Economic Analysis and Policy 56 (2017) 114–125

Contents lists available at ScienceDirect

Economic Analysis and Policy

journal homepage: www.elsevier.com/locate/eap

Full length article

Which farming systems are efficient for Vietnamese coffee farmers?

Thong Quoc Ho [a,b,*], Viet-Ngu Hoang [a], Clevo Wilson [a], Trung-Thanh Nguyen [c]

[a] *School of Economics and Finance, Queensland University of Technology, Australia*
[b] *Department of Economics, Tay Nguyen University, Viet Nam*
[c] *Institute for Environmental Economics and World Trade, Leibniz University Hannover, Germany*

ARTICLE INFO

Article history:
Received 4 August 2017
Received in revised form 5 September 2017
Accepted 5 September 2017
Available online 8 September 2017

JEL classification:
Q1
O13

Keywords:
Vietnam's coffee production
Farming synchronization, segregation, diversification
Efficiency
Input distance function

ABSTRACT

This paper provides a comparative assessment of the productive efficiency of three common coffee growing systems in Vietnam: mono-cropping, synchronization and segregation. Results from an input distance function approach deliver several important findings. First, the average inefficiency level is estimated to be around 18% although inefficiency varies significantly between the three farming systems. Second, the synchronized system of growing coffee and the other industry crops is found to be the most efficient farming system. Third, coffee mono-cropping is less efficient than synchronized systems due to the presence of economies of scope between coffee and industrial crops. Fourth, the least efficient system is segregated cultivation of coffee and rice. Food insecurity is seen as a primary reason for coffee farmers diversifying into rice. These findings provide empirical evidence of agronomic benefits being derived from synchronized systems, and which are translated into higher productive efficiency. Policy options promoting synchronized farming systems may therefore enhance both economic and agronomic benefits.

© 2017 Economic Society of Australia, Queensland. Published by Elsevier B.V. All rights reserved.

1. Introduction

Coffee production is one of the primary economic sectors in the Central Highlands region of Vietnam with nearly 96% of Vietnam's export of coffee coming from this region. Due to significant price increases in the early 1990s, the area used for coffee cultivation increased by approximately 400% from 1999 to 2000. This expansion appears to be a natural adaptation of farmers in response to past increases in prices. However in subsequent periods the resulting increases in market supply caused prices to drop to a level which, by 2001, was lower than the production cost (Marsh, 2007). This forced many coffee farmers into bankruptcy (Wollni and Zeller, 2007) and is seen as one of the reasons motivating coffee farmers to diversify their business and for the presence of several distinct farming systems in Vietnam.

In this study, we consider three typical coffee growing systems in Vietnam: mono-cropping, synchronization and segregation. The nature of specialization and diversification vary significantly across these three distinct systems. Mono-cropping farms have only one land plot and grows only coffee. Segregated farming systems have more than one plot of land with each plot growing one primary type of crop. For example, where farms have two plots, one plot grows coffee and another plot grows rice. Synchronized farming systems grow coffee together with other industrial crops in one plot and rice in a separate plot(s). There is an obvious need to know which farming system are most efficient for coffee farmers in

* Correspondence to: Queensland University of Technology, Business School, School of Economics and Finance, W/S14, Z755, 02 George Street, QLD 4000, Brisbane, Australia.
E-mail address: quoc.ho@qut.edu.au (T.Q. Ho).

http://dx.doi.org/10.1016/j.eap.2017.09.002
0313-5926/© 2017 Economic Society of Australia, Queensland. Published by Elsevier B.V. All rights reserved.

Vietnam — an issue which the existing literature provides no empirical evidence. This literature gap is, therefore, the primary motivation of the present paper.

It is noted that diversified systems, particularly through crops diversification, may obtain higher yields and/or cause less environmental damage (Letourneau et al., 2011). This is known as complementary or synergy effects among crops sharing the same environment. However, there may be diseconomies of scope or negative effects of synergy as empirically observed in, for example, Coelli and Fleming (2004). Since appropriate crop diversification strategies can deliver positive effects of synthesis, it could be expected that coffee farmers would be motivated to diversify by growing industrial crops such as pepper or durian which may also mitigate market risk. However, it becomes less clear why coffee farmers have chosen the segregated system in which rice and coffee are grown in separate land plots given it does not deliver positive synthesis effects and could produce diseconomies of scope (Villano et al., 2010). More particularly, some studies have hypothesized that Vietnamese coffee farmers diversify to rice because of the insecurity created by low incomes and volatile market conditions (i.e., Dang, 2003). If this is true, segregated farms face a trade-off between productive efficiency and income or poverty risks. In this paper, we aim to provide empirical evidence on this trade-off hypothesis. Our empirical results are therefore designed to indicate the rationale for Vietnamese farmers' decisions over which crops to grow rather than accepting that they may be made on *ad hoc* or irrational basis (Dang and Shively, 2008). As such, this study can provide a useful guide for policy makers in raising the productivity of Vietnamese coffee farmers.

We utilize several techniques to examine differences in the level of productive efficiency among the three farming systems using a dataset of 167 farms surveyed in five Central Highlands communes in 2012. The input distance function is used to estimate efficiency scores for each farm. Parametric and non-parametric tests are then applied to assess if these differences are statistically different across the farming systems of the three districts. Additionally, the input distance function allows us to examine economies of diversification which is based on the concept of economies of scope in diversified farms (Baumol et al., 1982; Willig, 1979). While there are several approaches to measuring scope economies (Chavas and Di Falco, 2012; Chavas, 2008; Ofori-Bah and Asafu-Adjaye, 2011; Chavas and Kim, 2010; Hajargasht et al., 2006), we use Coelli and Fleming's (2004) model as it does not require price information and provides a more straightforward interpretation of both efficiency results and diversification economies of each pair of crops.

The remaining part of this paper is set out in eight sections. Section 2 provides a literature review. Section 3 provides a measure of economies of diversification using the distance function. Section 4 sets out the empirical models, data sources and the use of relevant variables. Survey and descriptive statistics are presented in Section 5. Section 6 provides the empirical results. Section 7 discusses the presence of agronomic benefits and the way in which they are translated into efficiency improvements and provides an explanation of why coffee farmers still choose rice. Section 8 sets out the conclusions, policy recommendations and avenues for further study.

2. Literature review

The various dimensions of farming management practices are well captured in the literature (Bell and Moore, 2012). In particular the farming system in which crops use the same resources, i.e., water and nutrients simultaneously, is known as an intercropping system or synchronization (van Asten et al., 2011). Another common farming integration system is crop rotation: however it is not applicable to perennials such as coffee and other industrial crops. In addition, segregated systems are known as integration of spatially separated crops. This farming practice is found to be attractive to smallholder farmers cultivating both subsistence crops and cash crops (Solís et al., 2009). For example, in the Central Highlands of Vietnam, coffee is a dominant crop and farming is mostly small scale (Luong and Tauer, 2006) mixed with some diversified subsistence crops, i.e., rice (Doutriaux et al., 2008). Therefore, by examining the economic benefits of different farming practices, i.e., crop specialization (not integrated organizationally), segregation (only integrated organizationally) and synchronization (integrated organizationally, spatially and temporally) (Bell and Moore, 2012), it is intended to make a useful contribution to the farming management literature.

Crop diversification in synchronized systems has, on the one hand, the potential to deliver agronomic and ecological benefits; however realizing these potential benefits depends on the characteristics of ecosystems and the choice of crops (Bacon, 2005; Dang and Shively, 2008; Kremen and Miles, 2012; Padrón and Burger, 2015). On the other hand, there are little or no agronomic benefits from crop segregation, although this type of farming system may have other desirable outcomes in terms of food security and allocation of inputs (Bell and Moore, 2012).

