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Journal of the Asia Pacific Economy

ISSN: 1354-7860 (Print) 1469-9648 (Online) Journal homepage: www.tandfonline.com/journals/rjap20

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To cite this article: Tuan Nguyen-Anh, Chinh Hoang-Duc, Anh Le-Ngoc & Thinh Nguyen-An (2024) Drivers of land use efficiency among ethnic minority groups in Vietnam: a longitudinal study, Journal of the Asia Pacific Economy, 29:2, 506-524, DOI: 10.1080/13547860.2022.2044658

To link to this article: https://doi.org/10.1080/13547860.2022.2044658

Published online: 03 Mar 2022.

JOURNAL OF THE ASIA PACIFIC ECONOMY
2024, VOL. 29, NO. 2, 506–524
https://doi.org/10.1080/13547860.2022.2044658

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Drivers of land use efficiency among ethnic minority groups in Vietnam: a longitudinal study

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ABSTRACT

This paper examines factors influencing agricultural land-use efficiency among 35 ethnic minority groups in Vietnam during the 2010–2018 period. A hybrid approach comprising the Difference-in-Difference model with Propensity Score Matching (DID_PSM) is adopted to examine the effect of different land sizes, land elevations, and land tenure on land-use efficiency. The results show that: (1) land size and agricultural production form an 'U-shaped' relationship; (2) farming on high land decreases efficiency by around 7.7%–8.0%; (3) farmers purchasing or hiring land in long-term are 7.3%–8.2% more efficient. The paper also discusses typical land characteristics of mountainous areas including steep and fragmentation related to the three comparing factors. From these results, implications are made for Vietnamese authorities about 'land accumulation' policies and other 'farming on elevation' techniques.

KEYWORDS

land use efficiency; ethnic minorities; propensity score matching; land size; land elevation; land tenure

1. Introduction

In developing countries like Vietnam, where economic growth and overall development revolves around agricultural activities, land is one of the most important resources (FAO and UNEP 1999). This resource is even more crucial for small-scale farming households whose livelihoods mainly depend on agricultural outputs, which requires them to optimise land use. In Vietnam, 53 ethnic minorities, accounting for 14.6% of the total population (GSO 2020), reside primarily in mountainous areas with difficulties in topography, accessibility, and farming land (Son, Chi, and Kingsbury 2019). An average ethnic household owns about 0.72 hectares of cultivated land, which is insufficient to maintain their sustainable livelihoods. This implies that these groups are vulnerable to both transitions in ecology and socio-economy caused by climate change or inequality. Since the Doi Moi in 1986, the Vietnamese government has implemented several farmland redistribution policies and regulations to provide enough land for farmers to ensure national food security. However, these policies were inefficiently adopted in the mountainous topography where farmlands are challenging to be allocated proportionally (Tran et al. 2015). Therefore, over the

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last decade, the government has instituted several support policies toward increasing the agricultural producing capacity of ethnic groups, such as extension programs, land tenure promotion, land accumulation, or micro-credits. However, the effectiveness of these policies has not been assessed by reliable studies. Moreover, the literature on land-use efficiency of ethnic minorities or small farming households in mountainous areas is insufficient. As of Min, Waibel, and Huang (2017), studies are based on crossectional data, which could not reflect the longitudinal changes in land-use efficiency and its drivers, including support policies.

Land use inefficiency is mainly characterised by three fundamental limitations as small cultivated areas; steep farming lands; and lack of land tenure of the fields (Abdulai, Owusu, and Goetz 2011; Henderson 2015; Looga et al. 2018; Ferreira and Féres 2020; and Wang et al. 2020). Therefore, this study uses these disadvantages to build theoretical hypotheses to determine the impacts of these constraints on land use efficiency among ethnic people in Vietnam.

Some previous studies have investigated the relationship between farm size and production efficiency in developing countries. Ferreira and Féres (2020) used farm size as a differential factor with other demographic variables and market imperfection frameworks to analyse efficiency differences between small and large farms in the Brazilian Amazon. The results indicated a proportional relationship between farm size and technical efficiency. Bojnec and Fertő (2013) indicated the positive impact of the total cultivated land area on farming technical efficiency among Slovenia farming families from 2004 to 2008. Ogundari (2013) studied the impact of the total cultivated land area and other inputs on ethnic communities, the capability of increasing land-use efficiency by using more cropland, and factors influencing the technical efficiency. Accordingly, we propose our first hypothesis:

Hypothesis 1: Larger areas of cultivated land increases the productions of food crops of ethnic minorities over time.

