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Scale and scope economies in small household rice farming in Vietnam

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Abstract

The Vietnamese agricultural sector has experienced a dramatic structural change based on increased specialization in rice cultivation. However, small-scale rice-farmers have continued to grow multiple crops, especially in less developed provinces. While the literature advocates crop diversification for reasons of both economic and ecological sustainability, there lacks empirical evidence as to whether crop diversification brings efficiency and productivity gains to small farms. The present study is the first applications of the input-oriented stochastic distance function approach in estimating scale and scope economies using data of multi-crop farming households in Vietnam. We find strong evidence of product-specific economies of scale. Scope economies are also present for rice, vegetable, and other annual crop production. This suggests that crop diversification enhances efficiency and productivity. However, there still exists significant technical inefficiency in crop production, indicating opportunities to expand farm output at the existing level of inputs and technologies. More specifically, our empirical results indicate that it is desirable to expand vegetable and other annual crop production in mountainous areas while rice cultivation can be further expanded in delta and coastal regions.

Keywords: input distance function, stochastic frontier, economies of scope, economies of scale, product-specific

1. Introduction

Scale and scope economies are important economic concepts that both help a decision making unit — whether it is a farm or a firm — to reduce cost. While the concept of scale economies refers to a larger production volume to drive down unit cost, the concept of scope economies means to engage in a wider range of business activities to reuse resources. In the agricultural sector, these two concepts deserve particular attention as they relate to the scale of crop specialization and the degree of crop diversification. In the developing world, crop diversification has been considered an important strategy for the sustainable growth and development of the agriculture sector (Rahman 2009; Lin 2011; Nguyen *et al.* 2019; Birthal *et al.* 2020; Li *et al.* 2020), and the decision on farms' production structure in terms of the scale of production depends on many interrelated

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factors (Mishra *et al.* 2004; O'Donnell 2016; Huang *et al.* 2017; Rahman and Anik 2020). With respect to small farms, empirical literature reports many benefits of crop diversification. For small landholders diversification away from rice specialization into high-value vegetables has been found to improve their income in China (van den Berg *et al.* 2007), reduce income uncertainties in Sudan (Guvele 2001), improve the nutritional status and enhance the food security situation in many other developing countries (FAO 2012). In the context of changing climate, crop diversification has been identified as an adaptive management tool to enhance resilience in agricultural systems (Sarker *et al.* 2020), to reduce the impacts of drought and enhance water use efficiency in agricultural production (Kar *et al.* 2004), and to suppress pest outbreaks and dampens pathogen transmission (Lin 2011). It is noted that these benefits can only be realized if farmers diversify crop cultivation and remain diversified for a sufficiently long period of time.

The literature has also shown that large landholders have a belief that intensively managed monocultures are more productive than diversified agricultural systems (Lin 2011). Such a belief appears to have led to widespread specialization in rice production in Asia. Policy interventions are also a driving factor given their effect on the bottom line of farming operations. Rice specialization has been promoted through several governmental policy interventions such as land use policies and the provision of subsidies in several Asian countries, including China, South Korea and Thailand (Kim *et al.* 2012; Nguyen *et al.* 2012; Barker *et al.* 2014). In addition, Kim *et al.* (2012) argue that the properties of production technologies and resulting benefits of specialization play an important role in explaining the puzzle of rice specialization and hence the low level of crop diversification of small farms in Asia. In other words, the literature has shown that smaller farms tend to be more diversified while larger farms tend to be more specialized. But this pattern is not observed in some Asian developing countries where rice farming is concerned (Gardner 2009; Barker *et al.* 2014), and the reasons for this have not been well researched.

Vietnam is a good example for examining these issues, namely the scope and scale economies, in small household farming. It is one of the fastest growing economies in the world with clear evidence of economic structural transformation, also in the agricultural sector (Appendix A). The annual gross domestic product (GDP) growth was about 7% during the 2004–2014 period (Do *et al.* 2019), and non-agricultural sectors currently contribute more than 80% to the national GDP (Nguyen *et al.* 2019). This has facilitated the operation of cropland markets and created the opportunities for land users to expand their farms aiming at a higher level of farm productive efficiency and agricultural productivity (Nguyen *et al.* 2021). However, the Vietnam's agricultural sector is still charactetised by a high number of small farms with rice being the most dominant crop. Indeed, Vietnam is known to be one of the largest rice-producing countries and one of the greatest rice exporters (Appendix B). Until recently, rice self-sufficiency remained the key element of Vietnam's food security policy (Nguyen 2017). Historical policies relating to land use, price support and other subsidies have encouraged farmers to continue to concentrate on rice production in Vietnam (Barton 2015; Duong and Thanh 2019). In 2011, nearly 8.9 million farm households cultivated 8.9 million ha of cropland, making the average farm size in Vietnam to be among the smallest in the world (Huy and Nguyen 2019). Recent statistics show that nearly 3.8 million ha of cropland are restricted to rice cultivation for reasons of food security. These relate to the perceived need for self-sufficiency in rice production and rice price stabilization purposes under the existing government's Resolution on National Food Security (GOV 2009). Vietnam's government also introduced price support measures to stabilize rice prices (Huy and Nguyen 2019).