There is a rich literature on various synchronized systems of crop diversification (i.e., Rahman, 2009; Kim et al., 2012), but only a few studies examine coffee farming (i.e., van Asten et al., 2011) and no study compares the productive efficiency between synchronized and segregated systems. For synchronized systems, it can be expected there will be a direct transformation of agronomic and ecological benefits into economic benefits through reductions in consumption of inputs without sacrificing output levels or through increasing output levels without requiring more input consumption. For example, the agronomic literature has identified crops such as avocados and fruit trees as being suitable for cultivation with coffee (Borkhataria et al., 2012) joint-production of which can result in less fertilizer being required. It is noted that lower fertilizer consumption delivers both a cost reduction and a reduction in negative environmental impacts. But synchronized systems may require greater management attention (Bell and Moore, 2012). However, growing different crops in different land plots in segregated systems may not deliver benefits of synchronization and in many situations segregation exposes farms to a higher risk of productive inefficiency. This comes about through misallocation of resources as farmers maybe inefficient in allocating limited resources among different plots growing different types of crops (Bell and Moore, 2012).

Although benefits of diversification are often highlighted in the literature, evaluating these benefits in economic terms is not straightforward. One reason is that a relationship between agronomic or ecological benefits and monetary benefits is not straightforward because of the diversity of impacts of input and output prices on monetary outcomes accrued to farmers, consumers and society as a whole. However, it can reasonably be expected that there is a direct transformation of agronomic benefits into improvements in productive efficiency. Therefore, we focus on this direct transformation and use these efficiency changes to quantify the impacts of diversification in coffee growing.

Coelli and Fleming (2004) suggest that diversification economies derived from an extra unit of one output can be measured by increases the marginal efficiency level of producing an extra unit of another output, holding other variables constant. This increase in marginal efficiency is due to deflating the amount of inputs to the extent that it puts the observed farm closer to the production frontier. The existence of diversification economies, therefore, implies that joint production of two outputs can improve the productive efficiency in comparison to the situation where there is separate production of two specialized outputs. An empirical study employing the input distance function by Coelli and Fleming (2004) is based on a small panel data set of 18 coffee smallholders collected in 1992 and 1993 in six villages in Papua New Guinea. They examine diversification economies of pairs of crops, i.e., coffee and subsistence food, coffee and cash food and subsistence and cash food production. The authors report weak empirical evidence of diversification economies between coffee and subsistence food production. As well, diseconomies of diversification from the combination of coffee and cash food production are identified, implying a negative impact of diversification on efficiency.

Vedenov et al. (2007) uses a data set of 24 coffee-producing districts in Mexico covering the period 1997 to 2002 employing the input distance function approach to estimate technical efficiency of the districts. The authors use Coelli and Fleming's (2004) method of measurement to examine economies of diversification for three different pairs of crops (coffee–corn, coffee–other cash crops and corn–other cash crops). However their calculations of diversification (dis)economies are not reliable given inappropriate use of the derivation formulae (see discussion in Section 3). Our literature review finds two empirical studies – that of Coelli and Fleming (2004) and Vedenov et al. (2007) – which focus on measuring diversification economies in coffee production. However, they do not offer a comparative analysis of differing farming systems.

Empirical analysis comparing efficiency of differing farming systems is particularly important in the context of coffee production in Vietnam. Coffee growing is the primary economic activity in the Highlands region of Vietnam, where most coffee is produced. In response to favorable coffee prices in the early 1990s, farmers increased cultivation of coffee leading to increased supply and downward pressure on coffee prices. Coffee farmers, then appear to have to diversify into rice cultivation and other industrial crops. To-date, there are three distinct farming systems for small farmers in the Highland regions of Vietnam: mono-cropping, synchronization and segregation. However there are few empirical studies on the productive efficiency of coffee farming in Vietnam (Garcia and Shively, 2011; Cheesman and Bennett, 2008) none of which compare efficiency across the different types of farming systems.

In summary, we identify two important gaps in the empirical literature on coffee farming. First, there is no empirical study examining the efficiency effects brought by different diversification strategies of coffee farmers (i.e. different crop mixtures such as segregation versus synchronization). Second, there is no previous efficiency study focusing on the three typical farming systems for coffee cultivation in Vietnam — the world's second largest coffee producing country. Our study aims to fill these two gaps by empirically examining the efficiency benefits of diversification in the framework of input distance functions. In doing so we aim to provide both farmers and local agricultural extension officers new information which can lead to greater efficiency in agricultural practices.

3. Input distance function

The measure of diversification proposed by Coelli and Fleming (2004) in the framework of the input distance function has several advantages. First, it is applicable to cases where data on input prices are not available. Second, this measure allows the derivation of complementary effects directly from the distance function. Third, an inefficiency model can also be estimated to examine factors that can explain variations in the technical efficiency across farms. Following Coelli and Fleming (2004), the input distance function is defined as:

$$\mathrm{d}\left(x,y\right)=\left\{D:\left(\frac{x}{D}\right)\in L\left(y\right)\right\}, \tag{1}$$

where $L\left(y\right)$ refers to the set of all input vectors x that can produce the output vector y. The distance function, $d(x,y)$, is non-decreasing in x, and non-increasing in y, and linearly homogeneous and concave in x. If x belongs to the input set of y (i.e., $x\in L\left(y\right)$) then the value of the distance function is equal to or greater than one ($d\left(x,y\right)\geq 1$). The distance is equal to unity if x belongs to the isoquant of y. That is, the firm is said to be technically efficient or inefficient if the value of the distance equals one or exceeds one respectively. Note that the value of the distance equals the inverse of the traditional input-oriented technical efficiency score as proposed by Farrell (1957).

Coelli and Fleming (2004) suggest that diversification economies produced from an extra unit of output i increases the marginal efficiency level of producing an extra unit of output j, holding other variables constant. That is, the first partial derivative of the distance function with respect to the ith output is the marginal distance of producing an extra unit of the ith output. The cross derivative of the distance with respect to the ith and jth output represents the effect of change in one additional unit of the jth output on the marginal distance of producing ith output.[1] The existence of diversification economies implies joint production of two outputs – the ith and the jth – delivers higher input-orientated efficiency. That is, there is less input consumption with the given level of output than that of producing two outputs separately. Economies of diversification[2] between two outputs is therefore observed if:

$$\partial^2 D\left(\mathbf{x},\mathbf{y}\right)/\partial y_i \partial y_j < 0, \quad i,j = 1,\ldots,q. \tag{2}$$

Note that a positive cross derivative with respect to the ith and jth output implies diseconomies of diversification.[3]

We also examine the absolute values of the cross derivative to infer the relative magnitudes of the diversification economies. This provides an indication of the relative effects of diversification economies when there are more than two outputs (i.e. more than one pair of two outputs i and j). More specifically, if economies of diversification are observed, the most favorable combination (i.e. largest marginal efficiency gain due to joint production) is quantified as:

$$Max\left\{\left|\frac{\partial^2 D}{\partial Y_i \partial Y_j}\right|\right\}, \quad i \neq j \text{ and } i,j = 1,\ldots,q \text{ for the largest efficiency gain due to joint production.} \tag{3}$$

If diseconomies of diversification are observed, the combinations that have minimum negative effect on the efficiency loss due to joint production is:

$$Min\left\{\frac{\partial^2 D}{\partial Y_i \partial Y_j}\right\}, \quad i \neq j \text{ and } i,j = 1,\ldots,q \text{ for the least efficiency loss due to joint production.} \tag{4}$$

Since inputs and outputs are normalized at their means, for more meaningful interpretations of the empirical results of the average farm, the expression (2) can be represented as[4] :

$$\Delta D_{Y_i|\Delta Y_j=1} = \frac{\partial^2 D}{\partial Y_i \partial Y_j} = \frac{D}{Y_i Y_j}\left(\beta_i \beta_j + \frac{1}{2}\beta_{ij}\right) < 0. \tag{5}$$

Theoretically, this distance D is always positive; therefore from expression (5) we see that $\left(\beta_i\beta_j + \frac{1}{2}\beta_{ij}\right) < 0$implies evidence of the diversification economies.

