Production Efficiency and Technology Differences in 'Clean and Safe' Vegetable Farming Systems in Northern Thailand

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Abstract

'Clean and safe' agricultural products are an important issue among consumers, farmers and governments. Many developing countries develop their produce at various points along the 'clean' continuum based on four different production practices related to use of synthetic chemicals. Organic farming is applied to technologies with no chemicals or synthetic fertilisers used during production or processing. It was initially developed by farmers and non-government organisations in Thailand, and subsequently implemented by the Thai government through a series of policies on clean produce to meet international standards. Safe-use and pesticide-free practices lie between organic and conventional practices, and are possible steps when converting conventional farms to organic farms.

The main purpose of this paper is to examine the production efficiency of four different vegetable farming practices. We compare the technical efficiencies and technology gaps of the four farming systems in northern Thailand of which three – organic, pesticide-free and safe-use - are designated 'clean and safe'. Farm-level data on vegetable production were collected from random samples of farms using these technologies. A standard stochastic production frontier was estimated for each system to obtain technical efficiency (TE) estimates with respect to their respective cohorts. The likelihood ratio test indicates that significant technology differences exist between these farming practices. Accordingly, a metafrontier model was estimated, enabling the estimation of technical efficiencies and technology gap ratios (TGRs) for vegetable farms operating under the different production systems. The model was checked for self-selectivity bias and it was found that there was no such problem.

Results show that all vegetable farming groups have a low mean technical efficiency and individual technical efficiencies that range widely within each group. 'Clean and safe' farms achieved a higher TE score than conventional farms, indicating a more efficient use of inputs in producing a certain level of output. Technical efficiency with respect to the metafrontier implies that the technology gap ratios of 'clean and safe' farmers are significantly lower than those of conventional farmers where the mean TGR was 0.802. Hence, conventional technology has a higher production capacity but lower efficiency in transforming inputs into outputs. For 'clean and safe' farms, production technology constraints are highest on organic and safe-use farms. Technology constraints are lower on pesticide-free farms, where the mean TGR was 0.642. The fact that safe-use vegetable farms are found to have the lowest mean technology gap ratios is interesting in that synthetic chemical use is expected to improve output capacities. Restrictive regulations can be a major technology barrier since

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safe-use farms, like organic farms, are required to conform to strict standard practices. The farms are inspected both on farming practices and for the issuance of produce qualifications and were expected to have the lowest mean TGR. Although the mean TGRs are low on 'clean and safe' farms, all four farming systems were found to have at least one farm that lay on the metafrontier. This result means that at least some farmers practising different methods are able to eliminate technological constraints to achieve the highest possible output regardless of the technology used.

Finally, we examined factors affecting the performance of vegetable farmers. Scope exists to improve the performance of farmers in all groups as technical efficiencies and TGRs of farms vary widely in all groups. The inefficiencies of all individual farming systems are influenced by different factors such as effective assistance providers, farm location, farmer education and number of vegetable species grown. In order to strengthen 'clean and safe' farm productivity, internal and external constraints on farmers need to be overcome through collaborative assistance and support from relevant organisations in both the public and private sectors. Improvements are needed for agronomic technology, supply chains, farmer capacity in production and marketing, and effectiveness of technology transfer strategies.

Key words: organic farming, technical efficiency, stochastic metafrontier, northern Thailand

1. Introduction

The effect of agricultural produce on safety, health and the environmental has gained increasing attention to consumers across the globe. While developed countries' interests are primarily focused on certified organic production, Thailand, as a developing country, has adopted various levels of 'clean' such as safe-use chemical, pesticide-free and no chemical to environmental friendly practices notably as organic. 'Clean and safe' market demand continues to increase (Vanit-Anunchai and Schmidt 2005; Posri *et al.* 2007; Johnson *et al.* 2008), but lack of 'clean and safe' produce of good quality and in sufficient variety are constraining development of the 'clean and safe' vegetable industry (Kramol *et al.* 2005; Posri *et al*. 2007; Lorlowhakarn *et al.* 2008).

In this paper we analyse the technical efficiencies of smallholder farms that operates in different 'clean and safe' vegetables farming methods in northern Thailand. Specifically, farmers were categorised into three groups based on their use of synthetic chemicals: organic, pesticide-free and safe-use. Organic farming refers to technologies without the use of chemicals or synthetic fertilisers during production or processing. Pesticide-free and safe-use practices on the other hand, are possible stages before converting conventional farms to organic farms.

Technical efficiencies of the three farming systems were predicted using stochastic frontier analysis. To make productivity comparisons across farming system, a metafrontier approach was employed. The technology gaps were estimated on vegetable farms under different technologies relative to the potential technology available.

Our objectives were to identify factors affecting production in different vegetable farming systems and to evaluate farm performance. This paper is organised as follows. First, we give a brief overview of 'clean and safe' vegetable farming systems in northern Thailand. Then issues of productivity differences in 'clean and safe' farming are discussed after which we describe the analytical framework incorporating stochastic frontier analysis and metafrontier analysis. Discussion of results and their implications are presented in the next two sections and we end with some conclusions.

2. ‘Clean and safe’ farming systems in Thailand

‘Clean and safe’ agricultural systems in Thailand are mainly developed for socio-economic and ecologically sustainable development as well as to increase awareness of health and environment hazard pressure. Although rice is the most important crop in Thailand base on consumption, production and income, vegetable crops are also significant as an alternative source of household income and are considered to be essential goods particularly in the North. When food safety issues are considered, vegetables are subject to a high risk from chemical contamination because of production practices and consumption behaviour (Vanit-Anunchai 2006; Posri *et al.* 2007). As a result, a project on safe chemical use in the production of vegetables was first implemented in Thailand in 1993.