It is argued that the intensive and repeated production of rice has had an increasingly negative impact on the quality of farmland posing a threat to the country's agricultural sustainability (McPherson 2012; Barton 2015). More importantly, rice specialization while successful in major agricultural producing regions (Mekong River Delta and Red River Delta) has not delivered the same benefits to small farms located in less developed areas of Vietnam.[1] Earlier literature has reported that small farmers in Vietnam diversified their crops to improve their livelihoods notwithstanding the policies favouring rice production had remained in place (Minot *et al.* 2006; Tran and Vu 2020) and crop diversification was as an effective way to tackle the economic, social and environmental issues attached to rice specialization (Marsh *et al.* 2006; Dawe 2010). Even though farmers also grow many other crops such as maize, sweet potato, cassava, sugarcane, soybean, and vegetables to fulfill the family food

[1] Note that rice is very productive on lowland and this higher land productivity provides an incentive for farmers to plant rice extensively on irrigated land. However, these productivity advantages do not apply to upland. In sum, diversification strategies also depend on agro-climatic conditions. In the analytical framework of Kim *et al*. (2012), these issues can be captured in the productivity factor rather than policy or market factors.

requirement as well as for sale, recent reports indicated a relatively slow process of crop diversification (World Bank and MPIV 2016; Nguyen *et al.* 2017).

Given this background, our study aims to examine the economics of crop specialization and diversification in Vietnam by investigating scale and scope economies in small household farming. We contribute to the literature in several aspects. First, this is the first empirical application measuring crop-specific and global estimates of scale and scope economies of small farms, which are supposed to be at a high level of subsistence farming. This allows us to provide direct estimates of not only the degree to which farming households could benefit economically from increasing the scale of specialization in specific crops, but also from diversifying away from specialization to multiple crops. To our understanding, previous literature only examined global scale economies of agricultural production but not the scale economies of cultivation in each crop (i.e., crop-specific scale economies) (Nguyen 2017; Takeshima *et al.* 2020). Second, to avoid reliance on information on the prices of farm inputs, which is difficult to obtain precisely in a developing country context, we employ the stochastic input distance function approach. Our findings are expected to improve an understanding of the factors that explain farms' specialization in rice production and provide insights into how to motivate small farms to increase the level of their diversification and to do so in a sustained way as well as to provide land use policy-makers useful information on where to facilitate crop diversification or specialization.

The remaining of the article is organized as follows. Section 2 describes the data and methods used for the study. Section 3 presents and discusses the empirical results. Section 4 summarizes the findings and policy implications.

2. Data and methods

2.1. Data

Data for this study are taken from a large-scale survey under the research project "Thailand Vietnam Socio-Economic Panel — TVSEP (DFG FOR 756)".[2] The project aims to advance the concept and the methodology of measuring vulnerability to poverty in the economic and political context of emerging economies.[3] In Vietnam, the above survey was conducted in three provinces, namely Dak Lak, Thua Thien Hue, and Ha Tinh. Since Dak Lak is the traditional coffee growing area in Vietnam due to its basaltic soil which is appropriate for coffee plantations. Farmers in this province are specializing in coffee production (monoculture) (Ho *et al.* 2018). Thus, this province is excluded in our study.

Thua Thien Hue and Ha Tinh are two neighboring provinces in the Central North of Vietnam and are common in regard to (i) a relatively low average per capita income, (ii) a relatively high share of the agricultural sector in the regional GDP, and (iii) poor infrastructure, especially for irrigation and transportation. In addition, due to topography and climatic conditions, crop production in these two provinces is diverse.

The survey questionnaire collects information on 502 variables in 10 sections representing the livelihoods of the surveyed households. Section four covers all farming activities and includes information on cropland size, the cultivated crops (e.g., rice, maize, peanut, soybean, cassava, and various types of vegetables) planted during the last 12 months, on which land parcels, the inputs used (e.g., seeds and seedlings, labor, fertilizer, herbicide and insecticide), as well as output quantity and output prices. The household questionnaire was administered to the household head. In case the household head was not available, his or her spouse was interviewed.[4]

The three-stage procedure for data collection follows the method described by Nguyen *et al.* (2017). The first stage involves the selection of sampled districts in each province. The selected districts are representative of the province in terms of the livelihood platforms, activities and outcomes. The second stage involves the selection of sampled villages within the selected districts with a probability proportional to the size of the population. At the third stage, a fixed-size sample of ten farm households in each sampled village is randomly chosen from a list of households with equal probability of selection.

We use the household survey data collected in 2013, which includes information on all farming activities during the last 12 month period. The total sample size for these two provinces are about 1 200 households. Households in urban districts/villages and rural households that are landless, or where information on land or other key variables is missing, are excluded from the sample. Therefore, the final sample for our analyses includes 532 households in Ha Tinh and 393 households in Hue. Thus, our total sample for the analysis is 925 rural

[2] See https://www.tvsep.de/overview-tvsep.html
[3] For more information about the project, see Klasen and Waibel (2015).
[4] Both questionnaires are available and can be downloaded from the above webpage of the project.

farm-households. As the study site includes different districts in coastal, mountainous, and delta regions, we include regional dummies to account for this regional heterogeneity. The number of farms from coastal districts, mountainous districts, and delta districts is 288, 231, and 406, respectively.

Table 1 presents the summary of the key demographic characteristics of the surveyed households. The average household size is about five persons of which about 18% are children and 16% are old members. 82% of surveyed households are male-headed and the average education level of households are 8 years. About 15% of surveyed households belong to ethnic minority groups.[5]

Table 2 summarizes farm inputs and outputs of surveyed households in 2013. The outputs include rice (kg), vegetables (kg), and other annual crops (PPP USD). The inputs include cultivated land (ha), labour (day's labour), fertilizer (kg), and other cost (PPP USD). The average farm size is 0.41 ha. On average a sampled farming household employed 118 days of labour and 1 684 kg of fertilizers and produced 1 897 kg of rice, 457 kg of vegetables and other annual crops valued at 57 (PPP USD 2005) in the surveyed year.