4. Empirical model specifications

A translog input distance function is used in this study to characterize the production technology as it is more flexible than the Cobb–Douglas functional form and does not require restrictions of rectangular hyperbola isoquants (Morrison-Paul et al., 2000). The fully specified translog input distance function is specified as:

$$\begin{aligned}\ln D_i^I = {} & \alpha_0 + \sum_{k=1}^{q} \beta_k \ln y_k + \frac{1}{2}\sum_{k=1}^{q}\sum_{k'=1}^{q} \beta_{kk'} \ln y_k \ln y_{k'} + \sum_{m=1}^{p} \alpha_m \ln x_m + \frac{1}{2}\sum_{m=1}^{p}\sum_{m'=1}^{p} \alpha_{mm'} \ln x_m \ln x_{m'} \\ & + \frac{1}{2}\sum_{m=1}^{p}\sum_{k=1}^{q} \tau_{km} \ln x_m \ln y_k\end{aligned} \tag{6}$$

where $i = 1,\ldots,N$ refers to the number of firms, q and p represent the number of outputs and inputs.

According to O'Donnell and Coelli (2005), the homogeneity of degree +1 in inputs implies:

$$\sum_{m=1}^{p} \alpha_m = 1, \qquad \sum_{m=1}^{p} \alpha_{mm'} = 0, \qquad \text{and} \sum_{m=1}^{p} \tau_{km} = 0. \tag{7}$$

Plugging the constraints in Eq. (7) into Eq. (6), we have:

$$\begin{aligned}\ln\left(D_i^I/x_1\right) = {} & \alpha_0 + \sum_{k=1}^{q} \beta_k \ln y_k + \frac{1}{2}\sum_{k=1}^{q}\sum_{k'=1}^{q} \beta_{kk'} \ln y_k \ln y_{k'} + \sum_{m=2}^{p} \alpha_m \ln\left(x_m/x_1\right) \\ & + \frac{1}{2}\sum_{m=2}^{p}\sum_{m'=2}^{p} \alpha_{mm'} \ln\left(x_m/x_1\right)\ln\left(x_{m'}/x_1\right) + \frac{1}{2}\sum_{m=2}^{p}\sum_{k=1}^{q} \tau_{mk} \ln\left(x_m/x_1\right)\ln y_k.\end{aligned} \tag{8}$$

1 This is also similar to the utility theory which states the cross partial derivative of the utility function with respect to good X and good Y is positive if these two goods are complements in consumption ($U_{XY} = \frac{\partial^2 U}{\partial X \partial Y} = \frac{\partial}{\partial X}\left(\frac{\partial U}{\partial Y}\right) > 0$). This means that consuming more of good Y increases the marginal utility of good X.

2 There are both similarities and differences between the term 'diversification economies' used in this study and the term 'output complementarities' used in other studies. Villano et al. (2010) define output complementarities as a marginal increase of one output as the result of increasing the quantity of another output. However, the cross derivative of the input distance function in expression (2) with respect to the ith and jth output does not match this definition of output complementarities.

3 Note that $\partial^2 D\left(\mathbf{x},\mathbf{y}\right)/\partial y_i \partial y_j \neq \partial^2 \ln D\left(\mathbf{x},\mathbf{y}\right)/\partial \ln y_i \partial \ln y_j = \beta_{ij}$. Vedenov et al. (2007) only used interaction between only two outputs (β_{ij}) in calculating this measures while interaction term ($\beta_i\beta_j + \beta_{ij}$) should be used. More details are provided upon an email request.

4 See Appendix for the derivation of the cross derivative of the input distance function with respect to output i and output j.

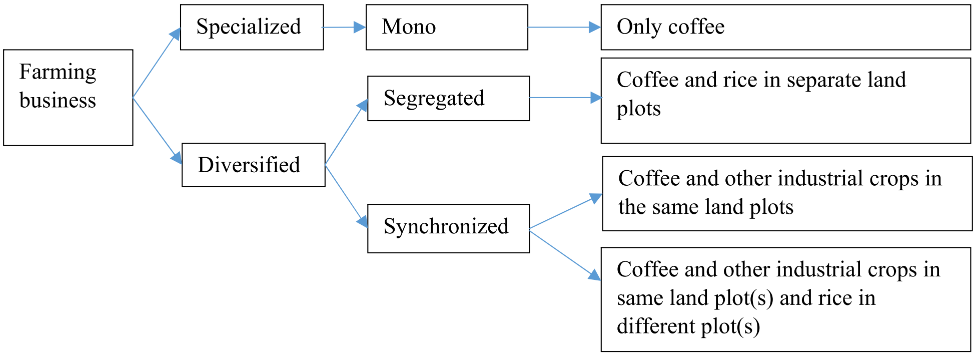

Fig. 1. Three distinct farming systems.

The symmetry requires that $\beta_{kk'} = \beta_{k'k}$ and $\alpha_{mm'} = \alpha_{m'm}$.

Following Coelli and Perelman (1999), the "$-\ln(D_i^I)$" term is set to be $v_i - u_i$, and re-arranging Eq. (8) gives an input distance function as:

$$\begin{aligned} -\ln x_1 = {} & \alpha_0 + \sum_{k=1}^{q} \beta_k \ln y_k + \frac{1}{2}\sum_{k=1}^{q}\sum_{k'=1}^{q} \beta_{kk'} \ln y_k \ln y_{k'} + \sum_{m=2}^{p} \alpha_m \ln (x_m/x_1) \\ & + \frac{1}{2}\sum_{m=2}^{p}\sum_{m'=2}^{p} \alpha_{mm'} \ln (x_m/x_1) \ln (x_{m'}/x_1) + \frac{1}{2}\sum_{m=2}^{p}\sum_{k=1}^{q} \tau_{mk} \ln (x_m/x_1) \ln y_k + v_i - u_i \end{aligned} \tag{9}$$

where y refers to output; v_i, captures the effects of statistical noise which is assumed to be independently and identically distributed as $N\,(0,\sigma_v^2)$. u_i are non-negative random variables associated with technical inefficiency in production and which are assumed to be independently and identically distributed such that u is defined by the truncation at zero of the normal distribution with unknown variance σ_u^2 and unknown mean, μ, $[u_i \sim (|N(0,\sigma_u^2)|)]$.

We follow Battese and Greg (1977) in calculating and explaining the variance parameters, σ_v^2 and σ_u^2 as $\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$ and $\sigma_s^2 = \sigma_u^2 + \sigma_v^2$ for the model. The parameter γ is ranged between zero and one, where $\gamma = 1$, there is no random noise and where $\gamma = 0$, technical inefficiency is not present. The input distance is presented as $D_i = E[\exp(u_i)|e_i]$, where $e_i = v_i - u_i$.

The inefficiency model is specified as:

$$\mu = \delta_0 + \sum_{l=1}^{L} \delta_l z_l \tag{10}$$

where $\mathbf{z}_s$ are exogenous variables associated with the production environment. This explains how the observed output level can be produced using the minimum level of inputs. However, inefficient firms utilize the actual level of inputs which is due to the technical inefficiency effect. It is assumed that these factors indirectly affect the production technology so that the deterministic frontier does not capture these variables. Instead, they are treated as factors explaining inefficiency variation of the stochastic input distance function. These independent variables are known as factors characterized by the production technology and relate to input and output production factors.