The development of organic farming, which was the only recognised ‘clean and safe’ agriculture at the time, was driven mainly by non-government organisations (NGOs) to counterbalance the Green Revolution. The systems first appeared in home gardens and were expanded to commercial farms (Panyakul 2003). ‘Clean and safe’ has gained wider public interest to the public since 2001, after the Thai government implemented a series of policies related to ‘clean and safe’ food and farming. The most important Act was in 2004-2005 when the Government ran the Food Safety Year 2004 campaign to motivate public awareness for safety and food quality (Salakpetch 2007). Moreover, the Ministry of Public Health declared 2004 as the ‘Year of Health for All’ and campaigned for so-called ‘clean and healthy food’. In the following year, organic agriculture was promoted as a national agenda covering issues such as food safety, soil and natural sources conservation, and farmer awareness of consumers’ health. The agenda aims to reduce agricultural chemical use by 50 per cent and increase organic land up to 2.72 million rai (0.44 million hectares) by 2009.

Since May 2008, there has been progress on the national plan for organic agriculture promoted by the National Organic Agriculture Development Board. The board is a collaboration of government agencies, private organisations, NGOs and resource persons from farmer groups and academia. It aims to improve the quality of life of farmers and consumers, promote food security, poverty reduction, and enhance capacity in organic production and marketing. Four strategies were formulated to achieve the goals: focusing on consolidating the knowledge base, capturing local knowledge, marketing improvement and networking (National Organic Agriculture Development Board 2008).

Northern Thailand, particularly Chiang Mai Province, is considered the most promising and important vegetable producing region with its diverse ecosystems and favourable growing conditions for tropical and sub-tropical crop species (Gypmantasiri *et al.* 2000). ‘Clean and safe’ farming systems in northern Thailand were initially practiced by smallholder farmers in their home-gardens. After ‘clean and safe’ agricultural products became an important issue among traders and government organisations, the systems were also adopted commercially near big cities.

Agricultural conversion to ‘clean and safe’ production systems, including organic farming practices in northern Thailand, are commonly encouraged by alternative or sustainable agriculture initiatives of NGOs. Also, government policies have been developed for implementation by both public and private organisations (Kramol *et al.* 2009). Two types of ‘clean and safe’ agricultural production systems are operating, following different approaches. The first type is based on self-sufficiency, emphasising household food security, food safety and income stability (Panyakul 2003). This farming and marketing system is often organised through groups and networks, encouraged mainly by NGOs, and by government organisations and universities. Natural ecosystems with a polyculture of local vegetables, herbs, medical plants and fruit crops are implemented in a home-garden system.

Outputs are mostly sold in alternative markets such as farmers' markets and special retail outlets which sell green and healthy products. Only a few smallholder farmers distribute their organic produce to supermarkets and hypermarkets. The second line of production is focused more on the market-driven organic production system and is mostly engaged by private exporters and organisations such as the Royal Project Foundation (Kramol *et al.* 2005). The produce is mainly distributed to supermarkets and hypermarkets and exported to overseas markets.

Clean and safe' agriculture in northern Thailand is in various stages of conversion from the heavily dependent use of chemicals to no use of chemicals. The range of 'clean and safe' vegetable farming practices in Thailand can be seen as a clean continuum (McCoy and Parlevliet 2000) (Figure 1). The clean continuum ranges from production practices that allow the use of high chemical inputs, safe-chemical, pesticide-free to no chemical use with environmental friendly practices (organic). The ideal of the 'clean and safe' produce system is the organic method that allows the use of organic substitutes such as alternative fertilisers and herbal pesticides rather than synthetic chemicals. Safe-use and pesticide-free farming are intermediate practices between the organic and conventional farming. A pesticide-free farming system is considered a step taken before organic practice since its systems tend to have similar concepts to organic farming systems. However, the pesticide-free method allows the use of synthetic fertilisers to improve farmers' ability to enhance vegetable yields. The safe-use farming system allows the use of synthetic or artificial chemical fertilisers, insecticides, fungicides and herbicides provided the practices strictly follow the system's guidelines. Produce from this system is normally tested for safe levels of chemical residues. This farming practice follows the Good Agricultural Practice developed by the Departments of Agriculture and Agricultural Extension as a production guideline (Salakpetch 2007). Conventional farms are mainstream farming practices that conform to the standard, dominant farming approach (Kristiansen *et al.* 2006).

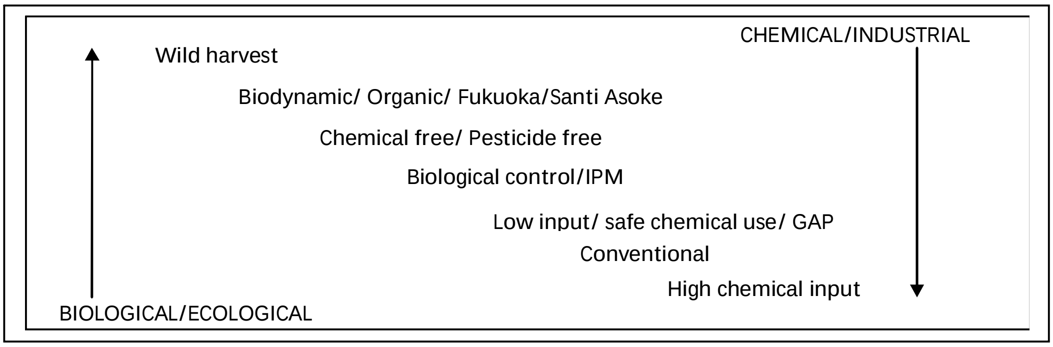

Figure 1 The range of 'clean and safe' farming systems in Thailand
Source: Adapted from McCoy and Parlevliet (2000).

The four systems are also different in terms of their diversification on farms, following the clean continuum as well. Organic farms are likely to have more vegetable species than others, while conventional has the least vegetable species on farms. Pesticide-free farmers tend to farm numerous cash vegetables based on market needed. While safe-use farms are in between pesticide-free farms and conventional farms in terms of farm diversification and vegetable species.