Farm efficiency varies across regions and countries because of different terrain and soil types. In Vietnam, since mountainous areas, taking up three-quarters of total land area, are home to the majority of ethnic minorities, considering the topography of cultivated land into land-use efficiency is necessary and relevant. Across different elevations, land quality and climate characteristics could differ, leading to different production output levels. Ghosh et al. (2014) suggested that in the mid-hills of the northwest Himalaya region, wheat, maize, cowpea, soybean production increase with a higher altitude from 600 to 1500 m. On the other hand, Boz and Haq (2019) showed that steep and high land negatively affect farming efficiency but with only a small magnitude. Different plants also react differently to land elevation. Poudel, Mishra, and Johnson (2017) studied coffee trees in Nepal and found that altitude positively correlates with efficiency. For food crops such as maize, Southavilay, Teruaki, and Shigeyoshi (2012) presented the opposite results: lowland cultivation is more effective than highland cultivation. Thus, the current literature has not identified the consistent results regarding the elevation – efficiency relationship since it tends to vary across crop types or regions. Thus, this study aims to examine this nexus via empirical evidence from Vietnamese food crops farming with:

Hypothesis 2: Changes in altitude affect land-use efficiency.

Land ownership theoretically affects land-use efficiency by providing farmers with legal access to their land and other necessary farming practices. However, it is not plausible that renting more land will increase the land-use efficiency since the leasing fee would impair the profits from that land slot. Also, farmers on rented land are less likely to implement land conservation or soil improvement practices than those with full land ownership, which negatively impacts agricultural production. In Uganda, farmers with full land ownership have more return on land investment and production than farmers farming under occupancy rights (Deininger and Ali 2008). In Pakistan, farmers invest less in rented plots than on their purchased plots (Jacoby and Mansuri 2009). Secured land ownership guarantees farmers to invest in land-improving and conservation targets (Abdulai, Owusu, and Goetz 2011). Facilitated land transfer rights, which help farmers to sell or rent their land, also supports land-improving measures. Regarding the agricultural land market in Vietnam from 1997 to 2001, land lease fees and increasing labour costs have negatively affected the area of rented land (Macaulay, Marsh, and Hung 2006). In the Mekong Delta of Vietnam, the limitation to land hinders the profitable livelihood of the farmers (Hoang et al. 2019). Vietnamese government had also issued several policies to encourage land tenure acquirement and land accumulation since 2008 (especially Resolution No. 26-NQ/TW) via two channels: (1) transfer of agricultural land use rights between farm households; and (2) transfer of agricultural land use right from farm households to enterprises. However, hitherto, the effects of these policies on actual land-use productivity of farmers have not been reviewed, especially for ethnic farmers, who are the target beneficiaries of these policies. Thus, this study aims to test the third hypothesis:

Hypothesis 3: Land tenure affects land-use efficiency.

To test the proposed hypothesis, we first adopt the stochastic production frontier (SPF) model to estimate agriculture input factors. Then, we use the combination of propensity score matching (PSM) and difference-in-difference (DID) method to indicate the impacts of land elevation and land tenure on land use technical efficiency. This synthesis method can overcome the weakness of individual PSM and DID, such as PSM's inability to account for temporal effect and DID's lack of power in matching.

The remaining of the study is organised as follows. The second section briefly reviews the ethnic minority people and their food crops in Vietnam. The third section introduces the data and research methods. The fourth section reports the results. The fifth section discusses the implications of the estimated results and provides policy recommendations to improve the land-use efficiency among ethnic minorities in Vietnam. Finally, the last section summarises the main findings.

2. Overview of agricultural land use of ethnic minorities in vietnam

Vietnam is a multi-ethnic country that hosts 54 ethnicities. About 82 million Kinh people account for 85.4% of the Vietnamese population; the remaining 53 minority groups make up 14.6% of the country's population. Ethnic minorities live primarily in mountainous areas including the Northern Midlands, the Central Coast, the Central Highlands and the Southern region. These households still live mainly on ’non-cash livelihoods’ such as agriculture and livestock; therefore, their link with the commercial market is weak. Shortage of food contributes partly to the persistent poverty of ethnic minorities (Asian Development Bank 2003; World Bank 2009). This shortage is driven by the difficulty of accessing land, particularly land with fertile soil, which results in low land-use efficiency. In Vietnam, ethnic minority groups cultivate mainly on low fertility land without legal certificates of land use (Singhal and Beck, 2015). Since the majority of ethnic minorities reside in mountainous areas, their cultivated lands bear specific characteristics such as steepness, fragmentation, and low fertility. Most of the land with a slope below 15 degrees (accounting for 21.9%) has been used for agricultural production or agroforestry. The area with a slope of 15 to 25 degrees accounts for about 16.4%, and the rest is land with a slope greater than 25%, which is almost impossible to cultivate. With such a slope, mountainous arable land of ethnic minorities has the following significant weaknesses: fragmentation, erosion, soil degradation, and drought.

Research on land use efficiency in Vietnam has received limited attention when only a few provinces or regions are focussed (Danni 2019). Moreover, as ‘sufficient nutrients’ is one of the criteria to evaluate multidimensional poverty, this insufficiency is more detrimental for land-use optimisation, especially for food crops. Land use for growing rice, corn, and cassava is a critical research issue in Vietnam in food security literature. Evaluating the efficiency of land use for food crops by ethnic minorities is necessary to eradicate the current limitations of the current agricultural production (Son, Chi, and Kingsbury 2019). The study results can offer a science-based foundation for policy implications to improve land-use efficiency in a sustainable manner.