2.2. Method

The two commonly employed approaches in studying scale and scope economies are cost functions and dual measure using distance functions (Ang *et al.* 2018). There exists ample empirical literature that utilizes cost functions in estimating scale and scope economies. Panzar and Willig (1981) and Baumol *et al.* (1982) use economies of scope to capture diversification benefits in a situation where an integrated system costs less in producing given outputs than a more specialized system. Fernandez-Cornejo *et al.* (1992) estimate the scope and scale economies of agricultural farms in Germany. They reveal that cost complementarities exist between multiple products. Schroeder (1992) estimates economies of scale and scope for agricultural supply and marketing cooperatives in the USA. He finds a strong potential for firm-wide economies of scale and product-specific economies of scale and scope. Recently, Chavas and Kim (2010) provide a generalization of different components of the benefits of diversification for a multi-product firm. In this framework, economies of diversification are captured by the cost reduction associated with producing outputs in an integrated firm when compared to firms either under complete or partial specialization. Economies of diversification are decomposed into four additive components reflecting the effects of complementarity among outputs, economies of scale, convexity, and the role of fixed cost. Kim *et al.* (2012) employ this framework in the context of rice farming in Korea. Their results

Table 1 Demographic characteristics of surveyed households

Variable	No. of observations	Mean	St. dev.	Min.	Max.
Household size (no. of persons)	925	4.86	1.64	1.00	11.00
Share of literate members (%)	925	86.26	20.29	0.00	100.00
Share of children (%) (≤16 years old)	925	17.89	21.01	0.00	80.00
Share of old members (≥60 years old)	925	15.55	29.20	0.00	100.00
Age of household heads (year)	925	54.03	13.09	20.00	91.00
Share of male-headed households (%)	925	81.51	38.84	0.00	100.00
Education of household heads (no. of school years)	925	8.87	4.76	1.00	20.00
Share of ethnic minority households (%)	925	15.14	35.86	0.00	100.00

Table 2 Descriptive statistics of input and output variables

Variable	Description	No. of observations	Mean	St. dev.	Min.	Max.
y_1	Rice (kg)	925	1 897.21	2 024.64	0.00	18 000.00
y_2	Vegetables (kg)	925	457.07	1 254.07	0.00	12 802.00
y_3	Other annual crops (PPP USD)	925	56.99	135.51	0.00	1 021.80
X_1	Land (ha)	925	0.41	0.44	0.04	5.20
X_2	Labour (day's labour)	925	118.35	112.51	7.00	733.00
X_3	Fertilizer (kg)	925	1 683.89	1 983.12	4.00	12 300.00
X_4	Other cost (PPP USD)	925	335.82	338.36	1.50	2 769.65

[5] Vietnam has 54 officially recognized ethnic groups of which the Kinh (or Vietnamese) is considered the majority with about 85% of the populations. Other groups are ethnic minorities.

show the positive and statistically significant effects of output complementarity. The complementarity effects are also stronger among non-rice activities and weaker on rice farms. Interestingly, their results show that non-decreasing marginal productivities is the main factor that helps explain why the Korean farming systems tend to be highly specialized in rice.

However, the cost function approach requires data on input prices, which is difficult to obtain in subsistence farming in developing countries. To avoid reliance on the prices of inputs as in the case of using cost functions, there exists an alternative approach which uses input distance functions given the duality condition of production and cost functions. Hajargasht *et al.* (2008) propose cost complementarity as a sufficient condition for scope economies. This approach requires to estimate a multi-output input distance function using econometric methods and then exploit the duality between the cost function and the input distance function to derive a measure of cost complementarities in terms of the derivatives of the input distance function. Cost complementarities are considered as sufficient conditions for scope economies, especially in the context of competitive markets. Among published empirical studies, most focus on the farm level in various contexts including mixed farming in Australia (Villano *et al.* 2010), mixed farming in Norway (Fleming and Lien 2009), dairy farming in Germany (Wimmer and Sauer 2020), mixed food and coffee farming in Papua New Guinea (Coelli and Fleming 2004), or cocoa farming in Ghana (Ofori-Bah and Asafu-Adjaye 2011). In Vietnam, Nguyen (2017) investigates the economies of crop diversification for rice farms in rural areas using data from the Vietnam Household Living Standard Survey 2006. The author estimates the input distance function and measure the effects of output complementarity. The results indicate output complementarity exists between rice and each of the other crops such as vegetables, starchy and annual industrial crops. This work captures the global scale economies of agricultural production but not the scale economies of cultivation in each crop (i.e, crop-specific scale economies). In other words, this study does not provide direct estimates on the degree to which farming households could benefit economically from increasing the scale of specialization in specific crops and from diversifying away from specialization to multiple crops.

Recently, Nemoto and Furimatsu (2014) and Färe and Karagiannis (2018) further extend the work of Hajargasht *et al.* (2008). Färe and Karagiannis (2018) propose that the cost sub-additivity should be a necessary and sufficient condition for scope economies. Sub-addibility means that the technical efficiencies of the production in which multiple outputs jointly produced are less than or equal to the sum of the weighted technical efficiencies of producing them separately. The complementarity condition is reversed to the sub-addibility. Note that sub-additional may exist in natural monopoly contexts but does not necessarily hold in the context of competitive firms (Baumol 1977). However, empirical applications are still very limited (Wimmer and Sauer 2020). In addition, Färe and Karagiannis (2018) only focus on scope economies. Nemoto and Furimatsu (2014) provide a more direct measure of scale and scope economies. These authors recover the cost function value at a relevant point from the input distance function, which allows an evaluation of the costs of both joint and separate production using a Box-Cox transformation. Due to this flexibility, we follow the method of Nemoto and Furimatsu (2014) to test scale and scope economies.

The input distance function $D^I(x, y)$ is defined on the input requirement set $L(y)$ as:

$$D^I(x, y)=\max_{\delta}\left\{\delta \left| \frac{x}{\delta} \epsilon L(y)\right.\right\} \quad (1)$$

where $L(y)$ is the set of all input vector, x, which can produce the output vector, y.