5. Farming systems and data collection

As depicted in Fig. 1, the sample is categorized into coffee specialized farms and diversified farms with more than one farming enterprise. There are two main types of diversified farms. The first are farms where different crops share or co-locate in the same plot of land. This is called a synchronized farming system, i.e., coffee — other industrial crops. The second type are farms are characterized by different crops being planted in separated plots of land. This is called a segregated farming system (also see Bell and Moore, 2012).

This survey was conducted in five communes in the Cu M'gar District, Dak Lak Province of the Central Highlands. In recent years, Vietnam produces about 20% of global coffee production of which the Central Highlands region contributes about 85%. Of the five provinces, Dak Lak is the largest coffee-growing region in terms of both cultivated area and production with about 50% of total national coffee production. The Cu M'gar District where our data is derived from is known as a key coffee planting area with diversified farm models (also see: Dang and Shively, 2008). In addition to coffee, other cash crops (avocado, pepper and fruit) and short gestation industrial and food crops (i.e., rice) are also cultivated.

The data collection procedure involved a two-stage random sampling technique. Firstly, five out of 13 communes in the district were randomly identified. Given the distribution of coffee farmers in the five selected communes was relatively

Table 1
Descriptive statistics of variables.

Variable	Variable definition	Obs	Mean	Std. Dev.	Min	Max
Outputs:						
$y1$	Coffee production in tons	167	1.27	1.34	0.00	8.00
$y2$	Rice production in tons	167	0.95	0.92	0.00	4.60
$y3$	Income from the other industrial crops in million VND	167	10.25	15.23	0.00	75.00
Inputs						
$x1$	Cultivating area in ha	167	0.69	0.48	0.10	3.50
$x2$	Chemical fertilizers applied in tons	167	1.04	1.15	0.00	7.37
$x3$	Irrigation water in thousand cubic meters	167	1.78	1.93	0.00	12.00
$x4$	Total labor used in man-days	167	147.37	110.19	0.00	660.00
$x5$	Other production cost in million VND	167	2.02	3.50	0.00	25.00
Socio-economic characteristics:						
$z1$	Ethnicity of the household head, 1 if Kinh majority and 0 for otherwise	167	0.43	0.50	0.00	1.00
$z2$	Number of years of completed formal education by household head	167	5.75	4.05	0.00	12.00
$z3$	Amount of credit loans to the household in million VND	167	21.34	20.91	0.00	115.00
$z4$	Farming experience of the household head measured in years	167	8.44	5.46	0.00	27.00
$z5$	Family size measured in persons	167	3.96	1.70	1.00	9.00
Diversity	Crop diversification (number of farms)	167				
$d = 0$	Coffee mono crop farms	20				
$d = 1$	Coffee and rice mixed farms	41				
$d = 2$	Coffee and the other industrial crops mixed farms	23				
$d = 3$	Rice and the other industrial crops mixed farms	12				
$d = 4$	Other combinations of crops	71				

equal, around 35 households in each commune were randomly selected. This procedure was used to ensure geographical representation of farmers with different production conditions across the district. In addition, this procedure also allowed the survey to be conducted to meet cost and time constraints. In total, 167 farmers were interviewed using the face-to-face technique with a structured questionnaire set.[5] The questionnaire sought information on demographics, household characteristics, input and output data, and socio-economic and geographical profiles relating to agricultural production. Prior to the main survey, a pre-test was conducted for the purpose of evaluation and refinement of the instrument. Descriptive statistics of all variables used in Eqs. (6)–(10) are set out in Table 1.

In the Central Highlands there are representatives of most Vietnamese ethnic groups working in the agricultural production sector. The Kinh group is in the majority with other groups classified as being local or migrated such as Ede, Mnong, and Tay. In the present study, a dummy for ethnicity is used as we expect there are differences in both farming practice and other socio-economic conditions between and the Kinh households and others minorities (Dang and Shively, 2008; van de Walle and Gunewardena, 2001).

Household characteristics are often included in the technical inefficiency model in empirical studies of smallholders farming. The common independent variables include: formal education level of household heads (Picazo-Tadeo et al., 2011; Illukpitiya and Yanagida, 2010), formal credit loans (Binam et al., 2004), crop diversification (Chavas and Kim, 2010; Illukpitiya and Yanagida, 2010), farming experience and age of household head (Cinemre et al., 2006; Ofori-Bah and Asafu-Adjaye, 2011); family size in number of persons (Bozoğlu and Ceyhan, 2007; Haji, 2006).

In terms of crop diversification, dummy coding is used for 'Diversity' to examine if the efficiency level varies between coffee mono crop farms (the base group) and farms having different multiple crops. If those dummy variables are statistically significant, we can interpret the extent of differences in the average efficiency levels of various groups of farms.

6. Empirical results

6.1. Maximum likelihood estimates

The result's maximum likelihood estimation (MLE) of the stochastic input distance function is presented in Table 2. The statistically significant negative signs of the first order coefficients of outputs imply an inverse relationship between the input distance and output quantities; that is, more outputs result in a smaller distance or a higher efficiency level. The estimated coefficients, β_1= -0.4956 and $\beta_2 = -0.2875$, indicate that an increase of coffee and rice production of 10% will decrease the distance to the frontier by about 4.956% and 2.875% respectively, *ceteris paribus*. These results indicate the greater capacity of coffee production relative to rice production in enhancing the overall input-orientated efficiency level. The estimated coefficients associated with coffee and rice also predict the same finding.

Positive and statistically significant coefficients for inputs represent the complementarity of these inputs with the land input. Larger farms are likely to invest more in all input factors on average. In addition, most of the coefficients of the interaction-variables are significantly different from zero. This implies non-linearities in the production technology and hence justifies the use of the flexible translog specification.

[5] The questionnaire is available upon request.

Table 2
MLE for the stochastic input distance function.