'Clean and safe' and conventional vegetables have different farming practices and marketing arrangements. Vegetable produce is distributed through wholesale traders. Organic vegetables are commonly distributed to special markets through marketing arrangements supported by NGOs, government organisations and private companies (Kramol *et al.* 2009). Marketing arrangements such as farmer markets, institutional markets and fairs are commonly found as marketing supports. Pesticide-free vegetables are commonly sold in the same markets as organic produce, while safe-use vegetables are mainly sold through conventional markets and partly distributed through farmer markets, institutional markets and fairs trade. Conventional vegetables are generally distributed through traders to wholesale markets.

3. Productivity differences in 'clean and safe' vegetable farming

Although vegetable production is only 0.7 per cent of GDP (NESDB 2004), vegetable crops have a higher potential marginal return per area than rice and fibre crops (Isvilanonda 1992). There is sparse literature on the productivity and efficiency of 'clean and safe' farming systems, especially in Thailand. Thai studies on 'clean and safe' farming productivity are concentrated on rice crops, comparing the profitability and performance of organic and conventional rice farming.

Studies on efficiency in organic farming in other countries have focused on livestock, dairy and mixed crop farms, particularly in Europe. Previous studies compared organic and conventional farms by estimating separate production frontiers using data envelopment analysis (DEA) and stochastic frontier analysis. Oude Lansink *et al.* (2002) compared the efficiency and productivity of conventional and organic farms in Finland using DEA. The study covered crop farms and livestock farms and concluded that organic farms are more efficient relative to their own technology but use significantly less productive technology than conventional farms. Kumbhakar *et al.* (2008) studied dairy farming in Finland and found that organic dairy farms were five per cent less efficient than conventional farms. In Italy, Madau (2007) compared organic cereal farm efficiency with the efficiency of conventional farms, and concluded that organic farms used their variable resources less efficiently. The mean technical efficiency estimates for conventional and organic production practices were nevertheless close at 0.902 and 0.831, respectively. The study also showed that efficiency played a crucial role in affecting productivity in the organic process. Sipil?inen and Oude Lansink (2005) took into account self-selectivity bias in a joint adoption and production model. The study controlled for possible selection bias and regional heterogeneity to estimate technical efficiency in organic and conventional dairy farming in Finland, and its development over time. They found that the technical efficiency scores of organic farms with respect to their own frontier are less than those for conventional farms; however, after six to seven years from the switch to organic production, technical efficiencies started to increase again. The metafrontier approach to estimating productivity and technical efficiency was developed by Battese and Rao (2002), Battese *et al.* (2004) and O'Donnell *et al.* (2008). It provides a basis to compare technical efficiency among farmers using different proudtion technologies and operating in different farming environments. To date, however, there are no studies using this approach to compare farms using different 'clean and safe' production technologies.

4. Analytical framework

There are two concerns in our attempt to measure production efficiency in different farming systems. First, self-selectivity bias (Heckman 1979) needs to be considered in order to avoid bias from the self-selection by famers to belong to one of the four farming systems. Second, estimation of the traditional stochastic frontier model to compare technical efficiencies among the four farming systems is not appropriate. To overcome the latter problem, the metafrontier approach is taken.

Three processes were followed:

1. Estimate a farmers' decision model using multinomial logit and include a selection variable from the decision model in the estimated stochastic frontier model. Then, test for the existence of self-selectivity bias.
2. Estimate individual vegetable farm frontiers and test whether or not differences in production technologies exist.
3. Estimate technology gap ratios and technical efficiencies by using a metafrontier framework.

Heckman (1979) was first to warn that sample selection bias may arise in practice because the decision-making units belong to a particular group being investigated through a process of self selection. The estimation of behavioural relationships is considered to arise from the problem of omitted variables. Following Heckman (1979), joint estimation of the decision and production models includes the determinants of selecting among four farming methods and the determinants of vegetable production productivity. A selection variable, the inverse Mill's ratio (IMR), was included in the production frontier model to test for self-selectivity bias. The result of a likelihood ratio test conclusively does not reject the null hypothesis that the coefficient of the IMR variable is zero. A *t*-test on the IMR variable shows the same result. Therefore, it was concluded that self-selectivity bias does not exist in this study.

After testing for self-selectivity bias, we then employed the other two estimation procedures. First, stochastic frontier analysis was used to analyse the technical efficiency of farms that use different production technologies. Second, a metafrontier approach was applied to discern technology gaps between the groups of farms using these different production technologies.

4.1 Stochastic frontier analysis

Based on Aigner, Lovell and Schmidt (1977), the stochastic frontier model is able to measure a composed error structure in production function estimation. A two-sided symmetric error captures the random effects that are beyond the control of the producer. A one-sided error component captures technical inefficiency. The stochastic production frontier model can be represented as

$$Y_i = f(X_i, \beta)\exp(V_i - U_i) \tag{1}$$

where Y_i is the scalar output of the i-th farm; X_i is a vector of N inputs used by producer i; $f(X_i, \beta)$ is the production frontier; and β is a vector of technology parameters which need to be estimated. V_i is intended to capture the effect of statistical noise and U_i expresses the technical inefficiency in production.

4.2 Metafrontier analysis

Firms in different circumstances (such as logistics and systems) face different production opportunities. In such cases, entrepreneurs make choices from different technology sets with varying sets of feasible input and output combinations. Technology sets differ in terms of human capital, economic infrastructure, resource endowments and socioeconomic environment. As a result, frontiers should be estimated separately for each technology set in order to measure the technical efficiency of the different groups of firms. However, the comparison of efficiency levels measured relative to different frontiers is commonly unattainable because one frontier may not be comparable to another. The metafrontier framework was first introduced by Hayami (1969) and Hayami and Ruttan (1970; 1971) and developed extensively by Battese and Rao (2002), Battese *et al.* (2004) and O'Donnell *et al.* (2008). The framework allows the comparison of technical inefficiencies across a number of firms in an industry which have different technologies. Measurement of the technology gap is undertaken in order to make this comparison. The boundary of an unrestricted technology set is defined as a common metafrontier, while the boundaries of restricted technology sets are defined as group frontiers.