$D^I(x, y)=1$ if and only if (x, y) is technically efficient. Due to the unobserved value of the distance function, the imposition of a functional form for $D^I(x, y)$ cannot be directly estimated but the linear homogeneity property of the input distance function can be exploited to solve the problem (Färe *et al.* 1993).

Assuming that x is an $m\times1$ input vector and y an $n\times1$ output vector, we approximate eq. (1) by a second-order polynomial of logarithmic inputs and Box-Cox transformed outputs[6] as:

$$\begin{aligned} D^I(x, y)=&a_0+\sum_{i=1}^{m}a_i\ln x_i+\frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}a_{ij}\ln x_i \ln x_j \\ &+\sum_{r=1}^{n}b_r\phi_Y(y_r)+\frac{1}{2}\sum_{r=1}^{n}\sum_{s=1}^{n}b_{rs}\phi_Y(y_r)\phi_Y(y_s) \\ &+\sum_{i=1}^{m}\sum_{s=1}^{n}c_{is}\ln x_i\phi_Y(y_s) \end{aligned} \quad (2)$$

where $a_{ij}=a_{ji}$ for i, j=1, 2, …, m and $b_{rs}=b_{sr}$ for r, s=1, 2, …, n. $D^I(x, y)$ measures the distance from (x, y) to the production function and represents the unobservable value of the distance function. The parameters in eq. (2) must satisfy the following regulatory restrictions:

$$\begin{aligned} &\sum_{i=1}^{m}a_i=1,\ \sum_{j=1}^{m}a_{ij}=0,\ i=1, 2, \ldots, m \\ &\sum_{r=1}^{n}c_{ir}=0,\ i=1, 2, \ldots, m \end{aligned} \quad (3)$$

The parameters of the input distance function can be used to measure technical efficiency.

[6] See Nemoto and Furumatsu (2014) for details on the Box–Cox transformation.

Another regulatory condition is concavity in inputs. These restrictions are globally imposed using the Cholesky factorization of Hessian matrix, as follows:

$$a_{ij}=\sum_{k=1}^{\min(i,j)}\delta_i^2\lambda_{ik}\lambda_{jk} \text{ for } i, j=1, 2, \ldots, m \quad (4)$$

where $\lambda_{ij}=\lambda_{ji}$, for i, j=1, 2, …, m and λ_{ij}=1 for i=1, 2, …, m. Then, λ_{ij} and δ_i are used to reparametrize the coefficients in eq. (2). As outputs and inputs are mean-corrected, the monotonicity conditions in outputs and inputs are locally imposed.

Following Battese and Coelli (1988) the technical efficiency for observation g is:

$$E\{\exp(-u_g)|\epsilon_g\}=\left[\frac{\Phi\left(\frac{\epsilon_g}{\sigma_v}-\sigma_*\right)}{\Phi\frac{\epsilon_g}{\sigma_v}}\right]\exp\left(\sigma_*^2-\frac{\epsilon_g}{\sigma_v}\right) \quad (5)$$

where, $\epsilon_g=\ln D^I(x^g, y^g)$ and $\sigma_*=\sigma_v\sigma_u/\sqrt{\sigma_v^2+\sigma_u^2}$.

The degree of ray scale economies (R_{SCALE}) is defined as:

$$R_{SCALE}=-\frac{1}{\sum_{r=1}^{n}\frac{\partial\ln D^I(x, y)}{\partial\ln y_r}} \quad (6)$$

where $R_{SCALE}\geq1$ represents the existence of scale economies and $R_{SCALE}<1$ represents diseconomies of scale. R_{SCALE} refers to proportionate change in the frontier output induced by a proportionate change in all inputs. For a production technology, ray scale (dis) economies exist when a percentage of inputs increases, causing a (smaller) greater percentage increase in outputs in one place.

The product-specific economies of scale (P^r_{SCALE}) refer to benefits that arise from the reduction of average production cost due to the expansion in production of a specific output. Product-specific scale economies exist if the production expansion of a particular output causes reduction in average cost. The degree of the product-specific scale economies is defined as:

$$P^r_{SCALE}=-\left(1-\frac{1}{D^I\left(x, y_{n-r}\right)}\right)\left(\frac{\partial\ln D^I(x, y)}{\partial\ln y_r}\right)^{-1} \quad (7)$$

where $P^r_{SCALE}>1$ indicates product-specific scale economies and $P^r_{SCALE}<1$ represents diseconomies. The degree of the product-specific economies of scale here is measured by a ratio of the average increment cost to the marginal cost. The average increment cost for a specific product (y_r) is the additional unit cost resulting from the increasing production of the pth output from zero to y_r, while the amount of all other outputs is kept constant (Nemoto and Furumatsu 2014).

The global economies of scope (G_{SCOPE}) refer to the benefits of joint production over specialized or separate production. Global scope (dis)economies exist if joint production of multiple outputs incurs (more) less cost than production of individual output. Global economies of scope also explain economies of diversification of individual farms or firms. The degree of the global scope economies (G_{SCOPE}) is defined as:

$$G_{SCOPE}=\sum_{r=1}^{n}\frac{1}{D^I\left(x, y_r\right)}-\frac{1}{D^I(x, y)} \quad (8)$$

where $G_{SCOPE}>0$ represents the existence of global scope economies and $G_{SCOPE}<0$ indicates diseconomies.

The product-specific scope economies (P^r_{SCOPE}) refer to the benefits that arise from the reduction of production cost due to the joint production of a specific product with other products (Nemoto and Furumatsu 2014). Product-specific scope economies exist if the joint production of a particular output with other outputs causes a reduction in cost. The degree of product-specific scope economies (P^r_{SCALE}) for the rth output is defined as:

$$P^r_{SCOPE}=\frac{1}{D^I\left(x, y_r\right)}+\frac{1}{D^I\left(x, y_{(n-r)}\right)}-\frac{1}{D^I(x, y)} \quad (9)$$

where, $P^r_{SCOPE}>0$ indicates the existence of product-specific scope economies and $P^r_{SCOPE}<0$ represents diseconomies.

