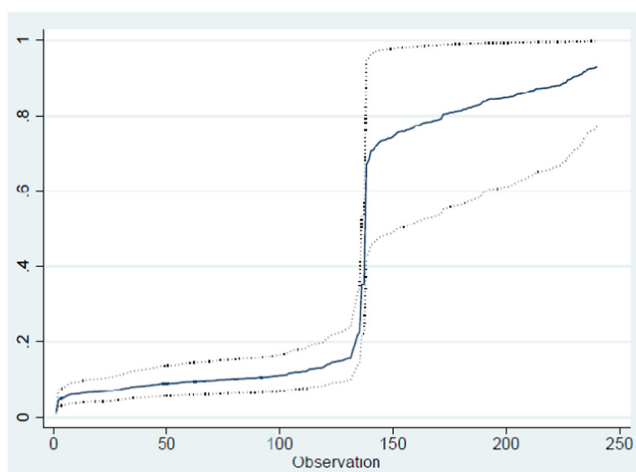

Fig. 2 Sample's technical efficiency and confidence interval. Notes: Observations are ranked in increasing order of technical efficiency. The solid line represents technical efficiency. The dashed lines correspond to the 95 % confidence interval.Source: the authors

Hossain et al. (2012) for Bangladeshi rice crops, around 50 % as indicated in Sect. 2. The distribution of technical efficiency is further illustrated in Fig. 2. Many tea producers have a low technical efficiency: approximately half of them have a technical efficiency lower than 50 %.

Conclusion

This paper studies the determinants of technical efficiency in tea production in northern Vietnam using the stochastic production frontier based on a survey of 244 farm households in 2012. Our results underline that tea production in this region suffers from a strong inefficiency (technical efficiency is on average about 41 %, much lower than previous findings). This result shows that there exists a huge potential for improving technical efficiency in the region. Hence, the main concern remains to identify the factors which could help reduce production technical inefficiency.

While extension policy is expected to play an important role in the evolution of agricultural production, in particular tea production in Vietnam, our finding casts doubt on the effectiveness of most of existing extension measures with respect to tea production technical efficiency. The insignificant effects of some extension measures and new varieties in our study show that existing extension practices should be modified in order to get positive effects on tea production technical efficiency. Of course, it should be noted that the purpose of extension activities is not limited to technical efficiency improvement. They can be implemented to improve other factors of farm performance (such as profit or economic efficiency). Additional research is thus needed to study the impact of extension activities on these performance indicators in order to draw clear policy recommendations.

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