World Development Perspectives 36 (2024) 100637

Contents lists available at ScienceDirect

World Development Perspectives

journal homepage: www.sciencedirect.com/journal/world-development-perspectives

Research paper

Voluntary sustainability standards and technical efficiency of Honduran smallholder coffee producers

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ARTICLE INFO

Keywords:
Technical efficiency
Stochastic Frontier analysis
Tobit model
Smallholder coffee producers
Voluntary sustainability standards

ABSTRACT

Sustainable coffee production promises to improve production techniques and enhance the socioeconomic conditions of smallholder farmers. Using primary survey data from 659 coffee producers in Honduras, this study assesses the impact of voluntary sustainability standards (VSS) on the technical efficiency of smallholder coffee production. The article uses the Stochastic Production Frontier Analysis model to analyze and compare the technical efficiency (TE) of certified and non-certified coffee producers. To provide reliable comparability between groups, the dataset was balanced using Covariate Balancing Propensity Score (CBPS). The results show that the mean technical efficiency was 52.86% for pooled certified farmers and 55.56% for non-certified smallholder coffee producers. Specifically, the technical efficiency of 4C farmers was 51.58%, 53.82% for the Fairtrade group, 60.56% for RA farmers, and 60.15% for the UTZ group, indicating substantial inefficiencies in the coffee production of the different certified groups. Results from Tobit's model for the determinants of TE indicated that variables such as the age of the household head, access to credit, and training attendance are among the main factors that significantly drive the technical efficiency of certified and non-certified farmers. Based on the findings, enhancing education opportunities, improving infrastructure for better market access and farm management, and expanding credit access are recommended to improve efficiency in the study area. Honduran smallholder coffee producers have considerable potential to increase output with existing technology by improving their technical efficiency. Therefore, stakeholders' efforts should focus on enhancing efficiency levels and capitalizing on potential gains for both certified and non-certified farmers, to ultimately improve the farmers' livelihoods.

1. Introduction

Coffee production has grown steadily over the past decades. While consumption is largely concentrated in the Global North, particularly in the European Union (EU), the USA, and Japan (Panhuysen & Pierrot, 2020), production is primarily centered in the Global South, within the tropical regions of developing countries, and predominantly carried out by small-scale farms (ICO, 2020). The global coffee market is associated with various socioeconomic and environmental challenges, such as price fluctuations, asymmetry of income distribution between downstream and upstream value chain actors, and agricultural intensification (Lenzen et al., 2012; Panhuysen & Pierrot, 2018).

Over the past three decades, Voluntary Sustainability Standards (VSS) have emerged as a prominent tool in the private sector to address these sustainability issues (Giovannucci & Ponte, 2005; Pierrot et al., 2010). These schemes are designed to improve the socioeconomic well-being of coffee-growing communities, reduce the environmental footprint of coffee production, and protect the health of affected ecosystems (Potts et al., 2014). However, it remains contested whether VSS truly leads to the sustainability outcomes they claim to achieve. Results from various *meta*-studies summarizing research on the effects of VSS on environmental, social, and economic sustainability are mixed (Dietz et al., 2022). This paper focuses on an impact dimension that is of vital importance, especially for improving the livelihoods of smallholder

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https://doi.org/10.1016/j.wdp.2024.100637
Received 30 May 2023; Received in revised form 17 September 2024; Accepted 22 September 2024
Available online 2 October 2024

farmers, but has been largely neglected in the existing VSS literature, i.e. the technical efficiency of smallholder coffee production.

According to Thiam et al. (2001), technical efficiency can be defined as the ability of a decision-making unit, such as a farm, to produce maximum output given a set of inputs, such as labor, land, seeds, fertilizers, and technology. It measures how well a farmer uses available resources to produce certain outputs. A farm is technically efficient if it produces the highest output given the available inputs and technology available. Conversely, a farm is technically inefficient if it produces a lower yield using the same inputs.

Technical inefficiency has been identified as a key factor contributing to low productivity, limited yields, and ultimately, poverty. To address these issues, all major VSS in the coffee sector offer specific training in farm management, good agricultural practices (GAP), and the efficient use of inputs such as water, fertilizers, and pesticides to improve the technical efficiency of smallholder coffee producers. However, despite these efforts by VSS, with the notable exceptions of studies by Hung et al. (2019) and Paz et al. (2024), there is little research explicitly examining the effects of VSS on the technical efficiency of smallholder coffee producers. Unlike studies focusing on yields, income, or productivity, research on technical efficiency offers deeper insights into the underlying factors that influence these outcome dimensions of VSS participation. While Ho et al. (2021) examine coffee farmers in Vietnam, and Paz et al. (2024) focus on Rwanda, both studies found that certified farmers demonstrated higher technical efficiency than their non-certified counterparts, attributing this difference to improved farm management.

One key takeaway from the general literature assessing the impacts of VSS on sustainability outcomes is that these effects are highly context-specific and can vary across countries (Dietz et al. 2021; Sellare et al., 2020). In this article, we expand the knowledge base by presenting the first empirical study to assess the impact of VSS on the technical efficiency of smallholder coffee production in Honduras, as well as the key determinants of this efficiency. We employ both a pooled analysis comparing certified and non-certified producers, and disaggregated comparisons of each certification group with non-certified farmers. The primary objectives of this research are to evaluate the technical efficiency of smallholder coffee farmers in Honduras, analyze the efficiency disparities between VSS-certified and non-certified producers, and identify the key factors influencing technical efficiency. By doing so, the study addresses a significant gap in the literature concerning the impact of various VSS certifications on technical efficiency in coffee production.

The two commonly used approaches for measuring technical efficiency are Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA), representing parametric and nonparametric methods. (Montaner et al., 1999; Mosheim, 2002; Nchare, 2007; Tran, 2007; Gregory & Featherstone, 2008; Garcia & Shively, 2011; Ho et al., 2014; Ho et al., 2018; Hung et al., 2019; Ho et al., 2021). This study uses SFA to estimate the technical efficiency of different certified and non-certified groups of smallholder coffee farmers in Honduras.

1.1. Socioeconomic of coffee production in Honduras

In 2022, Honduras's population was 9.7 million, with 55 % living in urban areas and 45 % in rural areas (INE, 2022). During the same year, the GDP per capita was USD 2,771 (World Bank, 2022), one of the lowest in the world.

Honduras faces a high level of poverty and inequality, holding the second-highest poverty rate in Latin America. Of the total population, 14.8 % lived on less than USD 1.90 per day, and 49.2 % lived on less than USD 5.5 per day (World Bank, 2021). In rural areas, 70 % of the population lives in poverty (INE, 2022). Moreover, inequality, measured by the Gini coefficient, was 48.2, one of the highest in Latin America in 2019 (World Bank, 2021). Regarding the Human Development Index (HDI), the score was 0.634 for 2019, classified as a medium HDI level (UNDP, 2020).

Coffee plays a significant role in the Honduran economy. The country is the sixth-largest coffee producer worldwide and the largest in Central America, producing 5.4 million 60 kg-bags during the coffee year 2021/2022 (USDA, 2022). Coffee contributes 3 % to the Honduran GDP and 30 % to its Agricultural GDP (IHCAFE, 2017). Coffee is extensively grown in rural areas, covering 15 of the 18 Honduran departments and 210 of the 298 municipalities. Smallholder farmers produce the majority of the coffee; of the 120,000 farmers registered with the Honduran Coffee Institute (IHCAFE), 95 % or 114,000 are smallholders, 4.55 % or 5,460 are medium-sized farmers, and only 0.45 % or 540 are large size farmers. Coffee farmers are highly vulnerable to natural disasters and climate change; for instance, hurricanes Eta and Iota impacted the coffee sector in Honduras, causing a spike in leaf rust incidence in November and December 2020 (USDA, 2021), moreover, in 2021, wet weather conditions and the outbreak of leaf rust further affected the productivity (USDA, 2022).