To ensure food security for ethnic minorities, farming land tenure security needs to be addressed. Swidden agriculture (or shifting cultivation; slash-and-burn) is popular among ethnic minority groups in Vietnam, where the agricultural production type was restricted by the government to protect deforestation. As the ethnic populations increased and the possible cultivated land did not, swidden agriculture became more frequent (Jen 2007). Moreover, poor farming techniques with traditional farming equipment and soil degradation also resulted in farming inefficiency, which forced ethnic farmers to seek new plantations areas. These practices lead to difficulties in planning arable land, which causes inefficiency in land allocation and the shortage of cultivated land among ethnic minorities. Therefore, the Vietnamese government has issued many residential lands and community land policies for ethnic minorities in accordance with the customs, practices, cultural identity, and actual conditions of each region. Most recently, the National Assembly issued the National Target Program for Socio-Economic Development in ethnic minority and mountainous areas in the 2021–2030 period, clearly stating that: by 2025, address the shortage of houses, residential land, production land and domestic water to support ethnic minorities in agricultural production activities. These supportive policies aim to: (1) improve the schemes to transfer property rights to reallocate agricultural production land to ethnic minorities and mountainous farmers; and (2) increase farmers’ capacity by education, agriculture extension, and livelihood transition supports.

3. Methodology

3.1. Input-output variables and data source

The correlative link is assumed between input-output relations and the existence of land use efficiency (scale, pure and comprehensive efficiency). Farming efficiency is estimated using the fundamentals of stochastic frontier analysis (SFA) or data envelope analysis (DEA). The variables, which are synthesised from a vast number of previous studies, are categorised into both input and output indicator groups. Illustrations of the rationales that allow selecting input-output variables are described in Table 1.

This study uses the data reported from biannual surveys from 2010 to 2018 of the Vietnam Committee for Ethnic Affairs about ethnic minorities socio-economic and production characteristics. Although Vietnam hosts 53 ethnic groups in total, some of them represent only a small proportion of the total population. This survey selects 35 ethnic groups which are Tay, Thai, Hoa, Khmer, Muong, Nung, H'mong, Dao, Gia-rai, Ede, Bana, Xo Dang, San Chay, Co Ho, Cham, H're, M'nong, Ra-glai, Bru-Van Kieu, Tho, Giay, Ko Tu, Gie Trieng, Ma, Kho Mu, Co, Ta Oi, Cho Ro, Khang, Xinh Mun, Ha Nhi, Lao, La Chi, La Ha, Bo Y. Subsequently, only ethnic groups which live across the country receive the support by the government. In total, 3.646 observations were used in the studied period. Both input and output variables are logarithmized to fit the production functions, which are described in Table 2.

Ln(output) represents the logarithmic value of the output of a surveyed household from 2010 to 2018. Data in Table 2 shows a slight decrease of output from 8.066 in 2010 to 7.439 in 2018. Accordingly, other logarithmic values of inputs such as land, labour, fertiliser and pesticide and seeds of food crops also decrease. On the other

Table 1. Variables of input and output.

Variables	Description	References
Output	Total food crops output produced by the farmers in 2010, 2012, 2014, 2016 and 2018, respectively (kg)	To and Nguyen (2020) Hong and Yabe (2015); Mishra, Khanal, and Mohanty (2017); Khan and Damalas (2015)
Land input	Total land used to produce food crops of each household in 2010, 2012, 2014, 2016 and 2018 (m2)	Bojnec and Fertő (2013); Akram (2019)
Labour input	Total number of labour hours used to produce food crops of each household in 2010, 2012, 2014, 2016 and 2018 (hours)	Hong and Yabe (2015); To and Nguyen (2020)
Fertilizer input	Total amount of fertilizer used to produce food crops of each household in 2010, 2012, 2014, 2016 and 2018 (kg)	Hong and Yabe (2015); Wu (2011); Li et al. (2011a)
Pesticide input	Total amount of pesticide used to produce food crops of each household in 2010, 2012, 2014, 2016 and 2018 (kg)	Khan and Damalas (2015); Cooper et al. (2016)
Seed input	Total amount of seeds used to produce food crops of each household in 2010, 2012, 2014, 2016 and 2018 (kg)	To and Nguyen (2019); Linh (2012); Mishra, Khanal, and Mohanty (2017)
Extension	The access of the farming household to formal extension service	Chandio et al. (2019); Balcombe et al. (2008)
Microcredit	The access of the farming household to formal loans/credit	Bojnec and Fertő (2013); Li et al. (2011b)
Cooperation	Cooperation linkage between surveyed households and other farmers in purchasing inputs and selling outputs	Mnisi and Alhassan (2021); Regan et al. (2017); Ma et al. (2017)

Table 2. Descriptions of input and output variables.