Variable	Parameter	Coef.	Std. err.
Constant	α_0	0.2325***	0.0355
$\ln y1$ (coffee)	β_1	−0.4956***	0.0354
$\ln y2$ (rice)	β_2	−0.2875***	0.0298
$\ln y3$ (other industrial crops)	β_3	0.0508**	0.0245
$0.5(\ln y1)^2$	β_{11}	−0.0125***	0.0012
$0.5 \ln y1 * \ln y2$	β_{12}	0.0061***	0.0014
$0.5 \ln y1 * \ln y3$	β_{13}	−0.0034***	0.0010
$0.5(\ln y2)^2$	β_{22}	−0.0095***	0.0010
$0.5 \ln y2 * \ln y3$	β_{23}	0.0000	0.0001
$0.5(\ln y3)^2$	β_{33}	0.0017**	0.0008
$\ln(x2/x1)$ (chemical fertilizers/ area)	α_2	0.0836*	0.0483
$\ln(x3/x1)$ (irrigation water/ area)	α_3	0.0856***	0.0311
$\ln(x4/x1)$ (labor/ area)	α_4	0.1316*	0.0772
$\ln(x5/x1)$ (other cost/ area)	α_5	0.0620***	0.0175
$0.5[\ln(x2/x1)]^2$	α_{22}	0.0074***	0.0021
$\ln(x2/x1) * \ln(x3/x1)$	α_{23}	0.0077	0.0234
$\ln(x2/x1) * \ln(x4/x1)$	α_{24}	−0.0552***	0.0177
$\ln(x2/x1) * \ln(x5/x1)$	α_{25}	−0.0034	0.0035
$0.5[\ln(x3/x1)]^2$	α_{33}	−0.0027**	0.0012
$0.5 \ln(x3/x1) * \ln(x4/x1)$	α_{34}	0.0055*	0.0033
$0.5 \ln(x3/x1) * \ln(x5/x1)$	α_{35}	0.0161***	0.0055
$0.5[\ln(x4/x1)]^2$	α_{44}	−0.0029	0.0024
$0.5 \ln(x4/x1) * \ln(x5/x1)$	α_{45}	−0.0350***	0.0069
$0.5[\ln(x5/x1)]^2$	α_{55}	0.0023***	0.0006
$\ln(x2/x1) * \ln y1$	τ_{21}	−0.0098	0.0230
$\ln(x2/x1) * \ln y2$	τ_{22}	0.0033*	0.0019
$\ln(x2/x1) * \ln y3$	τ_{23}	−0.0057***	0.0015
$\ln(x3/x1) * \ln y1$	τ_{31}	0.0029*	0.0016
$\ln(x3/x1) * \ln y2$	τ_{32}	0.0027*	0.0014
$\ln(x3/x1) * \ln y3$	τ_{33}	0.0035***	0.0010
$\ln(x4/x1) * \ln y1$	τ_{41}	0.0018	0.0053
$\ln(x4/x1) * \ln y2$	τ_{42}	0.0017	0.0033
$\ln(x4/x1) * \ln y3$	τ_{43}	0.0071***	0.0026
$\ln(x5/x1) * \ln y1$	τ_{51}	−0.0148***	0.0048
$\ln(x5/x1) * \ln y2$	τ_{52}	0.0015**	0.0007
$\ln(x5/x1) * \ln y3$	τ_{53}	−0.0002	0.0002

*** Indicate significance at the 1% level.
** Indicate significance at the 5% level.
* Indicate significance at the 10% level.

Table 3
Inefficiency model.

Variable	Parameter	Coef.	Std. err.
Constant	δ_0	−6.4899***	1.2358
z_1 — Ethnicity	δ_1	−0.7900*	0.4750
z_2 — Education	δ_2	−0.1237**	0.0517
z_3 — Credit	δ_3	0.0003	0.0106
z_4 — Farming experience	δ_4	0.0125	0.0347
z_5 — Family size	δ_5	1.2460***	0.1869
Farming systems (coffee mono is based)			
Coffee and rice crops		−0.4275	0.7237
Coffee and the other industrial crops		−4.1516***	1.3734
Rice and other crops		1.5352	1.0054
Coffee, rice and other industrial crops		−1.2549*	0.7125

The Chi-squared, $\overline{\chi}^2 = 1948.19$ represents the effect of technical inefficiency which is statistically significant at the 99% confidence level (H_0:$\sigma_u = 0$, was rejected at the 1% level of significance). Since all production variables are mean-corrected prior to the estimation, the inverse of the sum of the output coefficients provides a measure of radial return to scale elasticity (Coelli and Fleming, 2004; Hajargasht et al., 2006). The empirical result, $-1/(\beta_1+\beta_2+\beta_3) = 1.37$ suggests the existence of scale economies.

Table 4
Complementary effects and diversification efficiencies.

Farming system	Sample size	Mean efficiency score	Economies of diversification using Eq. (5)[a]	Relationship with inefficiency in inefficiency model (i.e. Eq. (10)[b])
Coffee mono crop	20	0.79	N/A	Base
Coffee and rice crops	41	0.80	No (0.1875**)	−0.4275
Coffee and the other industrial crops	23	0.94	Yes (−0.0360**)	−4.1516***
Coffee, rice and other industrial crops	71	0.82	N/A	-1.2549*

[a] A negative (positive) sign refers economies (diseconomies) of scope.

[b] A negative (positive) sign implies a higher (lower) efficiency level compared with a coffee mono crop system.

** Represent the significance level at 95%.

* Represent the significance level at 90%.

6.2. Inefficiency model

The empirical results suggest an average level of input-orientated technical efficiency of around 82%. This implies that farmers could reduce inputs by 18% (i.e. 1–0.82) with the output levels remaining unchanged. The estimated results for the inefficiency model (Eq. (10)) are reported in Table 3.

Inefficiency was negatively associated with education and ethnicity and positively correlated with larger family size. This means that in comparison to the major ethnic group the Kinh people, other ethnic farmers tend to be less efficient. In addition, farms with household heads who had achieved a higher number of year of schooling obtained higher efficiency levels than their counterparts. Coffee households with smaller family sizes also appeared to reach higher efficiency levels than larger family size households. These findings are consistent with efficiency literature (Bozoğlu and Ceyhan, 2007).

6.3. Relative efficiency levels of differing farming systems

As shown in Table 4, both economies and diseconomies of scope are detected in differing farming systems. By definition, scope economies may lead to efficiency improvements; thus, the result of the inefficiency model also provides robustness to the result of diversification economies.

Table 4 provides summaries of efficiency scores across the three farming systems with three main findings. First, the synchronized farming system – farms growing coffee and other industrial crops – have the highest average efficiency scores (0.94 compared with the benchmark mono-cropping's average score of 0.80). Both parametric (t-test) and nonparametric (Kolmogorov–Smirnov) tests also confirmed these results are statistically significant.[6] Also, the combination of *coffee crop* and *other industrial crops* exhibit economies of diversification. The cross derivative of the distance function with respect to these two outputs, defined in Eq. (5), was calculated to be −0.0360, which is statistically different from zero. This implies that producing an extra unit of *other industrial crops* other than *coffee crop* could reduce the marginal distance by 0.036. A reduction in marginal distance means an improvement in the productive efficiency level in the production of both coffee and the other industrial crops. Note that the results from the inefficiency model also produce the similar implication that farms jointly cultivating coffee and other industrial crops are found to be more efficient than the other farming systems.

Second, there is statistically significant evidence of the diseconomies of diversification between coffee and rice in the segregated farming system. The cross derivative measure of 0.1875 for coffee–rice suggests that an extra unit increase in rice production volume leads to a 0.1875 increase in the marginal distance of producing coffee or vice versa. An increase in the value of the marginal distance means a reduction in the productive efficiency level. Note that the inefficiency model reveals a negative sign for the dummy of the coffee–rice farming group but this variable is not statistically significant while there is no statistical difference in the average values of efficiency scores between the two systems (i.e. mono coffee and coffee–rice). Since coffee and rice are cultivated in spatially separated plots of land, there does not exist agronomic and/or ecological symbiosis between these two crops. Our findings show that this segregated farming system does not provide any efficiency benefits. This raises the question as to why this farming strategy is still common in Vietnam's coffee growing community. Section 7 provides further discussion on this issue.

Third, the coffee mono crop system and the coffee–rice segregated system are found to be less efficient than farming systems growing coffee together with other industrial crops and/or rice. It could be inferred that these results are due to the presence of negative complementary effects between coffee and rice and positive complementary effects between coffee and other industrial crops. Section 7 also provides further discussions on this point.

[6] p-value of the t-test equals 0.0004 and this number of the Kolmogorov–Smirnov test was 0.001.