1.2. Voluntary sustainability standards

One of the proclaimed approaches and ways to achieving sustainability in coffee production is through different VSS and respective certification schemes (Potts et al., 2014; Rice, 2015). These non-mandatory third-party schemes aim to internalize externalities that arise in coffee production and can be viewed as market-based tools that motivate smallholder farmers to adopt sustainable production practices (Bray & Neilson, 2017).

Certification systems have been gaining recognition in broader society due to increased awareness of the economic, social, and environmental challenges associated with the intensification of conventional agricultural practices. This awareness has led to a growing demand for sustainable options to improve the environmental state and the socio-economic conditions of local communities and regions involved in coffee production (Pierrot et al., 2010; Samper & Quiñones-Ruiz, 2017). The coffee produced under these schemes has risen over the years, reaching 55 % of overall global production in 2019–2020 (Panhuysen & Pierrot, 2020).

The diverse certification systems promote the three components of economic, environmental, and social sustainability to different extents; however, they also share a set of common goals, mechanisms, and operational modes, including improving smallholder farmers' well-being through better production techniques and improved market access (Millard, 2011). According to the certification's theory of change, it is essential to provide farmers with the necessary knowledge, market tools, and premium payments, along with labor standards that can lead to increased quantity and quality of the product, as well as improved productivity and profitability, to improve their socioeconomic conditions (Bitzer & Steijn, 2019; Oya et al., 2018).

According to the certifications, if the promoted changes and conditions are implemented, along with the price premium, this could lead to the socioeconomic improvement of smallholder coffee farmers' livelihoods and other offered benefits. However, numerous *meta*-studies that have summarized the impact of VSS on socioeconomic indicators show mixed results and present diverse perspectives according to existing literature (DeFries et al., 2017; Millard, 2017; Oya et al., 2018; Samper & Quiñones-Ruiz, 2017).

Some studies point out that certifications do not lead to an increased income level for farmers (Jena et al., 2012; Jena et al., 2017) due to factors such as certification fees (Beuchelt & Zeller, 2011; Weber, 2011), lower yields, higher production costs, and lack of access to credit, despite the price premiums obtained (Estrella et al., 2022). Moreover, not all the certified coffee is sold as certified; for instance, in 2021, the share of certified volume sold relative to certified supply was 52 % for Rainforest Alliance and 53 % for UTZ (Rainforest Alliance, 2022). Therefore, producers still have a significant percentage of their coffee production not sold at the promised price premium. On the other hand, several studies highlight VSS's relatively positive effects on smallholder farmers' well-being (Arnould et al., 2009; Bolwig et al., 2009).

The certification type, region or country, legislative framework, study design, and methodology, among other factors, could contribute to the mixed and even contradictory results described before (Elliott, 2018).

Differences between various VSS –namely 4C, Fairtrade, Rainforest Alliance, and UTZ– in achieving overarching sustainability on the farm are also highlighted in a study by Dietz and Grabs (2021), showing the limited effectiveness of these schemes in achieving holistic sustainability and underlined the dependence of VSS on various other factors, such as maintained or increased yields, to be seen as successful (Dietz & Grabs, 2021). Additionally, smallholder farmers often lack the necessary resources to comply with standards and achieve anticipated sustainability levels, thus widening the gap between expected and actual outcomes of VSS application on the ground (Dietz et al., 2021).

In Honduras, most coffee is produced at higher altitudes, and a significant percentage falls under different VSS. The main VSS adopted are 4C, Fairtrade, Fairtrade/Organic, Rainforest Alliance, and UTZ. Fairtrade (32 %) and UTZ (35 %) have the highest adoption rates (Bunn et al., 2018; Rainforest Alliance, 2022), followed by 4C with 12 % (4C. 2021. Impact and continuous improvement, 2021) and Rainforest Alliance with 10 % of the Honduran coffee production (Rainforest Alliance, 2022).

2. Theoretical framework

In this study, parametric Stochastic Frontier Analysis (SFA) is used to estimate the efficiency of smallholder coffee farmers. The coffee production function is specified as a single output and multiple input specification that fits the SFA framework. Moreover, the SFA model enables the estimation of determinants of technical inefficiency (Coelli et al., 2005). Aigner et al. (1977) and Meeusen and Van den Broeck (1977) independently proposed that the SFA model helps measure technical efficiency from the combined error term.

Following the stochastic frontier analysis specification of Aigner et al. (1977) and Coelli (1995), the Cobb-Douglas production function is used to estimate the technical efficiency of smallholder coffee farmers'. Cobb-Douglas specification is the most commonly used analysis method in developing and developed countries, despite its well-known limitations (Bravo-Ureta & Pinheiro, 1997). Based on the natural logarithm, the model is specified as follows.

$$\ln Yi = \beta_0 + \sum_{J=0}^{n} \beta j ln X_{ji} + (v_i - u_i) i = 1, 2, 3 \cdots n \tag{1}$$

Where Yi is the total coffee production at the *ith* farm in kilograms; X_{ji} represents the vectors of inputs used by the *ith* farm; βj is the vector of parameters to be estimated, and $(v_i + u_i)$ is the combined error term. v_i is a symmetric error that accounts for random output error due to factors beyond the farmer's control, such as weather and disease outbreaks, and is known as statistical noise with the assumed distribution of independently and identically distributed. The other component is the non-negative randomness u_i, which represents inefficiency relative to the frontier in the production of the *ith* farm. The one-sided randomness is also assumed independently and identically distributed as u_i $|N\ (0, \delta_u^2\ |$.

The choice of the distribution for the one-sided randomness-technical inefficiency and the composite error term follows different distributions. While there is no prior justification for the choice of any specific distributional form of technical inefficiency, as different specifications lead to different estimates of cost inefficiency and make the model estimable (Førsund et al., 1980), the distribution is assumed and used to follow a half-normal (Aigner et al., 1977), that is, $u_i \sim N^+ (0, \sigma_u^2)$, while Meeusen and Van den Broeck (1977) opted for an exponential one. Others assumed truncated-normal (Stevenson, 1980) and gamma (Greene, 1980; Greene, 1993; Greene, 2008).

From the above SFA model, the deterministic production function and the stochastic production frontier can, therefore, be determined like $\beta_0 + \sum_{J=0}^{n} \beta j log X_{ji}$ and $\beta_0 + \sum_{J=0}^{n} \beta j log X_{ji} + (-u_i)$ respectively. The two noises are also assumed to be independent of each other and identically distributed across observations.

Technical efficiency for the *ith* farm, therefore, can be computed:

$$TE_i = \frac{logYi = \beta 0 + \sum_{i=1}^{n} \beta j \log X_{ji} + (v_i - u_i)}{\log Yi = \beta 0 + \sum_{i=1}^{n} \beta j log X_{ji} + v_i} \tag{2}$$

These technical efficiency values fall between zero and one and are used to estimate the impacts of demographic, socioeconomic, and other variables on it using the two-limit Tobit model later.