As the metafrontier envelops the group frontiers, efficiencies measured relative to the metafrontier can be divided into two components. The first component is associated with the common measure of technical efficiency that measures the distance from an input-output relative to the group frontiers. The other component measures the distance between the group frontiers and the metafrontier, which corresponds to the restrictive characteristics of the production technologies.

Following Battese and Rao (2002), equation (1) can be re-expressed as a stochastic frontier of each group-*k* frontier model as:

$$Y_i^k = f(X_i, \beta^k)\exp(V_i^k - U_i^k)$$

$$Y_i^k = f(X_i, \beta^k)e^{V_i^k - U_i^k} \equiv e^{X_i\beta^k + V_i^k - U_i^k} \tag{2}$$

where X_i is the inputs quantity of the ***i***-th firm; β^k is an unknown parameter vector associated with the *k*-th group; V_i^k represents statistical noise and is assumed to be independently and identically distributed as $N(0, \sigma_{V^k}^2)$ random variables; and U_i^k represent inefficiency defined by the truncation (at zero) of the $N(\mu_i^k, \sigma_{U^k}^2)$ distributions, where $U_i^k s$ are defined by an appropriate inefficiency model following Battese and Coelli (1995).

The technical efficiency of the *i*-th firm with respect to the group-*k* frontier can be obtained using:

$$\mathrm{TE}_i{}^k = \frac{Y_i^k}{e^{X_i\beta^k + V_i^k}} = e^{-U_i^k} \tag{3}$$

A stochastic metafrontier production function model in all firms can be expressed as:

$$Y_i^* = f(X_i, \beta^*) \equiv e^{X_i\beta^*} \tag{4}$$

where Y_i^* is the metafrontier output and β^* is the vector of metafrontier parameters satisfying the constraints:

$$X_i\beta^* \geq X_i\beta^k \text{ for all } k = 1,2,\ldots,K \tag{5}$$

The constraints given by equation (5) imply that the metafrontier function cannot fall below any of the group frontiers.

Following O'Donnell *et al.* (2008), an estimated metafrontier function which envelops the estimated group frontiers can be obtained by applying the optimisation problem.

Equation (2) can be alternatively expressed in terms of the metafrontier function in equation (4) as

$$Y_i = e^{-U_i^k} \cdot \frac{e^{X_i \beta^k}}{e^{X_i \beta^*}} \cdot e^{X_i \beta^* + V_i^k} \tag{6}$$

where $e^{-U_i^k}$ is defined by equation (3), the technical efficiency of the *i*-th firm with respect to the group *k* frontier. The second term represents the technology gap ratio (TGR) or metatechnology ratio (MTR).

$$\mathrm{TGR}_i \text{ or } \mathrm{MTR}_i^k = \frac{e^{X_i \beta^k}}{e^{X_i \beta^*}} \qquad \text{where } 0 \le \mathrm{TGR} \le 1 \tag{7}$$

The TGR measures the ratio of the output in the frontier production function for the *k*-th group relative to the potential output defined by the metafrontier function. As the value of TGR approaches 1, the gap between the group frontier and the metafrontier decreases.

The technical efficiency of the *i*-th firm relative to the metafrontier is denoted by TEm_i and is defined in a similar way to equation (3). It is the ratio of the observed output relative to the metafrontier output – the last term on the right-hand side of equation (6). Technical efficiency is then defined as:

$$\mathrm{TEm}_i = \frac{Y_i}{e^{X_i \beta^* + V_i^k}} \tag{8}$$

The technical efficiency relative to the metafrontier is the ratio of the observed output to the frontier output. Then,

$$\hat{\mathrm{TEm}}_i = \hat{\mathrm{TE}}_i^k \times \hat{\mathrm{TGR}}_i^k \tag{9}$$

where $\hat{\mathrm{TE}}_i^k$ and $\hat{\mathrm{TGR}}_i^k$ are predictors discussed in connection to equation (3).

4.3 Empirical model

In this study, ‘clean and safe’ vegetable farming systems are considered to be different, at least in terms of their sets of technology needs. Different technologies might have different production performances and efficiencies. Stochastic frontier analysis and metafrontier analysis, mentioned in the previous discussion, were used to estimate technical efficiency and the TGRs. The first one is used to analyse technical efficiency in each farming system and the second is used to compare production frontiers among farming systems .

A stochastic frontier production function is applied to cross-section data in four models of vegetable farming systems in northern Thailand. Vegetable farms in this study are categorised into four farming systems: three ‘clean and safe’ and conventional. With different technology sets among those four groups (three ‘clean and safe’ and conventional farming systems), the metafrontier approach is an appropriate method in order to make a comparison of the four systems. The expression of group frontiers and metafrontier is illustrated in Figure 4.

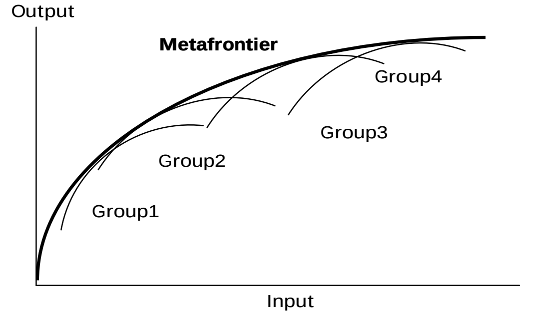

Figure 4 Metafrontier function model
Source: Battese *et al.* (2004)