7. Discussion

7.1. Evidence of agronomic benefits between coffee and other industrial crops

The results from both the diversification measure and the inefficiency model consistently confirm that growing other industrial crops in the same land plot of coffee provide efficiency benefits. It should be noted that our efficiency measures are not impacted by prices of inputs, and we argue that this observation can be due to at least three possibilities. First, the positive complementary effects of growing other industrial crops in the coffee plot is due to lower overall consumption of inputs compared to using inputs separately for coffee and other industrial crops. This is important for policy-makers as crop cultivation has been dependent on the heavy use of chemical inputs (Athukorala et al., 2015, p. 334). Reduction in the use of chemicals or more environmentally friendly practices to cope with environmental issues while increasing agricultural productivity to meet food security purposes was identified as an urgent need in many Asian countries (Ahmed, 2012),

Second, as our output includes the value of the other industrial crops, efficiency maybe affected by the prices of other industrial crops being more favorable than that of coffee. Third, there exists agronomic and/or ecological benefits which are translated into efficiency improvements. As data does not allow us to investigate the first two possibilities further, we argue that it is important for both farmers and local governmental agencies to pay more attention to the agronomic or ecological benefits of synchronization of coffee and other industrial crops. Interestingly, Ogundari (2013) also reported that combining coffee with other industrial crops such as bananas, provides agronomic and social benefits to farmers. This is in line with the India studies which indicate that crop diversification could both increase economic gain and environmental benefits (Mandal, 2014).

Industrial crops such as pepper and avocado when spatially synchronized with coffee therefore promise agronomic benefits to farmers as well as ecological benefits for the surrounding natural environment. Given that this type of crop diversification was not chosen by many Vietnamese coffee farmers, we also hypothesize that there could exist another type of trade-off. That is, there is the observed divergence between short-run loss and the longer-run gains — in the form of ecological benefits of inter-cropping coffee with other industrial crops such as pepper, avocados and bananas. It can be assumed that given the potential to translate the agronomic and ecological benefits into direct economic gains (for example via savings in production costs or additional flows of capital) is not directly observable by farmers, they tend to underestimate the values of these gains. This leads to underproduction of agronomic and ecological benefits. As a manifestation of market failure this shows there is a positive externality in appropriate crop synchronization (Chavas, 2008). Therefore, policy interventions can be designed so as to internalize these externalities. For example, government can provide incentives in the form of subsidies or cash rewards to coffee farms to encourage them to synchronize rather than segregate — particularly for crops that deliver agronomic values.

7.2. Why coffee farmers still choose rice

Table 5 provides a snapshot of socio-economic variations between different categories of farms in terms of crop diversification. Rice is a fairly common crop chosen by coffee farmers in the area covered by this research. One notable characteristic is that most farms cultivated rice for their own consumption. In other words, these farmers appear to have cultivated rice as a form of subsistence for food security[7] purposes as it is the major staple food in Vietnam. In addition, compared to other industrial crops (i.e., coffee or pepper) rice cultivation requires much lower capital investment (Amarasinghe et al., 2015). Therefore it is attractive to farmers who have little capital or have difficult access to capital.[8] This is also shown in Table 5 with coffee–rice farms having lower income levels and less access to credit loans than other farms.

In fact, empirical results also allow us to hypothesize that there is sup-optimal investment decision making. Coffee farmers, given resource constraints, cultivate rice as rice cropping requires less investment, has less risk and increases food security. But cultivating rice reduces their overall productive efficiency which causes higher production costs and lower total farm income. The literature has shown that subsistence production is commonly considered as less efficient than commercial crops (Kostov and Lingard, 2004) and that to enhance poverty alleviation, shifting from subsistence to cash crop production may be a desirable strategy for subsistence farmers (Solís et al., 2009). As it is desirable for policies to promote more efficient farming diversification, these results suggest several policy options which could be adopted to encourage farmers to diversify crops with a greater focus on efficiency gains. For example, if rice farmers have difficulties in accessing capital to cultivate non-rice crops, policies should target facilitating access to credit for these farmers. Similarly, if rice farmers have concerns over food security, policies should be designed to address these concerns.

---

7 Farming diversification in which rice is an option also delivers food security, i.e., rice–fish integration was found a viable diversification option in Bangladesh (Ahmed et al., 2011).

8 We note that low capital investment means lower financial risk; therefore it can be argued that farmers might be risk averse. However, we do not have data on which to base further analysis.

Table 5
Characteristics of rice versus non-rice farms and coffee–rice farms versus other farms.

	Non-rice farms ($n = 43$)	Rice and others farms ($n = 124$)	Other farms ($n = 126$)	Coffee–rice farms ($n = 41$)
Technical efficiency	0.87	0.81*	0.83	0.80
Total annual income in million VND	103.37	69.33**	87.10	50.41***
z1 — Ethnicity	0.63	0.35***	0.51	0.17***
z2 — Education	6.75	5.41*	6.00	4.98
z3 — Credit	26.24	19.65*	23.38	15.09**
z4 — Farming experience	10.05	7.89**	7.95	9.95**
z5 — Family size	4.19	3.88	4.13	3.41**

The significance levels of the t-test is indicated as:
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.010$.

8. Conclusions

This paper adds to the literature on crop farming diversification by coffee farmers by providing additional empirical evidence derived from estimations of the input distance function based on a new dataset of Vietnam's coffee farmers. Empirical results provide several important findings. First, the average inefficiency level is estimated to be 18%. Second, there is evidence of positive economic benefits in the form of economies of scope and diversification efficiencies flowing from the synchronized farming system, i.e., between coffee and the other industrial crops. We hypothesized that these benefits could come from agronomic values and more efficient consumption of inputs. In addition, segregated farming systems cultivating coffee and rice in differing plots of land.

While inter-cropping between coffee with other industrial crops – such as avocados and pepper – could provide some biological benefits to prevent further soil erosion in the Highlands of Vietnam as well as other related bio-diversification benefits (see: Singh, 2000; Ogundari, 2013), there is a tendency for farmers not to do so. Rather, coffee farmers still choose to cultivate rice as a segregated crop integration system. We argue that if farmers in long-run can be encouraged to move from rice towards other industrial crops they can increase the overall efficiency level of the coffee industry. It is therefore desirable to investigate further the nature of the market failure to achieve a socially optimal level of production of ecological benefits in the context of crop diversity. However, to achieve this optimal policy result, interventions is needed to remove or reduce barriers farmers face in terms of capital investment, to change risk-averse attitudes and to improve rice food security.

Further research could add robustness to some of this study's conclusions by examining larger datasets and panel data to better address the issue of heterogeneity in coffee farming. Further analysis of specific types of crops that deliver both efficiency gains, economies of scope and higher profitability to coffee farmers in Vietnam could also complement this study. In addition, it is desirable to investigate further the nature of the market failure in order to achieve a socially optimal level of production of ecological benefits from the diversification of synchronized crops.

Acknowledgements

The authors would like to gratefully acknowledge two anonymous reviewers for their valuable comments and suggestions. We are responsible for any remaining errors.

Appendix

Deriving cross derivative of the distance function with respect to Y_i and Y_j:

$$D(x,y) = A\prod_i^p X_i^{\alpha_i}\prod_i^q Y_i^{\beta_i}\prod_i^p X_i^{\frac{1}{2}\sum_j^p \alpha_{ij}\ln X_j}\prod_i^q Y_i^{\frac{1}{2}\sum_j^q \beta_{ij}\ln Y_j}\prod_i^q Y_i^{\frac{1}{2}\sum_j^p \tau_{ij}\ln X_j}$$

$$D(x,y) = \prod_i^q Y_i^{\beta_i}\prod_i^q Y_i^{\frac{1}{2}\sum_j^q \beta_{ij}\ln Y_j}\prod_i^q Y_i^{\frac{1}{2}\sum_j^p \tau_{ij}\ln X_j} A\prod_i^p X_i^{\alpha_i}\prod_i^p X_i^{\frac{1}{2}\sum_j^p \alpha_{ij}\ln X_j}$$