The variation of the noise variables relation:

$$\delta^2 = \delta^2{}_v + \delta^2{}_u; \gamma = \frac{\sigma_u^2}{\sigma^2} \tag{3}$$

The technical efficiency of production for the *ith* farm, according to Coelli and Battese (1996), is defined as:

$$TEi = exp(-Ui) \tag{4}$$

Estimation provides the coefficients of the explanatory variables, sigma, lambda, or gamma estimates, and the residuals, which can be computed from this information. The separate values of the combined error terms are essential for our objective of computing the (in)efficiency of each observation. Jondrow et al. (1982) subjected the predictor of $\widehat{U}$ as follows:

$$\widehat{U}i = E(\frac{U_i}{y_i} = U_i^* + \sigma^* \left[\frac{\varnothing\left(\frac{U_i^*}{\sigma^*}\right)}{\varnothing\left(\frac{U_i^*}{\sigma^*}\right)} \right] \tag{5}$$

where $\varnothing(.)$ and $\varnothing(.)$ are the probability distribution functions and cumulative distribution function of the standard normal variable, which are again specified as:

$$\widehat{U}i = -\left(y_i - \beta X_{ij}\right)\gamma \tag{6}$$

$$\delta^* = \delta^2{}_v {}^* \delta^2{}_u / \delta^2 \tag{7}$$

2.1. Empirical studies on efficiency

Existing empirical studies on efficiency can be categorized into two broad strands: parametric estimations and nonparametric estimations. This review compares both categories, focusing on the nonparametric category. It also considers the regions and samples used, focusing specifically on coffee production.

Perdomo and Mendieta (2007) estimated technical and allocative efficiency for Colombian small, medium, and large-scale coffee producers using data from three districts and the DEA method. They found mean technical efficiency of 3.76 %, 51.71 %, and 60.15 % for small, medium, and large-scale producers, respectively, with an overall mean of 42.38 %. Allocative efficiency was 36.13 %, 42.98 %, 18.86 %, and 36.50 % for small-scale, medium-scale, large-scale, and overall. Blackman and Naranjo (2012) studied the impact of organic certification on the environmental performance of coffee farmers in Costa Rica. Their results reveal that organic certification improves environmental performance by reducing chemical fertilizer use and increasing the adoption of environmentally friendly management practices. In Colombia, Ibanez and Blackman (2016) studied the environmental and economic impacts of organic coffee certification using propensity score matching and difference in difference method. They found a significant environmental improvement among the certified farmers regarding sewage disposal and increased use of organic fertilizers, although they failed in the economic gains difference.

Stochastic production frontier using the Cobb-Douglas production function and Translog production frontier are the two commonly used parametric approaches. Wollni (2007) used a sample of 216 households in Costa Rica to measure technical efficiency and the sources of efficiency for specialty coffee producers and conventional producers. The results of the stochastic frontier model indicate that specialty producers are 81 % technically efficient on average, while conventional farmers are 61 % technically efficient. Farm experience and age of the household head are found to be significant sources of technical efficiency, with experience having a positive effect and age having a negative effect. Technical efficiency increases with experience but decreases with age. In another study, Nchare (2007), using a translog stochastic production frontier function, found a mean technical efficiency of 89.6 % for Cameron coffee farmers.

The farmer's education level and credit access were identified as the two main socioeconomic factors affecting technical efficiency. Using a stochastic frontier model, Ngango and Kim (2019) found a mean technical efficiency of 82 % for small-scale coffee producers in Rwanda. Similar to other studies, they found a positive and significant effect of education, access to credit, extension services, improved coffee tree varieties, cropping system, and land consolidation on technical efficiency.

Ho et al. (2014) found a mean technical efficiency of 68.36 % for coffee producers in Vietnam, with key determinants including the education level of the household head, amount of credit, ethnicity, farm experience of the head, and extension service. In another study, Hung et al. (2019), using stochastic frontier and cost-benefit analysis, studied the technical efficiency of Vietnamese coffee producers by classifying them into sustainable certified and non-certified farmers. Despite the difference in technical efficiency between certified and non-certified farmers was found to be insignificant, they reported mean technical efficiencies of 88.24 % for sustainable certified farmers and 87.69 % for conventional farmers. The sources of technical efficiency varied: age and ethnicity had a negative effect on conventional farmers, while education and family size had a positive and significant effect on certified farmers.

These studies highlight significant differences in technical efficiency in coffee production among countries, with the sources of inefficiency also varying across countries. However, there are almost no studies that provide a comprehensive understanding of how VSS impacts the technical efficiency of coffee farmers. To address the gap in the literature, this study measures and compares the technical efficiency of certified and non-certified Honduran smallholder coffee farmers for the first time. Additionally, the factors influencing technical efficiency for these farmers are estimated and analyzed, offering valuable insights for improving both farming practices and policy interventions.

3. Methodology

This study compares the average efficiency levels of smallholder producers with different certifications to those of non-certified smallholder producers with similar and comparable characteristics. It aims to demonstrate how efficient or inefficient certified producers are in different regions of Honduras and identify the variables that affect this efficiency level.

3.1. Data collection and sample

The primary data used in this paper were collected during the second semester of 2016. Using a membership list of a large coffee trader in Honduras, certified and non-certified farmers from five different departments in the North, South, and Western regions were selected (Fig. 1). The sample comprised 659 households, with 400 certified and 259 non-certified farmers. Of the VSS-certified farmers, 135 were 4C, 95 Fairtrade, 76 Rainforest Alliance, and 94 UTZ (Table 1). To ensure that the control group was as similar as possible to the certified farmers, during this process a pre-sampling propensity score matching was applied to the list of farmers. However, after running the Covariate Balance Propensity Score on the sample during the analysis phase, the sample diminished to 330 certified and 211 non-certified households.

3.2. Covariate balancing propensity score

To provide reliable comparability between groups, the dataset was balanced using Imai and Ratkovic's (2014) Covariate Balancing Propensity Score (CBPS) using version 2021 0.22 package for R (Fong et al., 2021; R Core Team, 2021). CBPS presents significant advantages to matching methods while providing similar support for causal inference. Specifically, CBPS "dramatically improves the performance of propensity score weighting and matching estimators when estimating the average treatment effects in observational studies" (Imai & Ratkovic, 2014, p. 260). In essence, "CBPS estimates propensity scores such that both covariate balance and prediction of treatment assignment are maximized. The method, therefore, avoids an iterative process between model fitting and balance checking and implements both simultaneously" (Fong et al., 2021, p. 10).

CBPS fits covariate balancing propensity scores directly into the model. Firstly, the treatment for the CBPS model is defined as a dummy variable indicating whether producers are certified or not. Then, we considered the covariates for balancing, accounting for endogenous characteristics that might generate undesired discrepancies in the later stages of the experiment. Thus, the following covariates were used for balancing the treatment and control groups: literacy (dummy), coffee

Fig. 1. Study area and sample distribution in Honduras.

Table 1
Sample design and distribution per region and department for certified and non-certified producers.

Region	Department	4C	Fairtrade	Rainforest	UTZ	Certified	Non-certified	Total
Western	Copan	32		9	12	192	119	172
	Lempira	2	49	2	2		1	56
	Ocotepeque	13		31	40		1	85
Other	El Paraíso	63	46	4	34	208	103	250
	Yoro	25		30	6		35	96
Total households		135	95	76	94	400	259	659

plot size, full tenure (dummy), household size, altitude, sex, age, whether they are members of IHCAFE or not, distance to the nearest health center (in minutes), the proportion of shade 25 % to 50 %, distance to nearest market (in minutes), and quality rejections (dummy). As a result, the original sample of 659 farmers was reduced to a total of 541 (330 certified, 211 non-certified), as previously mentioned. Importantly, substantial improvements were observed in the standardized mean differences of all employed covariates. For more detailed results and comparisons between groups, see Fig. 2.