The specification of the translog functional form is given by

$$\ln Y_i^k = \beta_0^k + \sum_{j=1}^{5} \beta_j^k \ln X_{ij}^k + \tfrac{1}{2}\sum_{j=1}^{5}\sum_{s=1}^{5} \beta_{js}^k \ln X_{ij}^k \ln X_{is}^k + D_i^k + V_i^k - U_i^k \tag{10}$$

where *j* represents the *j*-th input (*j*=1,2,…,5) of the *i*-th firm (1,2,…,N_k); $\beta_{ij}^k = \beta_{ji}^k$ for all *j* and k; k_1= organic vegetable (OV) farming method, k_2= pesticide-free vegetable (OV) farming method, k_3= safe- use vegetable (SUV) farming method and k_4= conventional vegetable (CV) farming method; Y_i represents vegetable production (baht); X_1 is the total area planted to vegetables (rai); X_2 is seed used (baht); X_3 is labour used (man-days); X_4 is fertilisers used (baht); X_5 is crop protection used (baht); D_1 and D_2 are dummy variables for zero values of X_4 and X_5, respectively; D_3 is a dummy variable for farms that used only synthetic fertiliser and pesticide; and $D_{4(k)}$ is a location dummy variable of farms areas with altitude at least 750 meters. All variables except the dummies are mean-corrected to zero, hence, the first-order estimates of the coefficients in the model are interpreted as elasticity.

Following the technical inefficiency model specification of Battese and Coelli (1995), we have:

$$\mu = \delta_0 + \sum_{j=1}^{6} \delta_j Z_{ji} + \sum_{s=1}^{6} \delta_s D_{si} \tag{11}$$

where δ_{js} (*j*=0,1,..11) are unknown parameters; Z_1 is vegetable farming experience (years); Z_2 is land holding (rai); Z_3 is highest education of members working on farm (years); Z_4 is the average age of members working on farm; Z_5 is off-farm income (baht); Z_6 is the proportion of family labour working on farm; D_4 is a location dummy (1, if high land (> 750mm), 0 otherwise); D_5 is a dummy variable for information sources (1 if famers get agricultural information from mass communication, 0 otherwise); D_6 is a dummy variable for roles and political position (1 if farmers have any public roles or political position, 0 otherwise); D_7 is a dummy variable for faming system (1 if mixed vegetable farm operated in a sustainable way (including local vegetables), 0 otherwise); D_8 is a dummy variable for assistance provider (1 if an assistance provider is a government organisation, 0 otherwise); D_9 is a dummy variable for assistance provider (1 if assistance provider is an NGO, 0 otherwise); D_{10} is a dummy variable for assistance provider (1 if assistance provider is a private organisation, 0 otherwise) and D_{11} is a dummy for the number of vegetables grown on farms (1 if the farmer grows more than three vegetables, 0 otherwise).

4.4 Data and variables

The data used in this study were collected from a cross-section sample of vegetable farms in northern Thailand, focusing on Chiang Mai province in the crop year 2007/2008. An on-farm survey using questionnaires was applied to farmers on organic, pesticide-free, safe-use and conventional farms. The respondent farms were 104 organic farms (OV), 88 pesticide-free farms (PFV), 88 safe-use farms (SUV) and 97 conventional farms (CV).

Descriptive statistics of the variables included in the stochastic frontier production functions are summarised in Table 2 and Table 3. The average vegetable farm income is about 118,350 baht, which is approximately 42,267 baht per rai. Table 2 shows differences in total income per vegetable farm across farming systems where SUV and CV farms have about three times higher income than OV and PFV farms. However, differences are quite small when scaled on a per area basis. Average vegetable farm area is about 2.8 rai, which is about 0.45 hectare. SUV and CV farms have larger areas than OV and PFV farms. Seed use is about 5,521 baht per farm, with PFV farms having the lowest seed cost. The OV and PFV farms are labour-intensive but have lower fertiliser use and crop protection cost than the SUV and CV farms. Location of vegetable farm is expected to influence vegetable production since there are environmental differences such as temperature, soil condition and water sources. Only 36 per cent of farms were in locations that have an altitude of at least 750 metres and most of them are OV and SUV farms. Lastly, more than half of SUV and CV farms used only synthetic fertiliser and pesticide.

Table 2 Mean production and inefficiency variables by farming system

Variables	Farming system				
	OV	PFV	SUV	CV	All
Production variables:					
Vegetable output (baht)	50,641	68,217	193,853	167,929	118,350
Vegetable output (baht/rai)	38,955	45,478	43,078	43,059	42,268
Area (rai)	1.3	1.5	4.5	3.9	2.8
Seed (baht)	3,509	2,240	7,576	8,791	5,521
Labour (man day)	285.6	343.5	474.2	358.4	361.9
Fertiliser (baht)	2,808.9	5,063.7	31,108.3	28,801.6	16,628.7
Crop protection (baht)	2,121.5	975.9	6,743.2	8,726.8	4,632.4
Inefficiency variables:					
Vegetable farm experience (years)	12.0	17.3	15.1	21.0	16.3
Land holding (rai)	5.3	7.8	9.4	8.6	7.7
Highest member education (years)	4.3	6.8	6.1	5.9	5.7
Age of members working on farm	45.7	51.9	40.5	48.4	46.6
Off-farm income (1000 baht)	20.0	39.3	13.7	10.9	20.7
Proportion of family labour (%)	94.5	96.0	85.5	86.2	90.6

Table 3 Percentage of factors included in vegetable production and inefficiency model by farming systems

Variables	Farming system				
	OV	PFV	SUV	CV	All
Applied only synthetic chemical	0	0	57	64	30
Location at altitude is higher 750m	58	3	70	11	36
Information sources from mass communication	46	70	38	62	54
Roles and political in village	24	38	19	11	23
Practises mixed vegetable farm in sustainable way	29	45	1	0	19
Government assistance	14	94	28	0	33
NGO assistance	27	0	0	0	7
Private assistance	58	0	69	0	32
Farm more than three vegetables	71	81	39	30	55

Summaries of descriptive statistics of inefficiency variables are also provided in Table 2 and Table 3. The average age of members working in the farms is about 46 years old. Farmers have vegetable farming experience for 16 years on average. The PFV and CV farmers seem to have higher age and more experiences than others. The highest educational attainment is commonly in primary school, which is six schooling years. The PFV farmers are the most educated group while OV farmers are the least educated. OV and PFV farms had smaller land holding than SUV and CV farms, and had a high proportion of household members working on the farm. The latter also have less off-farm income. PFV households tended to receive a higher proportion of mass communication information, have public roles and political positions in the village, and practise vegetable farming in sustainable ways. Growing few vegetables improves the technical efficiency of CV and SUV farms in terms of simplifying farm management and marketing activities.