Variables	2010	2012	2014	2016	2018
Ln(output)	8.066	7.742	7.261	7.207	7.439
	(1.175)	(1.179)	(1.678)	(1.715)	(1.487)
Ln(land)	8.818	8.343	6.031	6.150	7.989
	(1.031)	(1.067)	(3.283)	(3.308)	(1.499)
Ln(labour)	4.427	4.178	4.183	4.143	4.141
	(0.335)	(0.445)	(0.446)	(0.411)	(0.440)
Ln(fertilizer)	1.248	1.254	1.198	1.145	1.156
	(0.234)	(0.342)	(0.453)	(0.436)	(0.298)
Ln(pesticide)	0.387	0.095	0.076	0.068	0.075
	(0.243)	(0.031)	(0.042)	(0.026)	(0.032)
Ln(seed)	0.216	0.095	0.083	0.053	0.043
	(0.123)	(0.043)	(0.054)	(0.032)	(0.035)
Extension	0.452	0.415	0.454	0.459	0.542
	(0.208)	(0.209)	(0.207)	(0.210)	(0.208)
Microcredit	0.249	0.193	0.150	0.251	0.286
	(0.433)	(0.395)	(0.358)	(0.434)	(0.452)
Cooperation	0.461	0.463	0.467	0.484	0.541
	(0.244)	(0.245)	(0.244)	(0.246)	(0.245)

hand, the standard errors of these values (in parentheses) increase over the period, which signifies the discrimination of ethnic minorities in utilising resources for farming activities. Some households attempted to exploit their farms; meanwhile, others might behave in the opposite way.

3.2. Methods

3.2.1. Stochastic production frontier model (SPF)

In this study, stochastic frontier analysis (SPF) is used to estimate land-use efficiency of selected ethnic farming households and to test for our first hypothesis. The traditional stochastic frontier production function estimates the panel data to quantify the change of production capabilities of farmers over time (Battese and Coelli 1995; Green 2005). The SPF can be written as

$$y(g_{it}) = \exp\left(f(ln(land)_t;\ ln(labour)_t;\ ln(fertilizer)_t;\ ln(pesticide)_t;\ ln(seed)_t|\beta_{1-5}) + e_{it}\right)$$

where g_{it} denotes the production of the minority producer i^{th} ($i = 1, 2, \ldots, N$; e_{it} is subject to model error term during period t^{th} ($t = 2010, \ldots, 2018$). Using the log-transformation on (1), we have

$$ln(g_{it}) = f(ln(land)_t;\ ln(labour)_t;\ ln(fertilizer)_t;\ ln(pesticide)_t;\ ln(seed)_t|\beta_{1-5}) + v_{it} - u_{it} \quad (2)$$

where v_{it} is a random error term assumed to be independently and identically distributed, which captures the random variation in the output due to factors beyond the control of producers. The technical efficiency u_{it} of the food-crop farming households are determined after estimating the production function (2) that will be used as response variable in DID_PSM method.

3.2.2. Difference-in-difference method combining the propensity score matching (PSM-DID)

To verify the second and the third hypotheses, the estimated land-use efficiency u_{it} from equation (2) is used as the response variable in the DID model (Imbens and Wooldridge 2009). To and Nguyen (2020) described the DID model that two groups of efficiency scores can be indexed by treatment status $T = 0, 1$. To test the second hypothesis, the T variable 0 indicates individuals who do not own their farm, that is the control group, and 1 indicates individuals who do, that is the treatment group. Similarly, the third hypothesis is tested by using the same technique where 0 determines farming households that cultivate on low land (<1000 m above the sea level); meanwhile, 1 stands for surveyed households that do not cultivate on high lands (>1000 m above the sea level). Assume individuals are observed in two time periods, $t = 0, 1$ where 0 indicates the year 2010, that is pre-treatment, and 1 indicates the year 2018, that is post-treatment. Every observation is indexed by $i = 1, \ldots, N$; individuals will have two observations each, one pre-treatment and one post-treatment.

Let $\overline{Y}_0^T$ and $\overline{Y}_1^T$ be the sample averages of the outcome for the treatment group before and after treatment, respectively. Similarly, let $\overline{Y}_0^C$ and $\overline{Y}_1^C$ be the corresponding sample averages of the outcome for the control group. In practice, by running the fixed effect regression or taking the deduction of treatment and control groups, the DID estimator ($\hat{\delta}_{DD}$) is estimated by:

$$\hat{\delta}_{DD} = (\overline{Y}_1^T - \overline{Y}_0^T) - (\overline{Y}_1^C - \overline{Y}_0^C) \tag{8}$$

The selection of the targeted households is non-random because of the focus on the ethnic groups in Vietnam. This heterogeneity issue may cause an 'estimation bias' of the DID estimator. Propensity score matching (PSM) is one of the most applicable methodologies to deal with non-random statistics. The matching algorithm such as Kernel, Mahalanobis or inverse probability effectively deciphers the issues caused by the omitted observations, heterogeneity or selection bias. Its application has more reliable results (Caliendo and Kopeinig 2008; Abadie and Imbens 2016). The mechanism of matching process that determines a counterfactual of each observation in treatment groups seeks for the best match observation in control groups (Wang et al. 2019). Similarly, using propensity scores as weights in fixed-effects regression was empirically used as another approach to minimise the heterogeneity issue (Winship and Radbill 1994; Imai and Kim 2019).