$$D(x,y) = \prod_i^q Y_i^{\beta_i+\frac{1}{2}\sum_j^q \beta_{ij}\ln Y_j+\frac{1}{2}\sum_j^p \tau_{ij}\ln X_j} A\prod_i^p X_i^{\alpha_i+\frac{1}{2}\sum_j^p \alpha_{ij}\ln X_j}$$

$$call\ f_i(y) = \beta_i + \frac{1}{2}\sum_j^q \beta_{ij}\ln Y_j + \frac{1}{2}\sum_j^p \tau_{ij}\ln X_j\,,\quad j > i \text{ and } i = 1,\ldots,q$$

$$\ln D = \sum_i^q f_i(y)\ln Y_i + \ln A + \sum_i^p\left(\alpha_i + \frac{1}{2}\sum_j^p \alpha_{ij}\ln X_j\right)\ln X_i$$

$$\frac{\partial \ln D}{\partial Y_i} = \frac{\partial \ln D}{\partial D}\frac{\partial D}{\partial Y_i} = \frac{1}{D}\frac{\partial D}{\partial Y_i} = \frac{\partial f_i}{\partial Y_i}\ln Y_i + \frac{f_i(y)}{Y_i}$$

$$\frac{\partial \ln D}{\partial Y_i} = \frac{\partial \ln D}{\partial D}\frac{\partial D}{\partial Y_i} = \frac{1}{D}\frac{\partial D}{\partial Y_i} = \frac{\partial f_i}{\partial Y_i}\ln Y_i + \frac{f_i(y)}{Y_i}$$

$$\Leftrightarrow \frac{\partial D}{\partial Y_i} = \left(\frac{\partial f_i}{\partial Y_i}\ln Y_i + \frac{f_i(y)}{Y_i}\right)D, \quad \text{since } j > i \text{ then } \frac{\partial f_i}{\partial Y_i} = 0 \Rightarrow \frac{\partial D}{\partial Y_i} = \frac{f_i(y)}{Y_i}D$$

$$\frac{\partial^2 D}{\partial Y_i \partial Y_j} = \frac{1}{Y_i}\left(\frac{\partial D}{\partial Y_j}f_i(y) + \frac{\partial f_i(y)}{\partial Y_j}D\right), \quad \text{likewise, } \frac{\partial D}{\partial Y_j} = \frac{f_j(y)}{Y_j}D$$

$$\frac{\partial^2 D}{\partial Y_i \partial Y_j} = \frac{1}{Y_i}\left(D\frac{f_j(y)}{Y_j}f_i(y) + \frac{\partial f_i(y)}{\partial Y_j}D\right) = \frac{D}{Y_i}\left(\frac{f_j(y)f_i(y)}{Y_j} + \frac{\partial f_i(y)}{\partial Y_j}\right)$$

Since, $f_i(y) = \beta_i + \frac{1}{2}\sum_j^q \beta_{ij}\ln Y_j + \frac{1}{2}\sum_j^p \tau_{ij}\ln X_j$, $j > i$ and $i = 1, \ldots, q$ then $\frac{\partial f_i(y)}{\partial Y_j} = \frac{1}{Y_j}\frac{1}{2}\beta_{ij}$.

Therefore, $\frac{\partial^2 D}{\partial Y_i \partial Y_j} = \frac{D}{Y_i}\left(\frac{f_j(y)f_i(y)}{Y_j} + \frac{1}{Y_j}\frac{1}{2}\beta_{ij}\right) = \frac{D}{Y_iY_j}\left(f_j(y)f_i(y) + \frac{1}{2}\beta_{ij}\right)$.

Since the variables are normalized at their means, then $f_i(y) = \beta_i$ and $f_j(y) = \beta_j$.

Then the second derivative of the input distance function with respect to Y_i and Y_j is negative if:

$$\left(\beta_i\beta_j + \frac{1}{2}\beta_{ij}\right) < 0$$

References

Ahmed, E.M., 2012. Green TFP intensity impact on sustainable East Asian productivity growth. Econ. Anal. Policy 42 (1), 67–78. http://dx.doi.org/10.1016/S0313-5926(12)50005-6.

Ahmed, N., Zander, K.K., Garnett, S.T., 2011. Socioeconomic aspects of rice-fish farming in Bangladesh: Opportunities, challenges and production efficiency. Aust. J. Agric. Resour. Econ. 55 (2), 199–219. http://dx.doi.org/10.1111/j.1467-8489.2011.00535.x.

Amarasinghe, U.A., Hoanh, C.-T., D'haeze, D., Hung, T.-Q., 2015. Toward sustainable coffee production in Vietnam: More coffee with less water. Agric. Syst. 136, 96–105. http://dx.doi.org/10.1016/j.agsy.2015.02.008.

Athukorala, W., Hoang, V., Wilson, C., 2015. Impact of agricultural chemicals on the environment and human health in Asia. In: Managi, S. (Ed.), The Routledge Handbook of Environmental Economics in Asia. Taylor and Francis.

Bacon, C., 2005. Confronting the coffee crisis: Can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in Northern Nicaragua? World Dev. 33 (3), 497–511. http://dx.doi.org/10.1016/j.worlddev.2004.10.002.

Battese, G.E., Greg, C.S., 1977. Estimation of a production function model: with application to the pastoral zone of Eastern Australia. Aust. J. Agric. Econ. 21 (3), 169–179.

Baumol, W.J., Panzar, J.C., Willig, R.D., 1982. Contestable Markets and the Theory of Industry Structure. Harcourt Brace Jovanovich, p. 538. http://dx.doi.org/10.2307/134928.

Bell, L.W., Moore, A.D., 2012. Integrated crop-livestock systems in Australian agriculture: Trends, drivers and implications. Agric. Syst. 111, 1–12. http://dx.doi.org/10.1016/j.agsy.2012.04.003.

Binam, J.N., Tonyè, J., Wandji, N., Nyambi, G., Akoa, M., 2004. Factors affecting the technical efficiency among smallholder farmers in the slash and burn agriculture zone of Cameroon. Food Policy 29 (5), 531–545. http://dx.doi.org/10.1016/j.foodpol.2004.07.013.

Borkhataria, R., Collazo, J.a., Groom, M.J., Jordan-Garcia, A., 2012. Shade-grown coffee in Puerto Rico: Opportunities to preserve biodiversity while reinvigorating a struggling agricultural commodity. Agric. Ecosyst. Environ. 149, 164–170. http://dx.doi.org/10.1016/j.agee.2010.12.023.

Bozoğlu, M., Ceyhan, V., 2007. Measuring the technical efficiency and exploring the inefficiency determinants of vegetable farms in Samsun province, Turkey. Agric. Syst.. http://dx.doi.org/10.1016/j.agsy.2007.01.007.

Chavas, J.P., 2008. On the economics of agricultural production. Aust. J. Agric. Resour. Econ. 52 (4), 365–380. http://dx.doi.org/10.1111/j.1467-8489.2008.00442.x.

Chavas, J.P., Di Falco, S., 2012. On the role of risk versus economies of scope in farm diversification with an application to Ethiopian farms. J. Agric. Econ. 63, 25–55. http://dx.doi.org/10.1111/j.1477-9552.2011.00319.x.

Chavas, J.P., Kim, K., 2010. Economies of diversification: A generalization and decomposition of economies of scope. Int. J. Prod. Econ. 126 (2), 229–235. http://dx.doi.org/10.1016/j.ijpe.2010.03.010.

Cheesman, J., Bennett, J., 2008. Smallholding size, irrigation infrastructure, and the efficiency of coffee production in Viet Nam revisited. For. Trees Livelihoods 18 (4), 321–335. http://dx.doi.org/10.1080/14728028.2008.9752641.