5. Results and discussion

The maximum-likelihood estimates of the parameters in the group frontiers and inefficiency models were estimated simultaneously. The values of explanatory variables in the translog stochastic frontier model were mean-corrected to zero; therefore the first-order parameter estimates are partial output elasticities for the individual inputs at their mean values. Estimations were obtained using the FRONTIER 4.1 program (Coelli, 1996).

5.1 Stochastic production frontier estimates

For all group frontiers, the technical inefficiency variables significantly add to the explanatory power of the model. Estimates of the stochastic frontier models are summarised in Table 4. All inputs are found to be statistically significant and have the expected positive effect on vegetable production. Area and labour showed highly significant effects on vegetable output for most farming systems, while seed is highly significant for all groups except SUV farms. Fertiliser is found to have highly significant and positive impact on SUV production while it is significant and positive at the 10 per cent level for OV farms. Crop protection is significant only for OV farms at the 10 per cent significance level.

The coefficient for the dummy variable for farms using only synthetic chemicals shows is negative and significant at the 5 per cent level for CV farms. The coefficient on the dummy variable for highland farms is positive for all groups and significant at 1 per cent level except for OV farms where it is significant at the 5 per cent level.

5.2 Inefficiency effects

Estimates of inefficiency effects are presented in Table 5. They show that farming systems are influenced by different factors, and coefficients have different signs among farming systems. Vegetable farm experience and having a government organisation as an assistance provider have negative and highly significant effects on inefficiency on SUV farms only. Having NGOs has a negative effect on inefficiency for OV farms. The mean age of members working on the farm and having roles and positions in the village show significant and positive effects on inefficiency for SUV farms only. Land holding is found to have a significant and positive effect on inefficiency for PFV farms but a negative effect on inefficiency for SUV farms. SUV and CV farm efficiencies improve with more education. Off-farm income is found to have a significant effect on inefficiency with negative signs for OV and SUV but with a positive sign for CV. Having a higher proportion of family labour working on vegetable farm is found to lead to greater inefficiency on PFV and SUV farms. Vegetable farms in highland areas and following sustainable practices show higher efficiency for PFV farms but lower efficiency for SUV farms. Lastly, SUV and CV farms growing more than three vegetables are significantly have higher inefficiency.

Table 4 Estimates of parameters of the translog stochastic frontier models

Variables	Farming Systems				Pooled frontier	Meta-frontier
	OV	PFV	SUV	CV		
Constant	0.716[a] (0.0202)	1.072[a] (0.141)	-0.112[b] (0.0579)	1.107[a] (0.197)	0.517[b] (0.278)	1.253
Area	0.192[b] (0.0815)	0.364[a] (0.0949)	0.502[a] (0.0484)	0.471[a] (0.0823)	0.333[a] (0.0464)	0.400
Seed	0.265[a] (0.0529)	0.218[a] (0.0798)	-0.0411 (0.0392)	0.203[a] (0.0577)	0.116[a] (0.0314)	0.153
Labour	0.546[a] (0.0889)	0.469[a] (0.135)	0.328[a] (0.0563)	0.205[b] (0.0869)	0.458[a] (0.0559)	0.339
Fertiliser	0.057[c] (0.0367)	0.0388 (0.0578)	0.392[a] (0.0757)	0.0963 (0.0826)	0.179[a] (0.0306)	0.135
Crop protection	0.0577[c] (0.04)	-0.0137 (0.0616)	-0.00870 (0.0318)	0.0595 (0.0622)	0.0343[c] (0.0249)	0.04
Fertiliser dummy	-1.298[a] (0.114)				-2.211[b] (1.0217)	-1.712
Crop protection dummy	0.0869 (0.771)	-1.0936 (0.981)			0.0596 (0.487)	-0.311
Synthetic chemical dummy			0.0550 (0.0856)	-0.188[b] (0.1)	-0.036 (0.0751)	-0.075
Highland dummy	0.445[b] (0.197)	1.896[a] (0.523)	1.451[a] (0.188)	1.242[a] (0.506)	1.0548 (2.933)	1.217
Sigma-squared	0.132[a] (0.0193)	0.333[a] (0.108)	0.208[a] (0.0311)	0.149[a] (0.0241)	0.240[a] (0.0227)	
Gamma	0.999[a] (0.000)	0.999[a] (0.000)	0.999[a] (0.000)	0.999[a] (0.273)	0.438[c] (0.273)	
Log likelihood function	-20.992	-50.195	-20.333	-43.037	-253.871	
LR test of one-side error	48.923	32.731	69.306	23.091	62.166	

Note: Figures in parentheses are standard errors

a, b, and c denote significant using a one-tailed test at 1, 5, and 10 per cent levels, respectively.