4. Results and discussions

To test our proposed hypotheses, Translog models are used since log-likelihood ratio test results between Cobb-Douglas and Translog function (Table 3) show that Translog is the better fit model (p-value < 0.05) to estimate the production Equation (1). The Translog function does not require any specific functional form and generates more realistic efficiency scores.

Compared to the Cobb-Douglas function, the Translog function includes all squared terms as well as interaction terms of input variables described in Table 2. In

Table 3. Log likelihood ratio test.

Model 1	Cobb- Douglas with time-variation				
Model 2	Translog with time-variation				
	#Df	LogLik	Df	Chisq	Pr(>Chisq)
1	12	−6062			
2	27	−2871.4	15	6381	<2.20e-16 ***

Significance level: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 4. The estimation result of translog function.

Items	Estimate	Robust Std. Error	z-value	Pr(>|z|)
(Intercept)	6.523	0.626	10.4187	2.20e-16***
Ln(land)	−0.465	0.082	−5.6985	1.21e-08***
Ln(seed)	0.072	0.040	−1.7873	0.07389*
Ln(labour)	−0.119	0.204	−0.5830	0.55988
Ln(pesticide)	0.062	0.101	−0.6163	0.53771
Ln(fertilizer)	0.474	0.090	5.2784	1.30e-07***
Ln^2(land)	0.059	0.003	19.6039	2.20e-16***
Ln^2(seed)	0.002	0.001	2.5458	0.01090**
Ln^2(labour)	0.007	0.023	0.3102	0.75637
Ln^2(pesticide)	−0.002	0.004	0.4980	0.61850
Ln^2(fertilizer)	0.142	0.003	55.0347	2.20e-16***
Ln(land)*Ln(seed)	0.021	0.002	9.5252	2.20e-16***
Ln(land)*Ln(labour)	0.044	0.011	3.9092	9.26e-05***
Ln(land)*Ln(pesticide)	0.034	0.012	2.8804	0.00397***
Ln(land)*Ln(fertilizer)	−0.075	0.006	−12.9443	2.20e-16***
Ln(seed)*Ln(labour)	0.000	0.003	0.0412	0.96712
Ln(seed)*Ln(pesticide)	−0.007	0.008	−0.8306	0.40617
Ln(seed)*Ln(fertilizer)	−0.032	0.002	−16.1259	2.20e-16***
Ln(labour)*Ln(pesticide)	−0.002	0.016	−0.1514	0.87965
Ln(labour)*Ln(fertilizer)	−0.088	0.016	−5.6061	2.07e-08***
Ln(pesticide)*Ln(fertilizer)	−0.041	0.006	−6.3766	1.81e-10***

Note. Ln(x_i), Ln^2(x_i) represent natural logarithmic form and square term of each variable x_i estimated in Table 2. Significance level: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

order to minimise the heteroscedasticity, we use clustering analysis in combination with translog function to estimate the robust standard error. Our analysis employs the location of the respondents (provincial level) as our clusters due to their shared farming and socio-economic characteristics.

4.1. Land size and other production inputs

4.1.1. Land size

The Translog model results from Table 4 show that the coefficient of Ln(land) is negative while that of Ln^2(land) is positive with the significant level p-value < 1%, which indicates that land size and land-use efficiency have a nonlinear, U-shaped relationship and the first derivative of this relationship at the current point is negative. This means that when land size increases, land use efficiency would first decline to a turning point and then increase afterwards. This result resembles the findings by Ferreira and Féres (2020), and Looga et al. (2018) in developing countries, which signifies consistency.

These coefficients indicate that, in current practice, farmers with smaller cultivated land areas have higher farming productivity than those with larger farms. Our

Hypothesis 1, thus, is rejected. One possible explanation for this is the lack of managing capacity of ethnic farmers. Their shorts in capital and technical assistance deter them from enjoying economies of scale. In fact, most ethnic farmers are still farming with family labour using traditional labour-intensive methods, which lowers their efficiency of farming, especially on a large scale. Therefore, an increase in land forces farmers to reallocate their restricted resources of labour and capital, leading to increasing inefficiency over one unit of cultivated area. Also, land fragmentation is another reason causing the inefficiency of land use. Cultivated land, if scattered to small areas, cannot bring about economies of scale effect. In the survey areas, although there are households who have access to a large area of land, the fact that land is not consolidated is more likely to reduce farming efficiency. This is because of the heterogeneity among land plots or the practice of monocropping leading to land deterioration.