Cinemre, H.a., Ceyhan, V., Bozoğlu, M., Demiryürek, K., Kılıç, O., 2006. The cost efficiency of trout farms in the Black Sea Region, Turkey. Aquaculture 251 (2–4), 324–332. http://dx.doi.org/10.1016/j.aquaculture.2005.06.016.

Coelli, T., Fleming, E., 2004. Diversification economies and specialisation efficiencies in a mixed food and coffee smallholder farming system in Papua New Guinea. Agric. Econ. 31 (2–3), 229–239. http://dx.doi.org/10.1016/j.agecon.2004.09.010.

Coelli, T., Perelman, S., 1999. A comparison of parametric and non-parametric distance functions: With application to European railways. European J. Oper. Res. 117 (2), 326–339. http://dx.doi.org/10.1016/S0377-2217(98)00271-9.

Dang, T., 2003. Coffee production, social stratification and poverty in a Vietnamese Central Highland community. Understanding Poverty in Vietnam and the Philippines, 71.

Dang, H., Shively, G., 2008. Coffee boom, coffee bust and smallholder response in Vietnam's central highlands. Rev. Dev. Econ. 12 (2), 312–326. http://dx.doi.org/10.1111/j.1467-9361.2007.00391.x.

Doutriaux, S., Geisler, C., Shively, G., 2008. Competing for coffee space: Development-induced displacement in the central highlands of Vietnam. Rural Sociol. 73 (4), 528–554. http://dx.doi.org/10.1526/003601108786471422.

Farrell, M.J., 1957. The measurement of productive efficiency. J. Roy. Statist. Soc. Ser. A 120 (3), 253–290. http://dx.doi.org/10.2307/2343100.

Garcia, A.F., Shively, G.E., 2011. How might shadow price restrictions reduce technical efficiency? Evidence from a restricted DEA analysis of coffee farms in Vietnam. J. Agric. Econ. 62 (1), 47–58. http://dx.doi.org/10.1111/j.1477-9552.2010.00269.x.

Hajargasht, G., Coelli, T., Rao, D.S.P., 2006. A dual measure of economies of scope. Econom. Lett. 100.

Haji, J., 2006. Production efficiency of smallholders' vegetable-dominated mixed farming system in Eastern Ethiopia: A non-parametric approach. J. Afr. Econ. 16 (1), 1–27. http://dx.doi.org/10.1093/jae/ejl044.

Illukpitiya, P., Yanagida, J.F., 2010. Farming vs forests: Trade-off between agriculture and the extraction of non-timber forest products. Ecol. Econom. 69 (10), 1952–1963. http://dx.doi.org/10.1016/j.ecolecon.2010.05.007.

Kim, K., Chavas, J.-P., Barham, B., Foltz, J., 2012. Specialization, diversification, and productivity: a panel data analysis of rice farms in Korea. Agric. Econ. 43 (6), 687–700. http://dx.doi.org/10.1111/j.1574-0862.2012.00612.x.

Kostov, P., Lingard, J., 2004. Subsistence agriculture in transition economies: Its roles and determinants. J. Agric. Econ. 55 (3), 565–579. http://dx.doi.org/10.1111/j.1477-9552.2004.tb00115.x.

Kremen, C., Miles, A., 2012. Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. Ecol. Soc. 17 (4), 40. http://dx.doi.org/10.5751/ES-05035-170440.

Letourneau, D.K., Armbrecht, I., Rivera, B.S., Lerma, J., Carmona, E.J., Daza, M.C., …, Trujillo, A.R., 2011. Does plant diversity benefit agroecosystems? A synthetic review. Ecol. Appl.. http://dx.doi.org/10.1890/09-2026.1.

Luong, Q.V., Tauer, L.W., 2006. A real options analysis of coffee planting in Vietnam. Agric. Econ. 35 (1), 49–57. http://dx.doi.org/10.1111/j.1574-0862.2006.00138.x.

Mandal, R., 2014. Flood, cropping pattern choice and returns in agriculture: A study of Assam plains, India. Econ. Anal. Policy 44 (3), 333–344. http://dx.doi.org/10.1016/j.eap.2014.08.001.

Marsh, A., 2007. Diversification by smallholder farmers: Viet Nam Robusta Coffee. In: Food and Agriculture Organization of the United Nations.

Morrison-Paul, C.J., Johnston, W.E., Frengley, G.A.G., 2000. Efficiency in New Zealand sheep and beef farming: The impacts of regulatory reform. Rev. Econ. Stat. 82 (2), 325–337. http://dx.doi.org/10.1162/003465300558713.

O'Donnell, C.J., Coelli, T., 2005. A Bayesian approach to imposing curvature on distance functions. J. Econometrics 126 (2), 493–523. http://dx.doi.org/10.1016/j.jeconom.2004.05.011.

Ofori-Bah, A., Asafu-Adjaye, J., 2011. Scope economies and technical efficiency of cocoa agroforesty systems in Ghana. Ecol. Econom. 70 (8), 1508–1518. http://dx.doi.org/10.1016/j.ecolecon.2011.03.013.

Ogundari, K., 2013. Crop diversification and technical efficiency in food crop production: A study of peasant farmers in Nigeria. Int. J. Soc. Econ. 40 (3), 267–287. http://dx.doi.org/10.1108/03068291311291536.

Padrón, B.R., Burger, K., 2015. Diversification and labor market effects of the Mexican coffee crisis. World Dev. 68, 19–29. http://dx.doi.org/10.1016/j.worlddev.2014.11.005.

Picazo-Tadeo, A.J., Gómez-Limón, J.a., Reig-Martínez, E., 2011. Assessing farming eco-efficiency: a data envelopment analysis approach. J. Environ. Manag. 92 (4), 1154–1164. http://dx.doi.org/10.1016/j.jenvman.2010.11.025.

Rahman, S., 2009. Whether crop diversification is a desired strategy for agricultural growth in Bangladesh? Food Policy 34 (4), 340–349. http://dx.doi.org/10.1016/j.foodpol.2009.02.004.

Singh, S., 2000. Contract farming for agricultural diversification in the India Punjab: A study of performance and problems. Indian J. Agric. Econ. 56 (3), 139–165.

Solís, D., Bravo-Ureta, B.E., Quiroga, R.E., 2009. Technical efficiency among peasant farmers participating in natural resource management programmes in Central America. J. Agric. Econ. 60 (1), 202–219. http://dx.doi.org/10.1111/j.1477-9552.2008.00173.x.

van Asten, P.J.A., Wairegi, L.W.I., Mukasa, D., Uringi, N.O., 2011. Agronomic and economic benefits of coffee-banana intercropping in Uganda's smallholder farming systems. Agric. Syst. 104 (4), 326–334. http://dx.doi.org/10.1016/j.agsy.2010.12.004.

van de Walle, D., Gunewardena, D., 2001. Sources of ethnic inequality in Viet Nam. J. Dev. Econ. 65 (1), 177–207. http://dx.doi.org/10.1016/S0304-3878(01)00133-X.

Vedenov, D., Houston, J., Cardenas, G., 2007. Production efficiency and diversification in Mexican coffee-producing districts. J. Agric. Appl. Econ. 39 (3), 749–763.

Villano, R., Fleming, E., Fleming, P., 2010. Evidence of farm-level synergies in mixed-farming systems in the Australian Wheat-Sheep Zone. Agric. Syst. 103 (3), 146–152. http://dx.doi.org/10.1016/j.agsy.2009.11.005.

Willig, R.D., 1979. Multiproduct technology and market structure. Am. Econ. Rev. 69 (2), 346–351.

Wollni, M., Zeller, M., 2007. Do farmers benefit from participating in specialty markets and cooperatives? The case of coffee marketing in Costa Rica. Agric. Econ. 37, 243–248.