3. Results and discussion

3.1. Estimated stochastic input distance function and efficiency scores

The maximum likelihood estimation (MLE) results of the stochastic input distance function model are presented in Table 3. The parameter γ reveals the existence of inefficiency. Most of the estimated coefficients are significantly different from zero at least at the 10% level. Table 3 shows that the coefficients associated with outputs and inputs are as expected. Of the three outputs, including rice, vegetables and other crops, the estimated coefficients also indicate that rice is the dominant crop, and the second primary crop is vegetables. The estimated inverse elasticity of output is 0.61 meaning that an increase of one percent in outputs could only require a 0.61 percent increase in inputs and *vice versa*. Of the 0.61 percent increase in inputs, 0.47 is for achieving one percent increase in the rice output, 0.1 and 0.04 percent are for gaining one percent increase in the vegetables and the other annual crops, respectively. This satisfies the regular properties of the input distance function.[7]

[7] The input distance function is non-increasing, quasi-convex in outputs and homogeneous of degree one in inputs (O'Donnell and Coelli 2005).

The majority of the estimated coefficients of interaction terms are statistically significant. This infers that there is evidence of nonlinear relationships between inputs and outputs among these production factors.

Fig. 1 presents the distribution of estimated technical efficiency. Almost one third of the technical efficiency ranges from 0.8 to 0.9. The average technical efficiency is 0.77, implying that about 23% of the total cost of production can be minimized by improvement in managerial efforts. Our estimated efficiency score is in line with that of Nguyen *et al.* (2021) but smaller than the one reported by Huy and Nguyen (2019). However, Huy and Nguyen (2019) use the data for the entire Vietnam while our sample is limited to poorer provinces of Ha Tinh and Thua Thien Hue. Our efficiency score estimate is in the range of 0.73–0.80 reported by Chen *et al.* (2009) for farm households in four regions of China and is higher than that for Bangladesh farmers reported by Rahman (2009) and Rahman and Anik (2020). The technical efficiency distribution shows that farmers in the coastal districts are performing better than the farmers in delta and mountainous districts (Fig. 2). Furthermore, farming households that produce crops in irrigated land are performing better than those using rain fed land (Fig. 3).

3.2. Estimated economies of scale

Table 4 presents the calculated results of the scale economies by outputs and districts. The first column shows the measurements of ray scale. The results indicate that all the farms exhibit ray scale economies implying increasing returns to scale. This suggests that farming households in all the districts are likely to benefit from significant economies of scale (Coelli and Fleming 2004; Rahman 2009). Both increasing returns to scale (Lu *et al.* 2018) and decreasing returns to scale (Khanal *et al.* 2018) have been reported in previous studies on small-scale farmers. The second, third and fourth columns present the product-specific scale economies for rice, vegetable and other annual crops respectively. The farming households operating at a larger scale exhibit a higher degree of all the three product specific scale

Table 3 Parameter estimates of the stochastic input distance function

Transformation	Estimate	Std. error	*z*-value	Pr(>|*z*|)	Significance level
(Intercept)	0.3726	0.0421	8.8433	0.0000	***
TransxCb1	–0.4722	0.0251	–18.8361	0.0000	***
TransxCb2	–0.1000	0.0144	–6.9381	0.0000	***
TransxCb3	–0.0434	0.0143	–3.0423	0.0023	**
TransxCa2	0.3021	0.0339	8.9108	0.0000	***
TransxCa3	0.0454	0.0263	1.7255	0.0844	.
TransxCa4	0.3525	0.0391	9.0193	0.0000	***
TransxCb11	–0.0495	0.0035	–14.0108	0.0000	***
TransxCb12	0.0015	0.0006	2.4241	0.0153	*
TransxCb13	0.0040	0.0032	1.2325	0.2178	
TransxCt12	–0.0060	0.0086	–0.6997	0.4841	
TransxCt13	–0.0216	0.0073	–2.9455	0.0032	**
TransxCt14	–0.0002	0.0094	–0.0253	0.9798	
TransxCb22	–0.0027	0.0004	–6.4584	0.0000	***
TransxCb23	0.0004	0.0004	1.1344	0.2566	
TransxCt22	0.0035	0.0011	3.2699	0.0011	**
TransxCt23	–0.0011	0.0008	–1.3316	0.1830	
TransxCt24	–0.0010	0.0013	–0.8110	0.4174	
TransxCb33	–0.0081	0.0037	–2.2239	0.0262	*
TransxCt32	–0.0055	0.0067	–0.8269	0.4083	
TransxCt33	0.0168	0.0051	3.3079	0.0009	***
TransxCt34	0.0048	0.0079	0.6048	0.5453	
TransxCa22c	–0.0049	0.0067	–0.7369	0.4612	
TransxCa23c	–0.0001	0.0087	–0.0115	0.9908	
TransxCa24c	–0.0286	0.0119	–2.4115	0.0159	*
TransxCa33c	–0.0098	0.0055	–1.7702	0.0767	.
TransxCa34c	0.0227	0.0097	2.3344	0.0196	*
TransxCa44c	–0.0382	0.0081	–4.7096	0.0000	***
σ^2	0.7061	0.1284	5.5004	0.0000	***
γ	0.8440	0.0356	23.7297	0.0000	***
μ[1)]	–1.5440	0.4627	–3.3370	0.0008	***

[1)] μ is the mean of the inefficiency term, u, that follows a truncated normal distribution.
***, ** and * refers to the level of significance at 0.01, 0.05 and 0.1, respectively.

economies. This implies the possibility of expanding individual crop scale to improve the efficiency of production.