Table 5 Estimates of parameters of the inefficiency effects

Variables	Farming Systems				Pooled frontier
	OV	PFV	SUV	CV	
Constant	0.933^{c}	-2.461^{b}	-0.765	1.178^{a}	0.298
	(0.647)	(1.2)	(0.747)	(0.375)	(0.522)
Vegetable farm	0.00656	0.00199	-0.0331^{a}	-0.00442	-0.00124
experience (years)	(0.00569)	(0.0128)	(0.00795)	(0.00438)	(0.00302)
Land holding (rai)	0.00973	0.0254^{c}	-0.0232^{a}	0.00539	0.00428
	(0.0105)	(0.0195)	(0.00904)	(0.00576)	(0.00388)
Highest education of	0.0154	-0.00098	-0.0289^{c}	-0.048^{b}	-0.00863
members working on farm (years)	(0.0155)	(0.0451)	(0.0196)	(0.0207)	(0.00967)
Average age of	0.000309	0.0053	0.0124^{c}	0.00443	-0.0019
members working on farm	(0.00609)	(0.0215)	(0.00742)	(0.00804)	(0.00437)
Off-farm income	-0.00208^{b}	-0.00121	-0.00405^{c}	0.00485^{b}	-0.000335
(1000 baht)	(0.00103)	(0.00314)	(0.00277)	(0.00225)	(0.000717)
Proportion of family	0.000297	0.0334^{b}	0.0167^{a}	-0.000499	0.00523^{b}
labour working on vegetable farm	(0.00338)	(0.0164)	(0.00357)	(0.00353)	(0.00248)
Location at altitude at	0.388	-2.818^{a}	1.428^{a}	1.165^{b}	0.697
lease 750m	(0.442)	(1.115)	(0.540)	(0.523)	(2.933)
Information sources	-0.0121	-0.317	-0.0711	-0.082	-0.0573
from mass communication	(0.0915)	(0.374)	(0.146)	(0.113)	(0.0644)
Roles and political	0.0219	-0.14	0.902^{a}	-0.0291	-0.06
position in village	(0.128)	(0.767)	(0.225)	(0.174)	(0.085)
Practises mixed	-0.088	-0.569^{c}	1.984^{a}		-0.269^{b}
vegetable farm in sustainable way	(0.166)	(0.431)	(0.677)		(0.122)
Assistance provider:	-0.501	0.0736	-1.816^{a}		-0.0212
government	(0.395)	(0.755)	(0.593)		(0.118)
Assistance provider:	-1.345^{a}				-0.93
non government	(0.372)				(0.743)
Assistance provider:			-0.439		0.348^{b}
private			(0.479)		(0.151)
Farm more than three	0.147	0.0736	0.621^{a}	0.258^{b}	0.259^{a}
vegetables	(0.129)	(0.755)	(0.136)	(0.112)	(0.0704)

Note: Figures in parentheses are standard errors

a, b, and c denote significant using a one-tailed test at 1, 5, and 10 per cent levels, respectively.

5.3 Metafrontier estimates

In order to test for differences in group frontiers, the pooled stochastic frontier was estimated. We rejected the null hypothesis of the generalised likelihood ratio test statistic that group frontiers are the same. The generalised likelihood ratio test statistic that group frontier are the same is LR=223.5, with a p-value of 0.000. Therefore, the estimation of metafrontier is justified. The parameter estimates of the metafrontier are presented in Table 4. The results show slightly different between the metafrontier and the pooled frontier with respect to the magnitude of parameter. All input variables have positive effect on mean vegetable production. The important factors that strongly influence vegetable production are area and labour (0.333-0.458). Seed and crop protection show lower effects on vegetable production with an elasticity in the range 0.1-0.2. Crop protection has low effects on production on both pooled and metafrontier (elasticities of 0.034 and 0.04).

The estimates of technical efficiencies and TGRs are presented in Table 6. The average technical efficiency estimates in all individual farming systems are relatively low at 0.416, 0.474, 0.434 and 0.337 for OV, PFV, SUV and CV, respectively. By looking at individual farming systems, the mean TE for PFV is higher than the mean TEs for SUV, OV and CV. However, in order to compare efficiencies across farming systems which have different technologies, technology gap ratios (TGRs) are taken into account.

On average, the estimated TGRs for OV, PFV, SUV and CV are 0.446, 0.631, 0.387 and 0.802 respectively. The TGRs illustrate technology gap of vegetable farms in individual vegetable farming systems compared to all vegetable farms according to farm performance. The TGR of conventional farms shows the highest value meaning that conventional farms have the least technology constraints than others. Average technical efficiencies with respect to the metafrontier (TEm) are also provided in Table 6. They range from 0.149 to 0.286. Pesticide-free farms have the highest TEm, followed by conventional, OV and SV farms.

The estimated density functions of TE, TGRs and TEm are presented in Figures 5 to 7. The distributions of these indicators are significantly different from each other, as confirmed by statistical tests conducted on the median values. All farming systems have a wide distribution; OV and PFV have much more heterogeneous technical efficiency than others. Maximum TGRs of one in every farming system indicate that farms in all systems are potentially able to remove technology constraints in order to improve their farm performance.

6. Discussion of results

The results of estimates of farm performance based on technical efficiency with respect to the specific production frontiers differ across farming systems. These results provide an indicator of the technical efficiency with which each of the farms was operating within their respective technological group. All vegetable farming groups have a low mean technical efficiency, from 0.337 for CV farms to 0.474 for PFV farms, and individual technical efficiencies that ranged widely within each group. This suggests that a high proportion of vegetable farms in northern Thailand were not able to use their inputs effectively to achieve the highest output possible, based on their own technology sets. 'Clean and safe' farms achieved a higher TE score than conventional farms, indicating a more efficient use of inputs in producing a certain level of output. It also suggests that the high input use on seed, fertiliser and pesticide did not achieve high farm output on most conventional farms. The TE values recorded here are lower than other studies (e.g. Madau 2005; Kumbhakar *et al.* 2008) presumably due the the more

Table 6 Estimates of TE, TEm and TGR

Model	Item	Farming systems			
		OV (N=104)	PFV (N=88)	SUV (N=88)	CV (N=97)
TE with respect to the group frontier (TE)	Mean	0.416	0.474	0.434	0.337
	Median*	0.293	0.411	0.278	0.320
	Min	0.099	0.042	0.043	0.054
	Max	1.000	1.000	1.000	0.965
	SD	0.276	0.241	0.326	0.178
Technology gap ratio (TGR)	Mean	0.446	0.631	0.387	0.802
	Median*	0.355	0.642	0.338	0.804
	Min	0.006	0.095	0.060	0.312
	Max	1.000	1.000	1.000	1.000
	SD	0.239	0.212	0.181	0.150
TE with respect to the metafrontier (TEm)	Mean	0.220	0.286	0.149	0.266
	Median*	0.091	0.256	0.116	0.235
	Min	0.001	0.030	0.024	0.050
	Max	0.995	0.944	0.597	0.794
	SD	0.231	0.175	0.121	0.151

Note: * denotes significant for median test at 1 per cent level using Kruskal-Wallis test.