Previous studies such as the work of Henderson (2015) explained this inverse relationship via labour market imperfection, which implies the asymmetry of capital-labour ratio across producers. However, in this case of ethnic farmers in mountainous areas, since they use mainly family labours, or in some occasions, hire their neighbours to do farming, no full market is formed for labour. Therefore, the observed relationship should be accounted mainly by the intrinsic ability and capacity to farm of farmers. Our results from the translog model with the interaction terms of land size and other agricultural inputs such as seeds, labour, and pesticides also confirm this. With positive, highly significant coefficients, these terms show that when cultivated land size increases, farmers must increase the number of seeds, labour hours, and the number of pesticides in order for farming efficiency to increase. We will discuss more about these production inputs below.

4.1.2. Other production inputs

As land-use impact assessment should not be limited to land size, we take into account other 'non-land' input factors as the number of seeds, fertiliser, pesticide, and labour. The results from Table 4 show that factors related to labour and pesticide have no linear or quadratic effect on the model estimation as a whole. In contrast, variables about the number of seeds and the amount of fertiliser issue positive coefficients with a high significance level (p-value $< 1\%$), implying that land-use efficiency would increase if farming households use more of these factors. Fertiliser promotes and supplements food crops with nutrients and allow them to achieve higher yields. Although fertiliser significantly increases farming productivity, the interaction term between land and fertiliser is significantly negative, which is also reported in the study of Tan et al. (2010). These results also indicate that ethnic farmers are under-utilising their land slots and also, their land soil is of low quality. Thus, increasing both the number of seeds and the amount of fertiliser per square metre could help increase farming efficiency. If only land quality is decent and the whole land spot is fully utilised, then adding more land and labour can increase production. Based on the value of Ln(seed), Ln^2(seed) and Ln(fertiliser), Ln^2(fertiliser) coefficients, we can infer that, at this current state, increasing fertiliser usage would bring about better results than increasing number of seeds.

Other interaction terms include Ln(seed)*Ln(fertiliser), Ln(labour)*Ln(fertiliser), and Ln(pesticide)*Ln(fertiliser) issue significant, negative correlations with farming technical efficiency. These results indicate substitutional relationships between fertiliser use and other inputs, including seeds, labour, and pesticide, which means that increasing both inputs would lead to a diminished increase in farming efficiency. However, since the single coefficient of fertiliser variable has a relatively large value, the decreasing effect of these interaction terms can not change the correlation direction. This implies that although farmers can increase all of the inputs to increase TE, in the current state, increasing only fertiliser is the most efficient action. This implication also strengthens our above discussion about low soil quality in the studied areas.

4.2. Land elevation

Table 5 shows estimation results that compare households farming on high land versus those farming on low land. The results indicate that, among six estimations, only Kernel matching with Mahalanobis generates a p-value above 0.05 (statistically insignificant). For difference-in-difference (DID) estimation with PSM, the results are consistent among the robust estimation, bootstrap estimation, weighted fixed-effects regressions, and inverse probability weighting (IPW) matching. In either weighted fixed-effects regressions or inverse probability weighting matching, the weights of the regression are specified as the Kernel propensity scores. The coefficients are 0.077 and 0.080, respectively, implying a 7.7%–8.0% higher technical efficiency in lower areas as compared to the food-crop farms at higher altitudes. In other words, regarding time changes from 2010 to 2018, households located on a lower land tend to have a higher agriculture production than those working with higher elevation farming areas. Our five adopted models issue coefficients with the variation of 1.249%, which implies consistency and reliability across models. The Hypothesis 2, therefore, is proven, suggesting a negative relationship between land elevation and land-use efficiency. Our result is contradicted to study on wheat and maize of Ghosh et al. (2014) and study on potato crop of Minda et al. (2018). One of the reasons these authors gave for the positive elevation–production relationship was that in certain areas, changes in elevation cause changes in climate conditions, including temperature and precipitation. These meteorological factors, in these cases, are favourable for the development of crops. However, in Vietnam, with the range of land elevation between 500 and 1500 m above sea level, these conditions might not hold true.

Table 5. DID with PSM estimation results using efficiency (high elevation).

Models	Coefficient	Robust std. err.	$\|t\|$	$P>\|t\|$
Kernel propensity score matching difference-in-differences (robust)	0.077	0.036	2.140	0.033**
Kernel propensity score matching difference-in-differences (bootstrap = 1000)	0.079	0.036	2.210	0.027**
Fixed-effects (within) regression using Kernel weights	0.079	0.036	2.170	0.030**
Fixed-effects (within) regression using ATT weights	0.080	0.036	2.210	0.027**
Inverse Probability Weighting matching difference-in-differences	0.079	0.035	2.260	0.024**
Coefficient of variation (%)	1.249			

Note. Significance level: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Moreover, in practice, the transportation system is more difficult in higher areas than in lower areas which lower the efficiency of the production process in general. Land fragmentation is also a factor contributing to the inefficiency of farming on high land. Previously, Looga et al. (2018) discussed that fields are more likely to be fragmented for higher topography which reduces land-use efficiency. Wang et al. (2020) and Rahman and Rahman (2009) also indicated that land fragmentation is a deteriorating factor for land-use efficiency of food crops in China and Bangladesh.