Fig. 4 shows the level of product specific scale economies for different regions. It indicates that most farming households are operating at scale economies. However, for a few households in all regions where the product specific scale economies scores are smaller than one scale, diseconomies are found to exist. It is found that farming households in delta districts exhibit a higher degree of scale economies in rice production which is also illustrated in Fig. 4-A. However, in the case of vegetable and other annual crop production, farming households in mountainous districts have a higher degree of scale economies compared to households in coastal and delta districts (also illustrated in Fig. 4-B).

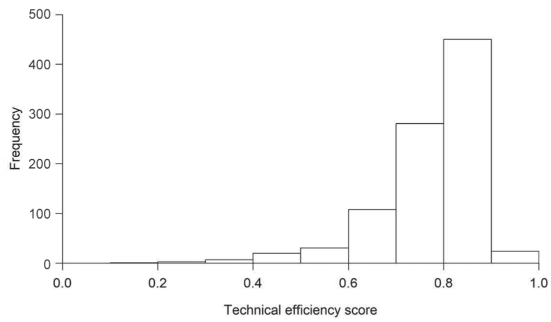

Fig. 1 Distribution of estimated technical efficiency scores.

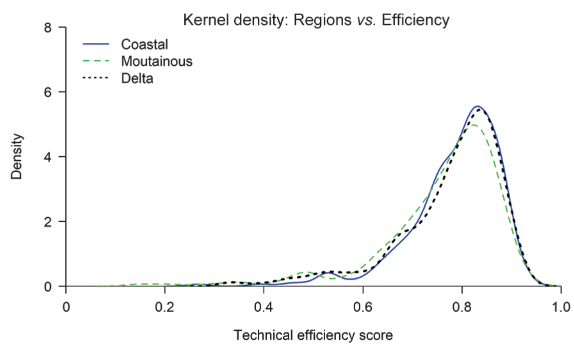

Fig. 2 Technical efficiency scores by regions.

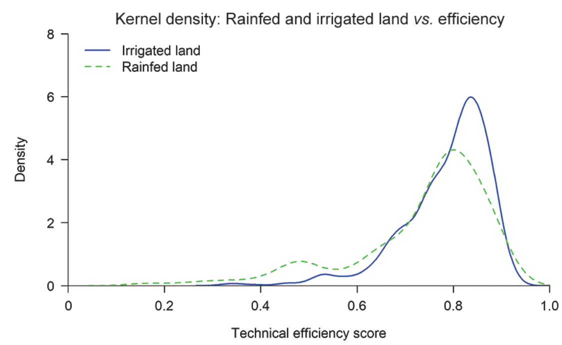

Fig. 3 Technical efficiency scores by irrigation status.

Table 4 Degree of scale economies

By region/crop	Ray scale economies (Rscale)		Product-specific scale economies: Rice production		Vegetable production		Other annual crop production	
	Rscale	No.[1)]	Rscale	No.[1)]	Rscale	No.[1)]	Rscale	No.[1)]
Region								
Coastal	1.63	0	1.46	31	3.04	27	5.83	15
Mountainous	1.62	0	1.22	67	3.97	13	6.83	13
Delta	1.63	0	1.50	36	3.17	33	5.82	20
All crops value								
Lower quantile	1.63	0	1.12	92	2.70	60	5.00	44
Median	1.63	0	1.51	22	3.37	8	6.25	1
Upper quantile	1.63	0	1.61	20	3.89	5	6.94	3
Rice quantity (y_1)								
Lower quantile	1.63	0	1.05	134				
Median	1.63	0	1.56	0				
Upper quantile	1.64	0	1.76	0				
Vegetable quantity (y_2)								
Lower quantile	1.63	0			2.60	72		
Median	1.62	0			4.46	0		
Upper quantile	1.63	0			5.16	1		
Other annual crops value (y_3)								
Lower quantile	1.63	0					5.44	47
Median	1.62	0					7.22	0
Upper quantile	1.62	0					9.34	1

[1)] No., number of farms exhibit diseconomies of scale (i.e., the score is smaller than one).
t-test indicates that the mean is statistically different from one at the confidence limit of 99%.

3.3. Estimated economies of scope

Table 5 presents both the global and product-specific degrees of scope economies with the first column showing the measurement of global scope economies while Fig. 5 plots the distributions across three types of crops. Most of the farming households exhibit positive economies of scope with only 31 out of 925 households operating with diseconomies of scope. This implies the presence of a complementarity effect derived from joint production and which is not present where there is specialization. These findings are consistent with that of Nguyen (2017) who