3.3. Stochastic production frontier analysis

The stochastic production frontier (SFA) used to specify the technology of the coffee farmers in Honduras is specified below (equation (8)), using STATA 16 for the estimation. All the variables used were in the natural logarithm forms except for the dummy variables.

$$\ln Yi = \beta_0 + \sum \beta 5 \ln(X_{ji}) + (v_i - u_i) \qquad i = 1, 2, 3 \cdots n \tag{8}$$

where Yi is the coffee yield in kilogram and i represents the *ith* coffee farm of the sample; X_{ji} are the *jth* inputs used by the *ith* farm measured as hired labor and family labor (measured in man-days), capital or tools purchased in that year (total cost in the local currency lempira), coffee trees (number of trees per ha), age of the coffee trees (years), fertilizer (kg) and land (measured in hectares of coffee land); β_0 and $\beta 1, \beta 2 \cdots \beta 5$ are the parameters estimated, and v_i *and* u_i are the composed statistical noise and technical inefficiency measures.

The Coelli and Battese (1996) technical (in)efficiency model is specified as:

$$|Ui| = \gamma_0 + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \cdots + \gamma_{16} X_{16} + Z_i \tag{9}$$

where Ui is the technical (in)efficiency of the *ith* farm, Xi is the farm-specific different variables used to estimate the (in) efficiency. Among others, the right-side variables are: X1 is the age of the farmers (years), X2 is the sex of the household head (dummy), X3 is the household size (number of household members), X4 is education level (years in school), X5 is Access to credit (dummy), X6 is farm size, X7 is the age of the coffee plantation, X8 is resistant variety (dummy), X9 is the proportion of shade 25 % to 50 %, X10 is fertilization based on technical assistance (dummy), X11 is training attendance (dummy), X12 is the distance to the plot, X13 is IHCAFE membership (dummy). γ_0 is the model intercept, and γi denotes the estimated unknown parameters; *Zi*, on the other hand, is a random error, defined by the truncation normal distribution.

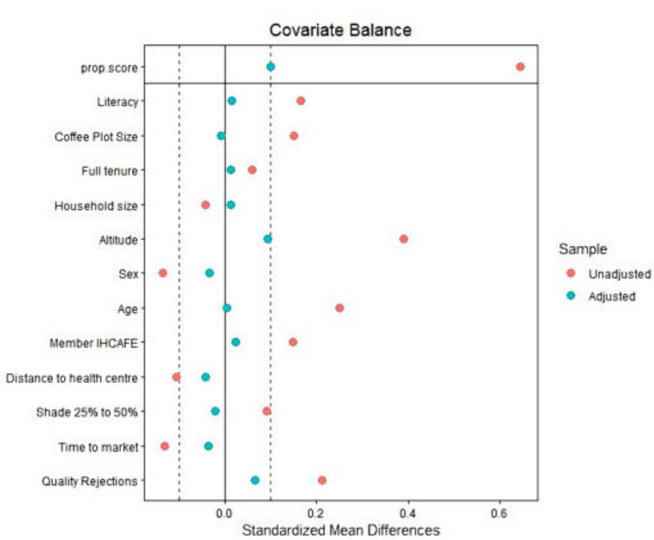

Fig. 2. Covariate balance results show improvement for all covariates.

Finally, the two-limit Tobit model was used to examine the impacts of the demographic, institutional, socioeconomic, environmental, and marketing factors of farm efficiencies. The two-limit Tobit model perfectly fits a kind of data censored from both sides for the dependent variable. In this case, the dependent variable is the technical efficiency, whose value falls between 0, the most inefficient, and 1, the fully efficient. The consistent estimation method of the unknown parameters for a type of dependent variable that has a value between 0 and 1, including the corner values, is the two-limit Tobit model (Maddala, 1983).

The model, therefore, is specified as:

$$Y^* = X_{ji}\beta_j + u_i \tag{10}$$

where Y^* is the latent continuous dependent variable, X_{ij} represents a matrix of different explanatory variables (including socioeconomic, demographic, institutional, and environmental variables), β_j are the unknown parameters to be estimated, and u_i is a vector of normally distributed error terms with variance σ^2. Then, to denote the observed variable by Y,

Y = 0 if Y * = < 0

$$Y = Y^* \, if \, 0 =< Y^* =< 1 \tag{11}$$

Y = 1 if Y * > = 1d

This is one of the censored regression models due to its dependent values, including the limits of the values, unlike the case of the truncated models. The interpretation of the coefficients, as McDonald and Moffitt (1980) emphasized, is that the coefficients are the marginal effects of the independent variables on the latent variable Y *.

4. Results

This section highlights the key results of the previously specified models of the Cobb-Douglas stochastic production frontier and farmers' measured technical efficiency levels. Furthermore, the estimated technical efficiency was used to analyze the technical (in)efficiency determinants among certified and non-certified farmers.

Table 2 contains the descriptive statistics of household, farm, and crop characteristics across the different certification groups, pooled and non-certified groups. UTZ farmers are, on average, older (50 years old) than the non-certified farmers and those in the other certified groups. The proportion of males as the household head is over 80 % for both the certified and non-certified groups. Households are composed of an average of four people for the different certified and non-certified groups. Certified farmers, particularly those in the Rainforest Alliance group and Fairtrade producers, had a higher proportion of literacy and

Table 2
Descriptive statistics and variables used for the analysis of certified and non-certified farmers.

Indicators	4C	Fairtrade	RA	UTZ	Certified	Non-certified
Household Characteristics						
Age	48	47	45	50	48	44
Male (%)	0.81	0.89	0.84	0.83	0.85	0.80
Female (%)	0.19	0.11	0.16	0.17	0.15	0.20
Household size	4.39	4.48	4.16	4.04	4.27	4.44
Own house (%)	0.96	0.95	0.99	0.95	0.96	0.92
Literacy (%)	0.90	0.94	0.99	0.93	0.94	0.90
Years of schooling	5.50	7.72	8.49	4.88	6.65	5.15
Higher education (University)	0.01	0.14	0.16	0.01	0.08	0.00
Distance to market (min)	45	43	45	46	45	50
Distance to coffee plot (min)	19	14	27	20	20	23
Own land (%)	0.77	0.87	0.78	0.77	0.80	0.77
Access to credit (%)	0.56	0.65	0.74	0.64	0.65	0.48
Farm Characteristics						
Farm area (ha)	5.29	6.76	13.79	6.58	8.10	4.84
Coffee area (ha)	4.30	3.29	9.26	4.18	5.26	3.78
Altitude (masl)	1059	1165	1182	1175	1145	1042
Forest Area (ha)	0.33	1.90	2.88	1.86	1.74	0.55
Share of income from coffee	0.96	0.85	0.88	0.94	0.91	0.91
Productivity qq/ha	23.95	16.90	41.04	29.71	27.90	26.47
Income coffee per ha	$ 1,916.16	$ 1,473.79	$ 3,408.40	$ 2,463.13	$ 2,315.37	$ 2,021.71
Production costs per ha	$ 942.18	$ 705.35	$ 1,268.10	$ 879.09	$ 948.68	$ 988.83
Gross profit per ha	$ 973.98	$ 768.44	$ 2,140.29	$ 1,584.04	$ 1,366.69	$ 1,032.88
Crop Characteristics						
Shade < than 25 %	0.13	0.03	0.30	0.19	0.16	0.20
Shade 25 % – 50 %	0.75	0.75	0.53	0.68	0.68	0.65
Shade 50 % – 75 %	0.12	0.22	0.16	0.13	0.16	0.14
Native Species (shade) (%)	0.40	0.62	0.62	0.57	0.55	0.35
Coffee plant rust resistant (%)	0.98	0.90	0.94	0.95	0.94	0.96
Coffee plant age <5, 5–8 years, > 8	0.63, 0.19, 0.13	0.46, 0.20, 0,24	0.41, 0.24, 0.30	0.51, 0.29, 0.12	0.50, 0.23, 0.20	0.55, 0.24, 0.12