Moreover, in mountainous areas, elevation often accompanies steep topography, which correlates with land-use inefficiency (Ma et al. 2017; Teshome et al. 2016). The cultivation in sloping land increases the probability of cropland abandonment. Labour migration has not yet resulted in rural depopulation at a large scale because the elderly parents and often also wives and children of the migrated labourer remain in the home village. According to Min, Waibel, and Huang (2017), land topography affecting cropland abandonment is not just occurring among Chinese ethnicities. The issue is also present among Vietnamese ethnic minorities.

4.3. Land tenure

For the third hypothesis, farming households cultivating on land acquired recently (up to 5 years before 2018) are compared to households who solely farm on their inherited land (Table 6). We consider five years as the empirically long enough time for farmers to invest and cultivate their land. Statistically, a five-year period can normalise shocks in agriculture data records due to temporary changes of weather or investment, which facilitates unbiased calculations. The result of robust and bootstrapped DID estimation shows the difference valued at approximately 7.3% and 8.2%, respectively. The positively significant results imply that farmers who recently acquired land have a higher land-use efficiency than farmers who have not. The results of fixed-effects regressions, bootstrapped kernel matching and inverse propensity score weighting matching show that the coefficients are 0.081, 0.079, 0.074 and 0.075, respectively, indicating a similar implication. Hypothesis 3, thus, is proven with a positive relationship between land tenure and land-use efficiency. These results are different to some previous studies, such as those by Abdulai, Owusu, and Goetz (2011), Jacoby and Mansuri (2009) or Macaulay, Marsh, and Hung. (2006). These studies discussed that land lease fees could be a reduction to farmers' production revenue. In addition, farmers were claimed to make less effort to improve land quality

Table 6. DID with PSM estimation results using ethnic groups efficiency clustering (land tenure).

Models	Coefficient	Robust std. Err	$\|t\|$	$P>\|t\|$
Kernel propensity score matching difference-in-differences (robust)	0.073	0.036	2.060	0.047**
Kernel propensity score matching difference-in-differences (bootstrap = 1000)	0.082	0.034	2.410	0.016**
Fixed-effects (within) regression using kernel weights	0.081	0.037	2.190	0.036**
Fixed-effects (within) regression using ATT weights	0.079	0.036	2.201	0.035**
Inverse Probability Weighting matching difference-in-differences	0.075	0.033	2.240	0.025**
Coefficient of variation (%)	4.668			

Note. Significance level: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

on rental lands than on owned lands. On the other hand, our result is similar to the study of Zhou et al. (2019). The technical efficiency of households acquiring land tenure from 2010 to 2018 is higher than that of farming households exclusively utilising their inherited farms because those who bid for the land tenure due to their purpose for further investment on cultivated farmlands. The most common objective to purchase or hire a more land is simply to increase agricultural production. The second common objective of acquiring or trading lands is to avoid land fragmentation by purchasing the surrounding areas. Farmers who are intended to increase their production invest in their farms which temporarily increase the land-use efficiency. Most recently, Kijima and Tabetando (2020) showed that in Kenya, renting land increased farmers' crop income. Eder, Salhofer, and Scheichel (2021) stated that farmers who intended to extend their production through land bidding or acquisition achieved a higher land-use efficiency than those who did not. Bradfield et al. (2020) also discussed that rental lands helped farmers to achieve economies of scale to increase their land-use efficiency. Also, farmers who acquired land themselves are more likely to dedicate themselves to farming as the major source of income to improve livelihood. Thus, their farming activities stand a higher chance to be more efficient. Tenaw, Zahidul, and Parviainen (2009) suggested that property rights encourage farmers to increase production activities and also assure sustainability.

5. Policy implications and conclusion

This study identifies factors influencing land-use efficiency among Vietnamese ethnic minorities living in the mountains. The stochastic frontier analysis in combination with the difference-in-difference model allows score matching of data on the agricultural production of 35 ethnic groups. Three hypotheses are proposed regarding the relationship of land-use efficiency to (1) cultivated areas, (2) high topography in mountainous areas, and (3) land tenure.

The results show that the land size for food crops is one of the most important inputs contributing to the technical efficiency of ethnic households. Land size and efficiency establish a U-shaped relationship which can be explained by a lack of experience in agriculture among ethnic farmers. A 7.7%–8.0% difference exists in land-use efficiency between households on low and high topography. In terms of land tenure, the study results suggest that farmers who purchased or hired land for the past five years have a 7.3%–8.2% higher efficiency than those who do not.