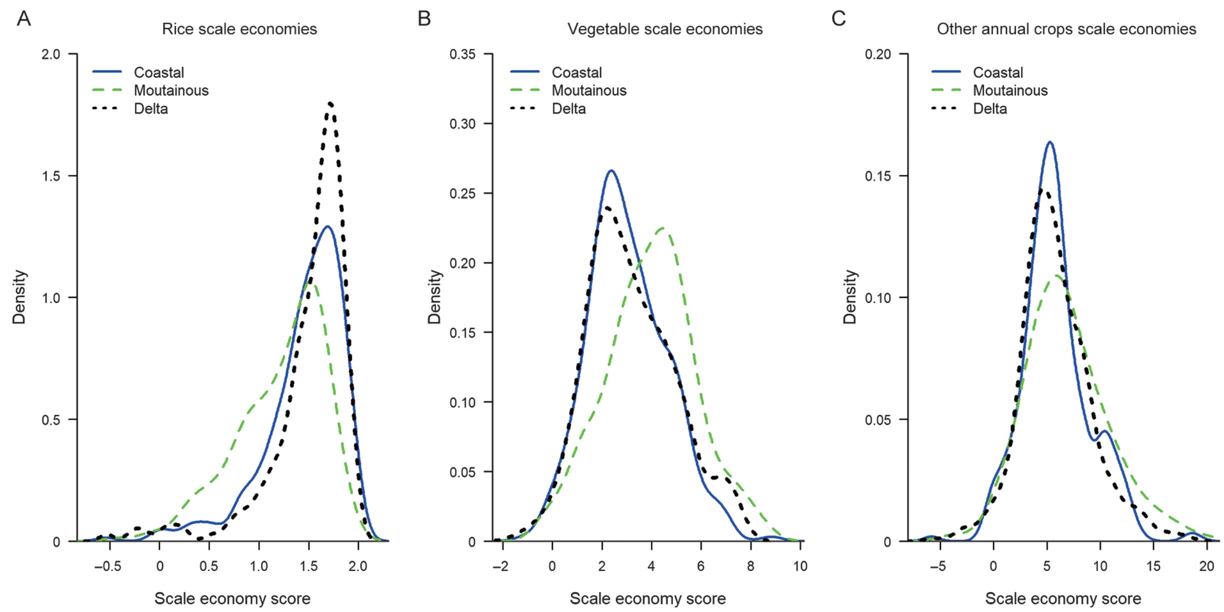

Fig. 4 Product-specific scale economies distribution.

Table 5 Degree of scope economies

By region/crop	Global scope economies (Gscope)		Product-specific cope economies[1)]					
			Rice production		Vegetable production		Other annual crop production	
	Gscope	No.[1)]	Gscope	No.[1)]	Gscope	No.[1)]	Gscope	No.[1)]
Region								
Coastal	0.39	9	0.18	36	0.19	21	0.20	15
Mountainous	0.48	4	0.24	19	0.24	17	0.24	2
Delta	0.37	18	0.17	53	0.18	39	0.20	10
All crops value								
Lower quantile	0.68	0	0.35	0	0.35	0	0.34	0
Median	0.33	2	0.15	17	0.16	13	0.17	3
Upper quantile	0.21	29	0.08	91	0.09	64	0.12	24
Rice quantity (y_1)								
Lower quantile	0.65	0	0.33	1				
Median	0.31	2	0.13	24				
Upper quantile	0.18	29	0.06	83				
Vegetable quantity (y_2)								
Lower quantile	0.46	4			0.24	6		
Median	0.30	8			0.13	19		
Upper quantile	0.29	19			0.12	52		
Other annual crops value (y_3)								
Lower quantile	0.44	20					0.23	1
Median	0.34	0					0.17	4
Lower quantile	0.25	11					0.10	22

[1)] No., number of farms exhibit diseconomies of scope (i.e., the score is smaller than zero).
t-test indicates that the mean is statistically different from zero at the confidence limit of 99%.

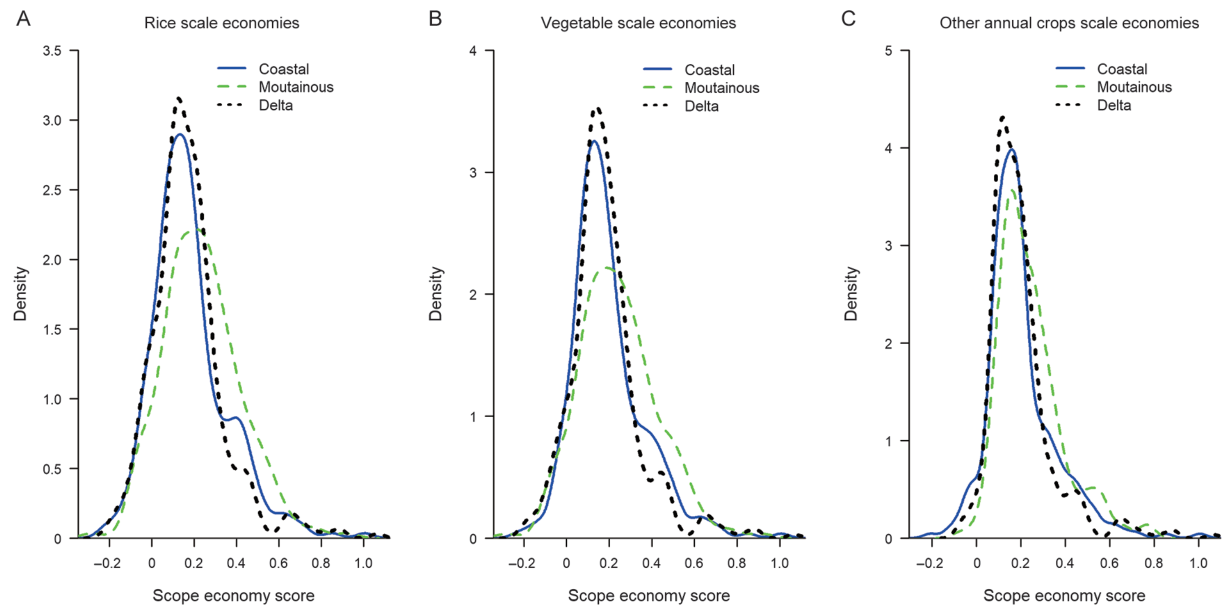

Fig. 5 Product-specific scope economies distribution.

finds output complementarity between rice as subsistence production and other crops or coffee and perennial crops in Vietnam (Ho *et al*. 2017). Overall, the results reveal an inverse relationship between scale of individual crops and the degree of economies of scope. For example, if farm size is fixed, the smaller scale of an individual crop may indicate a higher degree of crop diversification. This implies that crop diversification strategies are beneficial to the farmers.

The degree of scope economies is higher among farming households in mountainous districts followed by those in coastal and delta districts. This suggests that joint production is likely to reduce the cost of production more among the households in mountainous districts than in other districts. The second, third and fourth columns present the product-specific scope economies for rice, vegetable and other annual crops respectively. It is found that farming households in mountainous districts exhibit a higher degree of scope economies for all three types of crop production. These findings confirm that joint production tends to be more efficient than specialization. For instance, farming households have the opportunity to reduce the cost of production if they are involved in producing rice in addition to other vegetables or other annual crops rather than specializing solely in rice production.