Notes: 1 quintal (qq) = 46 kg.; ha = hectare.

higher education levels compared to non-certified farmers. The majority of farmers own the land where they produce coffee. Moreover, certified groups have higher access to credit compared to the non-certified group.

Regarding farm characteristics, RA and Fairtrade farmers had slightly larger farm areas than the control group. RA farmers also had a higher coffee cultivation area than the other groups; however, Fairtrade farmers had a smaller coffee area, but a higher proportion grew other crops. The average farm altitude was similar for RA, Fairtrade, and UTZ farmers and slightly lower for 4C and non-certified groups. The productivity levels of RA and UTZ farmers were higher than those of the control and other certified groups. Additionally, both income from coffee and production costs per hectare were higher for RA and UTZ farmers. The share of income from coffee was higher for the 4C and UTZ groups than RA, UTZ, and non-certified farmers, indicating that the latter groups have income from sources other than coffee.

Regarding crop characteristics, the most frequent shade coverage for both certified and non-certified groups was 25 %-50 %. The use of native tree species for shading was higher in the coffee plantations of certified groups than in non-certified groups. The use of rust-resistant coffee varieties was common for both certified and non-certified farmers. Moreover, for both groups, most of the coffee plantations were less than five years old.

4.1. Maximum likelihood estimate for the stochastic frontier analysis model

Table 3 below presents the maximum likelihood estimate parameters of the stochastic frontier Cobb-Douglas production function result obtained. This study classified the sample by certification type: 4C, Fairtrade, Rainforest Alliance, and UTZ. All certified producers were pooled and compared to a group of non-certified farmers to examine their efficiency differences.

All the coefficients for the certified and non-certified groups are significant at one percent and five percent levels of significance, and the coefficients' signs are as expected, except for the Fairtrade group. The coefficients' signs and significance indicate that coffee production is determined by the five main variables included in the model for Honduras coffee producers.

For the pooled certified farmers, the number of coffee trees per hectare contributed the largest share (1.106) to the coffee output variation, followed by fertilization (0.370), the age of the coffee trees (0.324), and labor (0.0835). However, land was found to have a negative sign (−0.534).

4C-certified farmers followed a similar pattern, with the number of coffee trees per hectare representing the largest share (1.432), followed by fertilization (0.375), the age of the coffee trees (0.319), and labor (0.0945). The value obtained for land was also negative (−0.622). In the case of Fairtrade-certified farmers, only the age of the coffee trees variable was found to be statistically significant (0.482).

For RA farmers, the number of coffee trees per hectare (1.693) and the fertilization variable (0.6043) contributed the most to coffee output variation, while land had a negative value (−0.406). Similarly, for the UTZ group, the number of coffee trees per hectare (1.228) represented the largest share of coffee output variation, followed by the age of the coffee trees (0.386), fertilization (0.213), and labor (0.109). As with the other certified groups, land for the UTZ group was found with a negative sign (−0.496).

In the case of non-certified farmers, the number of coffee trees per hectare also contributed the largest share (0.516) to coffee output variation. The age of coffee trees contributed 0.356, fertilization represented 0.347, and labor added 0.076. The land variable was also found with a negative sign for this group (−0.463).

Overall, the production function has a good fit, with certified producers' production function showing decreasing returns to scale –except the Fairtrade group– while non-certified producers exhibit increasing returns to scale. By adding the significant coefficients, the returns to scale indicate the proportion of output change when all inputs included in the model are changed in the same proportion, which is 1.350 for the

Table 3
MLE result for the stochastic production frontier model.

Variables	Parameter	4C Coefficient	(SE)	Fairtrade Coefficient	(SE)	Rainforest Alliance Coefficient	(SE)	UTZ Coefficient	(SE)	Certified Coefficient	(SE)	Non-certified Coefficient	(SE)
Production Frontier													
Constant (intercept)	β0	−7.666	(5.3638)	13.5079	(12.2672)	−12.0408*	(5.9039)	−5.0017**	(2.6327)	−4.8346**	(2.4103)	0.2071	(1.9919)
Ln Fertilization (kg)	β1	0.3747***	(0.0810)	0.0667	(0.1912)	0.6043***	(0.1169)	0.2133***	(0.0756)	0.3700***	(0.0465)	0.3467***	(0.0535)
Ln Age of coffee tree	β2	0.3191**	(0.1421)	0.4824***	(0.1768)	−0.0742	(0.2139)	0.3862***	(0.1138)	0.3241***	(0.0672)	0.3564***	(0.0864)
Ln Number of coffee tree	β3	1.4321**	(0.6245)	−0.9044	(1.4586)	1.6925**	(0.7047)	1.2283***	(0.3084)	1.1060***	(0.2852)	0.5162**	(0.2386)
Ln Total labor (man-day)	β4	0.0945**	(0.0504)	0.0486	(0.0641)	−0.0180	(0.0549)	0.1094***	(0.0423)	0.0835***	(0.0256)	0.0756*	(0.0403)
Ln Land coffee area (ha)	β5	−0.6222***	(0.0914)	0.0088	(0.2091)	−0.4058***	(0.1239)	−0.4958***	(0.1130)	−0.5335***	(0.0646)	−0.4628***	(0.0612)
Variance Parameters													
Usigma		1.0145***	(0.1109)	0.9283***	(0.2067)	0.7712***	(0.1162)	0.7681***	(0.0842)	0.9707***	(0.0622)	0.8527***	(0.0816)
Vsigma		0.2849*	(0.0701)	0.3161*	(0.3161)	0.1266***	(0.0733)	0.2261***	(0.0465)	0.2695***	(0.0381)	0.3274***	(0.0486)
Sigma squared		1.2994		1.2444		0.8978		0.9942		1.2402		1.1801	
Lambda		3.5615***	(0.1624)	2.9365***	(0.2272)	6.0902***	(0.1659)	3.3969***	(0.1115)	3.6024***	(0.0886)	2.6045***	(0.1184)
Gamma		0.9269		0.8961		0.9737		0.9202		0.9285		0.8715	
Log likelihood		−112.564		−51.302		−24.2611		−62.48		−278.49		−187.90	
Efficiency Level		51.38 %	(0.2159)	53.82 %	(0.1971)	60.56 %	(0.2194)	60.15 %	(0.1956)	52.9 %	(0.2163)	55.6 %	(0.1905)

Notes: Standard errors in parentheses and *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ significance.

pooled certified group and 0.832 for the non-certified group. The returns to scale for each certified group are as follows: 1.598 for 4C, 0.482 for Fairtrade, 1.891 for Rainforest Alliance, and 1.441 for UTZ.