From these results, we discuss the two current policies and practices in land reallocation and cultivation on sloping land. In the Decree 26-NQ/TW in 2008, the Vietnamese government set the groundwork for later policies in 2013 on 'land accumulation' with the focus to address diminishing productivity per land unit. The current policies related to land accumulation – No.45/2013/QH13, allow farmers to transfer agricultural land use rights between farming households or to enterprises (National Assembly of Vietnam 2013). Our results on land size – technical efficiency indicate that land accumulation, in the long run, would increase farming efficiency, which provides empirical analysis for this policy. In addition, that farmers acquiring or hiring cultivation land have a better agriculture productivity also suggests that promoting a free market of land use rights transfer would benefit farming efficiency among ethnic minorities. Other than contributions to policy assessment, this paper also provides evidence on the use of matching techniques with panel data to address the difference among ethnic groups. To and Nguyen (2019) concluded that land accumulation currently receives concern from both the policymakers and researchers in Vietnam. However, the current situation of the market mechanism of land acquisition/tenure in Vietnam is still in conflict with the food security problem (Ha, van Dijk, and Visser 2014). Farmers, when deciding to purchase or hire land, mostly desire to maximise the advantage of land use by growing market-oriented plants rather than planting food crops. Min, Waibel, and Huang (2017) emphasised the importance of land tenure markets of ethnic minorities in China as one of the drivers to transform agriculture. To this end, accelerating the issuance of farmland tenure certificates and giving a more priority to small-scale farming by ethnic minorities groups in mountainous locations is imperative.

Moreover, from the results of matching techniques with DID to account for time variance, we can examine the relationship between slope (implied by land elevation) and farming efficiency. These techniques allow for more reliable estimation thanks to the close clustering of ethnic groups with respect to time change which suggests that over the studied period, the farming efficiency of farmers on a higher elevation still do not improve compared to the efficiency of farmers on a lower land. This implies that current attempts to support farming on high elevation lands of the Vietnamese government are not efficient among ethnic groups. The topography of the field is important as a major threat to the land-use efficiency of the ethnic minorities. Among African countries, one of our recent meta-analyses also confirms that areas in lower altitudes experience higher farming technical efficiency, and this effect holds true across three regions, namely West Sub-Saharan, East Sub-Saharan, and South Sub-Saharan. Moreover, *de facto*, low production of farmland might cause farmers to abandon their land. Policymakers, therefore, should focus on ethnic farmers remaining on their fields or selling the farm on their own in the context of farmland distribution.

Farmland is a valuable resource of ethnic people in Vietnam mountainous areas. In the long run, aligning farmers' responsibility with their farms plays an important role in enhancing their farming efficiency. Our results indicate that purchasing or hiring more lands incentivized the ethnic farmers to increase their crop farming efficiency because their responsibility is now attached to their land (their fundamental source of income is agricultural production). Land tenure is important, but land tenure security is even more substantial. Purchasing land requires a large amount of money; meanwhile, hiring land requires less money. However, hiring land implicitly bears various risks such as unavailability of good land soil quality, difficulty in the contract process, or registered purpose of land use (Michler and Shively 2015; Ngango and Hong 2021; Zhou et al. 2019; Ma et al. 2017). We can easily transfer land ownership, but the land use purpose can not be easily transposed due to government regulation. Thereby, land tenure transfer and using purpose are necessarily facilitated to encourage farmers to accumulate farming land toward enhancing farming efficiency.

Besides important contributions, this study shows several limitations. First, the spatial scopes and data of the study impair its countrywide application. For example, biases introduced by cultivation customs or local cultures could affect the results. Second, other factors related to household capitals that might influence changes in land-use efficiency are not included. This is due to the lack of secondary data in the datasets. Also, since this study only addresses food crops, other products from agriculture are not included. Third, land fragmentation is not fully and empirically considered, which opens room for other studies.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Table A. Summary of data.

Variables	2010	2012	2014	2016	2018
Output (kg)	5402.601	4500.214	4328.673	4345.670	4430.929
	(5868.762)	(6589.148)	(7240.397)	(7723.963)	(7460.586)
Land (m2)	9918.222	6732.893	3674.981	4204.299	6445.112
	(8132.125)	(7145.697)	(6018.053)	(7143.076)	(7914.579)
Labour (hours)	87.215	70.215	70.542	66.764	67.510
	(28.504)	(28.504)	(29.056)	(23.935)	(27.000)
Fertilizer ('00 kg)	3.842	3.645	3.486	3.346	3.398
	(1.791)	(1.710)	(1.636)	(1.647)	(1.742)
Pesticide ('00 kg)	1.657	1.456	1.208	1.307	1.208
	(1.345)	(1.446)	(1.654)	(1.355)	(1.535)
Seed ('0 kg)	2.063	1.472	1.272	1.029	0.962
	(1.572)	(1.299)	(1.148)	(0.985)	(0.985)
Extension	0.452	0.415	0.454	0.459	0.542
	(0.208)	(0.209)	(0.207)	(0.210)	(0.208)
Microcredit	0.249	0.193	0.150	0.251	0.286
	(0.433)	(0.395)	(0.358)	(0.434)	(0.452)
Cooperation	0.461	0.463	0.467	0.484	0.541
	(0.244)	(0.245)	(0.244)	(0.246)	(0.245)