Table 6 presents the comparative analysis of technical efficiency, scale economies and scope economies by ecological region and irrigation status. The regional comparison indicates that farming households in coastal and delta regions are more technically efficient in crop production than those in mountainous regions. Farming households in coastal and delta regions have higher degrees of scale economies in rice production than those from mountainous districts. These findings reveal that increasing the scale of rice production is likely to improve farming households' efficiency in coastal and delta regions. However, the results suggest that in mountainous districts, farmers are likely to better off if they increase the scale of vegetable and the other annual crop production.

The comparison between irrigated and rain fed farming indicates that the former is more technically efficient than those cultivating crops in rain fed conditions. In terms of scale effect, irrigated farms have a higher degree of rice and other annual crop scale economies than rain fed farms. However, rain fed farms have a higher level of vegetable scale economies than irrigated farms. These results indicate that rice and other annual crops are more water sensitive than vegetables. Regarding scope effects, joint production seems to reduce the cost of production, especially in the case of rain fed conditions.

4. Conclusion

This paper provides one of the first estimates of global and crop-specific scale and scope economies of crop production by small farming households in two typically less developed provinces in Vietnam. Due to the lack of price data, we employed the input distance function

Table 6 Technical efficiency, scale economies and scope economies by regions and irrigation status[1)]

Efficiency and economy	Coastal *vs.* delta		Coastal *vs.* mountainous		Delta *vs.* mountainous		Irrigated *vs.* rain fed	
	t-test	Wilcoxon test	*t*-test	Wilcoxon test	*t*-test	Wilcoxon test	*t*-test	Wilcoxon test
Technical efficiency	1.36	60254	2.68***	37231**	1.61	50918*	4.78***	58974***
	0.1733	0.4917	0.0077	0.0195	0.1076	0.0715	0.0000	0.0000
Ray scale economies	0.82	59636	5.53***	41902***	5.23***	58145***	1.33	77098
	0.4133	0.6526	0.0000	0.0000	0.0000	0.0000	0.1852	0.2913
Rice scale economies	–1.44	52587**	6.27***	44810***	7.86***	67924***	8.79***	106280***
	0.1501	0.0239	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Vegetable scale economies	–1.03	56695	–6.08***	22857***	–5.35***	34451***	–12.39***	33708***
	0.4968	0.4968	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other annual crop scale economies	0.05	58855	–3.06***	28336***	–3.23***	39851***	6.13***	87421***
	0.9619	0.8807	0.0023	0.0037	0.0013	0.0016	0.0000	0.0000
Global scope economies	0.65	59404	–3.26***	26608***	–4.10***	35958***	–3.87***	59964***
	0.5188	0.7181	0.0012	0.0012	0.0000	0.0000	0.0001	0.0001
Rice scope economies	0.53	58844	–3.59***	26258***	–4.37***	35841***	–3.96***	60010***
	0.5985	0.8841	0.0004	0.0000	0.0000	0.0000	0.0001	0.0001
Vegetable scope economies	0.92	59687	–3.04***	27222***	–4.07***	36707***	–3.25***	62449***
	0.3557	0.6385	0.0025	0.0004	0.0001	0.0000	0.0013	0.0010
Other annual crop scope economies	0.18	59300	–3.32***	26587***	–3.80***	35985***	–4.13***	58623***
	0.8584	0.7482	0.0010	0.0001	0.0002	0.0000	0.0000	0.0000

[1)] Each indicator presented in the first column has two rows: the value of the test statistic in the first row, and the corresponding *P*-value in the second row.
***, ** and * refer to the level of significance at 0.01, 0.05 and 0.1, respectively.

approach based on the duality between cost and input distance functions. The advantage of this method is that it allows the testing of scale and scope economies for overall production as well as for specific crops in the presence of technical inefficiency without requiring data on input prices.

The results reveal the existence of significant technical inefficiency in crop production. This implies there is considerable opportunity to enhance crop production at the existing level of inputs and technologies. Also farming households operating under irrigated conditions are shown to be more efficient than those growing crops in rain fed farms. This finding justifies the need of further expansion of irrigation facilities in less developed regions of Vietnam.

Ray scale economies exist for all surveyed farms indicating that farms throughout the included provinces are likely to benefit significantly from the economies of scale. Moreover, the presence of crop-specific scale economies for rice, vegetables, and other crops suggest that farming households cultivating specific crop types on a large scale potentially gain higher economic benefits. Specifically, our empirical results show that rice cultivation can be further expanded in delta and coastal regions, while it is more advantageous to expand the scale of vegetables and other annual crop cultivation in mountainous districts.

Another important empirical finding is the evidence of output complementarity between crop types. This suggests that farming household can enhance cost efficiency by crop diversification. The policy implication is that there should be a priority for promoting farming households to grow multiple crops. Specifically, the three-crop type integration strategies appear to be beneficial for farmers, especially those located in mountainous districts.

Our research can be extended in several ways. Further research in other regions and over several time periods is needed to enrich the empirical evidence for Vietnam. Furthermore, our estimates of the scale and scope economies of crop production are analyzed in the context of crop production only. Farming households could economically benefit from diversification beyond crop production — for instance joint production of crops and livestock. Many countries including Vietnam have been promoting agriculture based non-farm businesses, for example, eco-tourism, with the objective of enhancing rural development. In this context, farmers' involvement in agriculture-based non-farm activities could also be more productive rather than being confined to the production of crops. Future studies could pursue these new avenues of research.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Appendices associated with this paper are available on http://www.ChinaAgriSci.com/V2/En/appendix.htm

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