From the standard error ratio of u (σ_u) and standard error of v (σ_v), the lambda (λ) values for the certified and non-certified farmers are 3.602 and 2.605, respectively. The lambda values were 3.562 for the 4C group, 2.937 for Fairtrade, 6.090 for Rainforest Alliance, and 3.397 for the UTZ group.

Based on these lambda values, another value of variation measure gamma (γ) can be computed using the formula $\left(\gamma = \lambda 2/[1+\lambda 2] = \frac{\sigma_u^2}{\sigma^2}\right)$. The computed gamma values for certified and non-certified farmers are 0.9285 and 0.8715, respectively, which means that 92.85 % and 87.15 % of the coffee output variation is due to the existence of technical inefficiency. The gamma values for the 4C, Fairtrade, Rainforest Alliance, and UTZ groups are 0.9262, 0.8961, 0.9737, and 0.9202, respectively. These results are also comparable with previous studies by Hung et al. (2019) for Vietnamese coffee farmers, which reported about 91.79 % and 71.68 % for certified and conventional farmers, respectively.

The mean technical efficiency scores (Table 4) were moderate for pooled certified and non-certified farmers, with non-certified farmers showing higher efficiency than the certified farmers. However, the results indicate that there is still a considerable level of inefficiency in using inputs for the corresponding output levels in both groups.

The average technical efficiency of the sample farms is 52.86 % for certified farmers, with a minimum of 2.6 % and a maximum of 90.68 %, and 55.56 % for non-certified farmers, with a minimum of 5.9 % and a maximum of 90.21 %. This means that, on average, certified and non-certified farmers would need to increase their output by 37.8 % and 34.6 %, respectively, to achieve the efficiency levels of their more efficient counterparts using the existing technology.

On average, the technical efficiency of both 4C (51.38 %) and Fairtrade (53.83 %) groups is lower than that of the non-certified group. Meanwhile, the average technical efficiency of Rainforest Alliance (60.56 %) and UTZ farmers (60.15 %) is higher than that of the non-certified group.

The relatively high technical efficiencies among non-certified farmers compared to the pooled group of certified farmers question the notion that sustainable-certified farmers would be more efficient than conventional farmers due to advantages such as more training and extension services on production, inputs, markets, and access to information. On the other hand, while potentially more profitable, sustainable-certified farmers were less technically efficient, suggesting that they have the potential for further output gains from technical efficiency with existing technology without compromising sustainability. Another possible reason for the lower efficiency levels among certified farmers may be that their agricultural practices hinder resource allocation, at least in the short term.

However, it is essential to note that when the certified groups are analyzed individually, the 4C and Fairtrade groups show lower technical efficiency than the non-certified groups. In contrast, the technical efficiency levels for the RA and UTZ groups are higher than those of the non-certified group. Therefore, in this case, the differences in technical efficiency must be examined on a certification-by-certification basis.

Moreover, the distribution summary statistics for the technical efficiency scores of the sampled study area, grouped as pooled certified and non-certified farmers, are presented in Table 4. From this table, most farmers are located in the technical efficiency score range of 40 %-60 and 60 %-80 %. The percentage of non-certified farmers was higher in both score ranges, with 36 % and 38 % of the sample, respectively, compared to 32 % of certified farmers in each score range. Regarding the certification groups, only the UTZ group (44 %) showed a higher percentage of farmers in the 60 %-80 % score range. On the contrary, the 4C group (30 %) had a higher percentage of farmers with technical efficiency below 40 %.

Table 4
Technical efficiency distributions per certifications.

Technical Efficiency	4C		Fairtrade		Rainforest Alliance		UTZ		Certified		Non-certified	
Mean	51.38 %**		53.82 %		60.56 %*		60.15 %**		52.86 %*		55.56 %	
Std. Error	0.0200		0.0265		0.0343		0.0207		0.0122			
p	0.0358		0.2746		0.0675		0.0298		0.0696			
Range ofTechnicalEfficiency (%)	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
< 20	13	11 %	5	9 %	2	5 %	5	6 %	28	9 %	10	5 %
20–40	22	19 %	8	15 %	6	15 %	8	9 %	53	18 %	32	15 %
40–60	33	28 %	21	38 %	11	27 %	26	29 %	96	32 %	75	36 %
60–80	39	34 %	17	31 %	14	34 %	39	44 %	96	32 %	80	38 %
>80	9	8 %	4	7 %	8	20 %	11	12 %	29	10 %	14	7 %
Total (n)	116		55		41		89		302		211	

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ significance.

These results contrast with the findings of Hung et al. (2019) on Vietnamese coffee farmers and Ngango and Kim (2019) on Rwandan coffee producers, who found that over 50 % of the sampled farmers had technical efficiency levels above 80 %. However, these results are not entirely inconsistent with other existing studies. For instance, Bravo-Ureta and Pinheiro (1997) found that 81.66 % of their sample of Dominican Republic coffee farmers had technical efficiency levels in the range of 50 %-80 %. One potential reason for this difference could be the sample type used in this study, which focuses solely on smallholder farmers, as well as the differences in technology and production advancements across countries. Therefore, cross-country comparisons require cautious interpretation and consideration of other factors.

4.2. *Tobit result for the determinates of technical efficiency*

From the above Cobb-Douglas stochastic production function, the maximum likelihood estimate of technical efficiency was directly estimated using the predict command and used to determine the factors influencing technical efficiency for certified and non-certified farmers' models. Following the Tobit two-limit model, the impact of demographic, socioeconomic, institutional, and environmental factors on the technical efficiency of certified and non-certified producers was estimated and presented in Table 5, along with their respective marginal effects.

The model's results revealed that the household head's age and access to credit significantly affect technical efficiency for the pooled certified group. Meanwhile, the age of the household head, the age of the coffee plantation, and training attendance significantly affect technical efficiency for the non-certified group.

For each certification studied, different variables significantly affect the technical efficiency. Specifically, in the 4C group, the significant variables are the age of the household head, years of schooling, and access to credit. In the Fairtrade group, farm size significantly affects technical efficiency. Regarding Rainforest Alliance farmers, training attendance and the distance to the plot are significant factors. Lastly, in the UTZ group, sex is the variable that significantly affects technical efficiency.

These results show that different variables have varying effects on the technical efficiency of both certified and non-certified farmers.

Age – The negative significant sign for the age of the household head for both the pooled certified and non-certified farmers suggests that technical efficiency decreases with the farmer's age. This finding indicates that older farmers may be less likely to adopt new coffee production techniques, which is consistent with previous studies (Mburu et al., 2014; Bäckman et al., 2011; Battese & Coelli, 1995; Coelli & Battese, 1996). However, it contrasts with the argument that age helps farmers acquire skills, accumulate experience in production techniques, and become more efficient. However, when analyzed on a certification-by-certification basis, age is not found to be significant for Fairtrade, Rainforest Alliance, and UTZ farmers.

Sex – As household heads, male farmers were found to be more technically efficient than their female counterparts. Nevertheless, for both the pooled certified and non-certified farmers, the coefficient for the sex variable was not significant. A similar pattern was observed when analyzing each certification group individually, except for the UTZ group, where sex significantly affected technical efficiency. Wollni (2007) found similar results for Costa Rican coffee production, indicating that sex did not affect technical efficiency, while Nguyen et al. (2019) observed a decrease in technical efficiency for female-headed households.

Household size—Household size was found to be insignificant in all sub-samples studied, including the pooled certified and non-certified farmers, and when each certification was analyzed separately, suggesting that household size does not affect technical efficiency in the case of Honduran coffee production.

Education – In this study, the variable education was not statistically significant for any group analyzed, including the pooled certified farmers, the individual 4C, FT, RA, and UTZ groups, and the non-certified farmers. However, previous studies have identified a significant and positive influence of education on farmers' technical efficiency, suggesting that those with more education tend to be more technically efficient (Bäckman et al., 2011; Poudel et al., 2015; Ho et al., 2014; Binam et al., 2008; Ngango & Kim, 2019). Other authors suggest that more educated farmers are better able to perceive, interpret, and respond to new information and adopt improved technologies, such as fertilizers, pesticides, and planting methods, more quickly than their less-educated counterparts (Mburu et al., 2014; Dessale, 2019).

Access to credit – Access to credit positively impacted technical efficiency but was only statistically significant for the pooled certified farmers and the 4C group. For the non-certified farmers, it was not statistically significant. Nevertheless, the lack of access to credit highlights the importance of financial resources in improving the efficiency of coffee producers, indicating that credit enables farmers to purchase inputs on time and manage their farms more efficiently, whereas a lack of credit has the opposite effect. This finding aligns with the results of Dessale (2019) and Hung et al. (2019).

Farm size – The impact of farm size on technical efficiency was not statistically significant for the pooled certified farmers, across certification types, and non-certified farmers. Therefore, despite the positive coefficients, farm size does not directly influence technical efficiency in the Honduran context. However, other empirical studies have found that large-scale farmers tend to be more technically efficient than small-scale farmers (Mburu et al., 2014), which contrasts with the argument that smallholder farm owners can manage their land better than large landowners (Dessale, 2019), as empirical evidence sometimes shows that technical efficiency increases with farm size.

Age of the coffee plantation—The age of the coffee plantation was found to negatively affect the technical efficiency of both certified and non-certified farmers. However, this effect was statistically significant only for non-certified farmers, suggesting that older plantations tend to

Table 5
Tobit's model results in the technical (in)efficiency of certified and non-certified producers.

Variable	**4C**		**Fairtrade**		**Rainforest Alliance**		**UTZ**		**Certified**		**Non-certified**	
	Coefficient (Std. Error)	Marginal effect (dy/dx)	Coefficient (Std. Error)	Marginal effect (dy/dx)	Coefficient (Std. Error)	Marginal effect (dy/dx)	Coefficient (Std. Error)	Marginal effect (dy/dx)	Coefficient (Std. Error)	Marginal effect (dy/dx)	Coefficient (Std. Error)	Marginal effect (dy/dx)
Constant	0.7453***		0.8236**		0.4149		0.4834***		0.6890***		0.5955***	
	(0.1655)		(0.3413)		(0.3821)		(0.1636)		(0.1112)		(0.1163)	
Age of the household head	−0.0036**	−0.0036	−0.0023	−0.0049	−0.0002	−0.0002	−0.0013	−0.0013	−0.0026**	−0.0026	−0.0016*	−0.0016
	(0.1655)	−0.0013	(0.0032)	−0.0046	(0.0035)	−0.0002	(0.0017)	−0.0013	(0.0011)	−0.0022	(0.0012)	−0.0015
Sex (dummy)	0.0035	0.0035	0.1156	0.0514	0.0159	0.0159	0.1246**	0.1246	0.0534	0.0534	0.0274	0.0274
	(0.0528)	0.0033	(0.1200)	0.0490	(0.1038)	0.0144	(0.0559)	0.1203	(0.0391)	0.0467	(0.0365)	0.0249
Household size	0.0138	0.0138	−0.0196	−0.0029	0.0315	0.0315	−0.0162	−0.0162	0.0057	0.0057	0.0047	0.0047
	(0.0105)	0.0128	(0.0161)	−0.0028	(0.0220)	0.0285	(0.0129)	−0.0154	(0.0071)	0.0049	(0.0065)	0.0043
Education (years of schooling)	−0.0131	−0.0131	−0.0063	−0.0014	0.0179	0.0179	0.0057	0.0057	−0.0025	−0.0025	−0.0119	−0.0119
	(0.0064)	−0.0122	(0.0097)	−0.0013	(0.0136)	0.0162	(0.0082)	0.0054	(0.0041)	−0.0021	(0.0057)	−0.0107
Access to credit (dummy)	0.1168***	0.1168	−0.0786	−0.0660	0.1529	0.1529	−0.0366	−0.0366	0.0600*	0.0600	0.0278	0.0278
	(0.0449)	0.1086	(0.0878)	−0.0621	(0.1121)	0.1413	(0.0465)	−0.0347	(0.0315)	0.0521	(0.0315)	0.0252
Farm size	0.0021	0.0021	0.0234***	0.0093	0.00001	0.00001	0.0017	0.0017	0.0011	0.0011	−0.0021	−0.0021
	(0.0040)	0.0019	(0.0083)	0.0088	(0.0056)	0.00001	(0.0025)	0.0016	(0.0022)	0.0010	(0.0027)	−0.0019
Age of the coffee plantation	−0.0079	−0.0079	0.0023	0.0024	0.0196	0.0196	−0.0033	−0.0033	−0.0009	−0.0009	−0.0103**	−0.0103
	(0.0071)	−0.0074	(0.0122)	0.0022	(0.0168)	0.0178	(0.0077)	−0.0031	(0.0049)	−0.0008	(0.0049)	−0.0094
Resistant variety	0.0764	0.0764	−0.0709	0.0890	0.22119	0.2219	0.0753	0.0753	−0.0062	−0.0062	0.0350	0.0350
	(0.0867)	0.0718	(0.1295)	0.0850	(0.1540)	0.2054	(0.0668)	0.0724	(0.0495)	−0.0053	(0.0542)	0.0320
Shade 25 % to 50 %	−0.0608	−0.0608	0.0465	0.1224	−0.1481*	−0.1481	−0.0318	−0.0318	−0.0412	−0.0412	0.0509	0.0509
	(0.0510)	−0.0561	(0.0967)	0.1170	(0.0759)	−0.1332	(0.0439)	−0.0302	(0.0317)	−0.0354	(0.0317)	0.0463
Fertilization based on technical assistance	0.0086	0.0086	−0.0549	−0.0014	−0.1231	−0.1231	0.0719	0.0719	0.0292	0.0292	−0.0010	−0.0010
	(0.0498)	0.0080	(0.0805)	−0.0013	(0.1102)	−0.1072	(0.0499)	0.0678	(0.0313)	0.0252	(0.0394)	−0.0009
Training attendance (dummy)	0.0472	0.0472	0.0452	−0.0205	−0.2360**	−0.2360	−0.0465	−0.0465	0.0377	0.0377	0.0591*	0.0591
	(0.0440)	0.0439	(0.1817)	−0.0193	(0.0991)	−0.1972	(0.0461)	−0.0441	(0.0338)	0.0328	(0.0335)	0.0540
Distance to plot (minute)	0.0001	0.0001	−0.0004	−0.0025	−0.0031**	−0.0031	0.0013	0.0013	−0.0007	−0.0007	0.0005	0.0005
	(0.0010)	0.0001	(0.0025)	−0.0024	(0.0015)	−0.0028	(0.0010)	0.0012	(0.0007)	−0.0006	(0.0006)	0.0004
Member of IHCAFE	−0.1370	−0.1370	−0.0433	−0.0433	−0.0046	−0.0046	0.1018	0.1018	−0.0648	−0.0648	0.0472	0.0472
	(0.0549)	−0.1240	(0.0489)	−0.0408	(0.1100)	−0.0041	(0.0834)	0.0984	(0.0351)	−0.0552	(0.0332)	0.0431
Test statistics												
Log likelihood	−1.1038		−42.59450		−0.1234		20.2799		−81.38		−9.53	
LR chi2 (13)	15.95**		15.45		13.73		18.42		20.86*		22.5**	

Notes: Standard errors in parentheses and *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ significance.

yield lower outputs. However, it is important to highlight the importance of agricultural practices such as renovation and pruning for maintaining productivity in coffee production.

Resistant variety – The analysis indicated that the use of rust-resistant varieties did not have a statistically significant effect on technical efficiency in coffee production within the Honduran context, regardless of whether the farmers were certified or non-certified.

Tree shade—Tree shade in the range of 25 % to 50 % had a negative effect on technical efficiency for the Rainforest Alliance group, with this effect being statistically significant only for this subsample. In contrast, the effect was not statistically significant for the other certified groups, the pooled certified farmers, or non-certified farmers. Therefore, regardless of whether the effect of tree shade was positive or negative, it should not be considered as such in the context of this study, except for the RA subsample.

Fertilization based on technical assistance – The results show that this variable did not significantly affect technical efficiency across the different subsamples analyzed in this study. This indicates that, within the specific context of Honduran coffee production, no apparent positive or negative effect can be associated with this practice on technical efficiency.

Training attendance—Training attendance positively affected technical efficiency for non-certified farmers, with statistical significance found only for this group. Although it could also positively affect the pooled certified farmers, no clear effect could be associated due to the lack of statistical significance. Nevertheless, some studies suggest that agricultural training, or any other training related to crop production, can enhance farmers' efficiency compared to those who are not trained. For instance, farmers trained primarily in agricultural practices showed a reduction in inefficiencies (Dessale, 2019).

Distance to plot – In the context of this study, distance to the plot negatively affects technical efficiency, specifically for the Rainforest Alliance group. The effect of this variable on the technical efficiency of the other subsamples was not statistically significant. Nevertheless, the quality of infrastructure development, particularly in rural areas, influences farmers' productivity. As the distance from the farm plot to the home increases, managing the plot becomes more challenging, which could reduce farmers' technical efficiency, as observed in the RA group.

Member of IHCAFE—The results indicate that membership in IHCAFE has a statistically insignificant effect on technical efficiency for both certified and non-certified farmers, suggesting that being a member of this organization does not have a clear impact on the technical efficiency of farmers in Honduras.

5. Discussion and conclusions

This study aimed to determine the impact of VSS on the sustainability and efficiency of smallholder coffee farmers in Honduras.

This research found substantial technical inefficiencies in Honduran coffee production, with non-certified farmers found to be more efficient than the pooled certified farmers. The average technical efficiency levels were estimated at 52.86 % for the pooled certified farmers and 55.56 % for non-certified smallholder coffee producers. These results indicate that both certified and non-certified coffee farmers have the potential to increase their coffee output by up to 47.14 % and 44.44 %, respectively, by increasing their efficiency level.

When examining certification by certification, the technical efficiency of 4C farmers was 51.58 % and 53.82 % for the Fairtrade group, both lower than the control group. In contrast, the Rainforest Alliance and UTZ groups were more efficient than both the non-certified and the other certified groups, with technical efficiency levels of 60.56 % for RA farmers and 60.15 % for the UTZ group. These findings suggest room for improvement in their efficiency levels: 48.42 % for 4C, 46.18 % for Fairtrade, 39.44 % for RA, and 39.85 % for UTZ farmers.

These findings have an important policy implication, demonstrating that Honduran smallholder coffee producers have considerable potential to increase output within the existing technology by improving their technical efficiency. Therefore, policymakers and other stakeholders should focus on enhancing efficiency levels and capitalizing on potential gains for the different farmer groups by allocating available resources effectively and adopting advanced technologies. This would improve coffee production, smallholder coffee farmers' livelihoods, the coffee sector's sustainability, and the Honduran agricultural sector.

As previously stated, certified producers can increase their coffee production without compromising social, environmental, or economic sustainability by better using existing resources on their farms. Identifying the determinants of inefficiency is crucial for addressing and overcoming these challenges. In this context, the results of the Tobit model for the determinants of technical efficiency revealed that different factors directly affect the technical efficiency of the pooled certified, the various groups of certified farmers, and the non-certified farmers.

For the pooled certified farmers, technical efficiency decreases significantly with the age of the household head, suggesting that older coffee producers may not be aware of new technologies or may not have received adequate training. This trend is also observed in the non-certified farmers. Moreover, male farmers are found to be more technically efficient than female farmers, highlighting the need to address gender-related disparities when tackling inefficiencies for the specific case of Honduran coffee production.

The effect of education on the technical efficiency of the different sub-samples was not statistically significant, so its impact is unclear in the context of Honduran coffee production. However, as other studies suggest, education still plays an important role in learning new agricultural practices, understanding agricultural instructions, using inputs efficiently, accessing new products, and adopting new information. This underscores the need to design and provide adequate basic educational opportunities for most farmers. Moreover, the effect of training attendance is significant only for non-certified farmers, while its effect on certified farmers remains unclear due to a lack of statistical significance. Therefore, stakeholders should promote, reinforce, and enhance training on good agricultural practices and other related areas, and follow up on the implementation of this training to improve not only the technical efficiency of farmers but also their economic sustainability.

Access to credit also plays a crucial role and has a direct positive impact on technical efficiency for certified farmers, enabling them to finance inputs, manage resources, and produce more efficiently. However, it is essential to point out that for non-certified farmers, the effect of credit is unclear since it is not statistically significant. Therefore, farmers may need additional financial resources to acquire inputs at the right time and apply them according to the crop needs. Stakeholders should strengthen credit availability and promote strategies to encourage saving habits among farmers.

Other variables analyzed in this study, such as farm size, the age of the coffee plantation, the use of resistant varieties, tree shade, fertilization based on technical assistance, distance to the plot, and membership in IHCAFE, have no clear effect on the technical efficiency of both certified and non-certified farmers due to a lack of statistical significance. Therefore, no apparent positive or negative effect can be associated with these variables in the specific context of Honduran coffee production.

Finally, this study makes significant contributions to researchers, policymakers, and NGOs as the first study on technical efficiency involving Voluntary Sustainability Standards in the Honduran coffee sector. It opens the field to understanding the technical efficiency of both certified and non-certified coffee farmers and invites further research on this topic.

Credit authorship contribution statement

David Navichoc: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Mengistu Alamneh:** Methodology, Writing – original draft.

Paulo Mortara Batistic: Methodology. **Thomas Dietz:** Funding acquisition, Writing – review & editing. **Bernard Kilian:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We gratefully acknowledge funding by the German Federal Ministry of Food and Agriculture (BMEL) (grant number 2219NR291) through the research project 'Transformation and Sustainability Governance in South American Bioeconomies' and the Ministry for Culture and Science of the State of North Rhine-Westphalia through the project TRANS-SUSTAIN (grant number 005-1503-0008). We are also grateful to the German Academic Exchange Service (DAAD) for the provision of a doctoral stipend to David Navichoc.

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