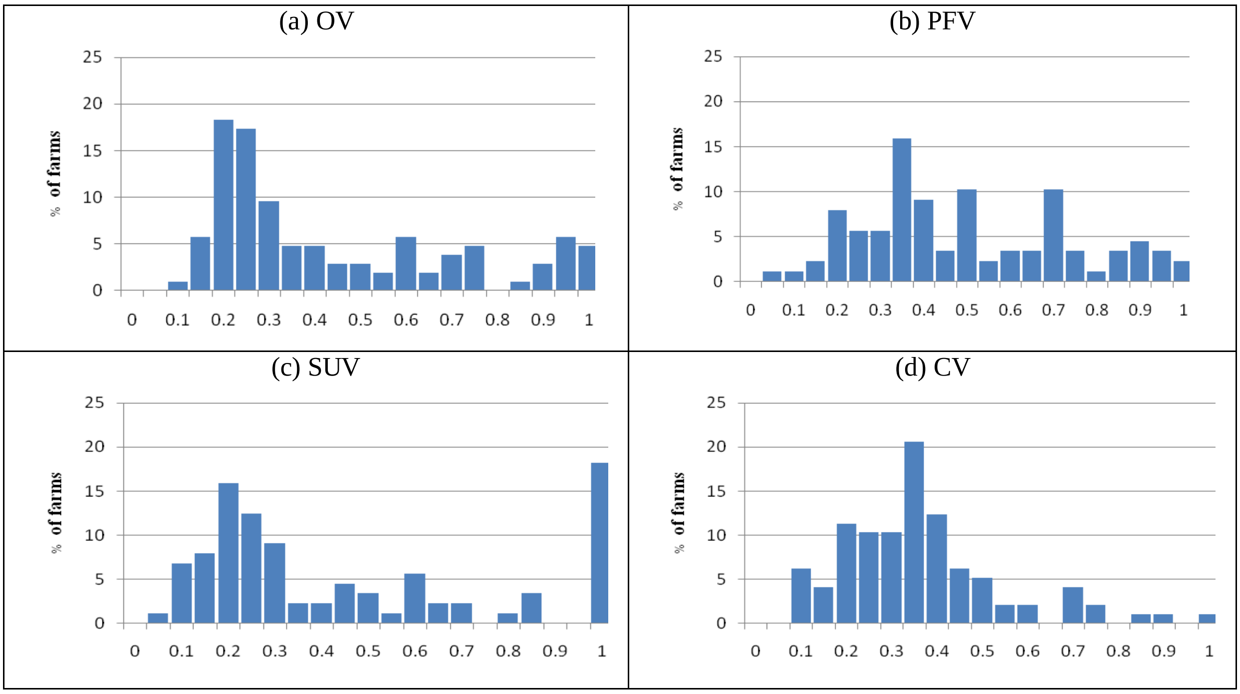

Figure 5 Density of farm-level technical efficiencies with respect to group frontier

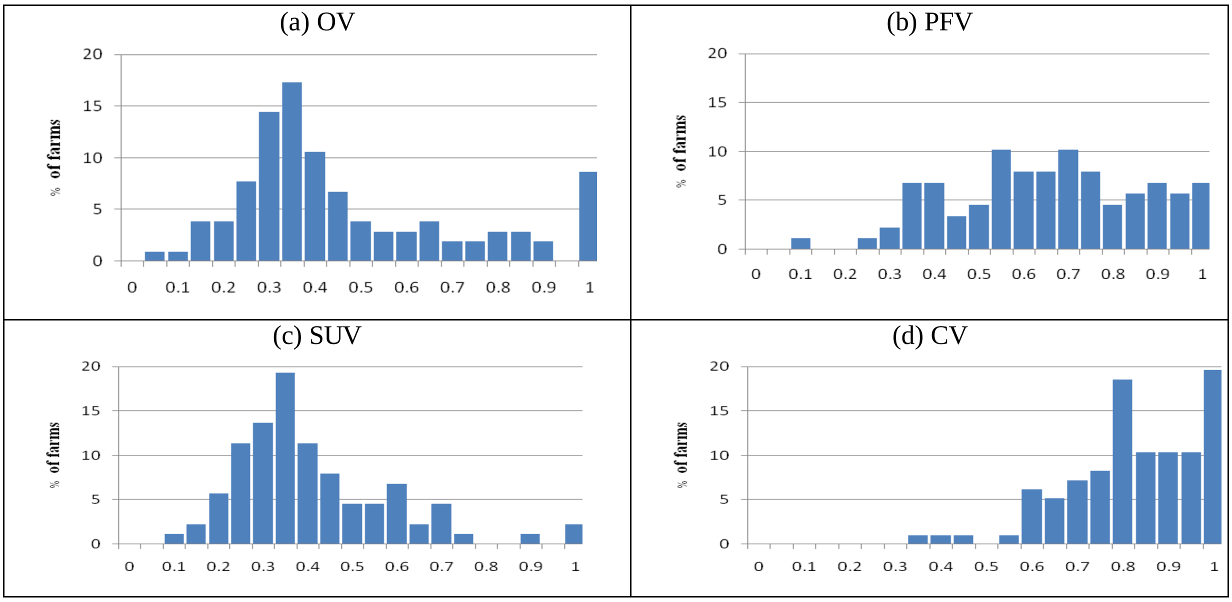

Figure 6 Density of technology gap ratios

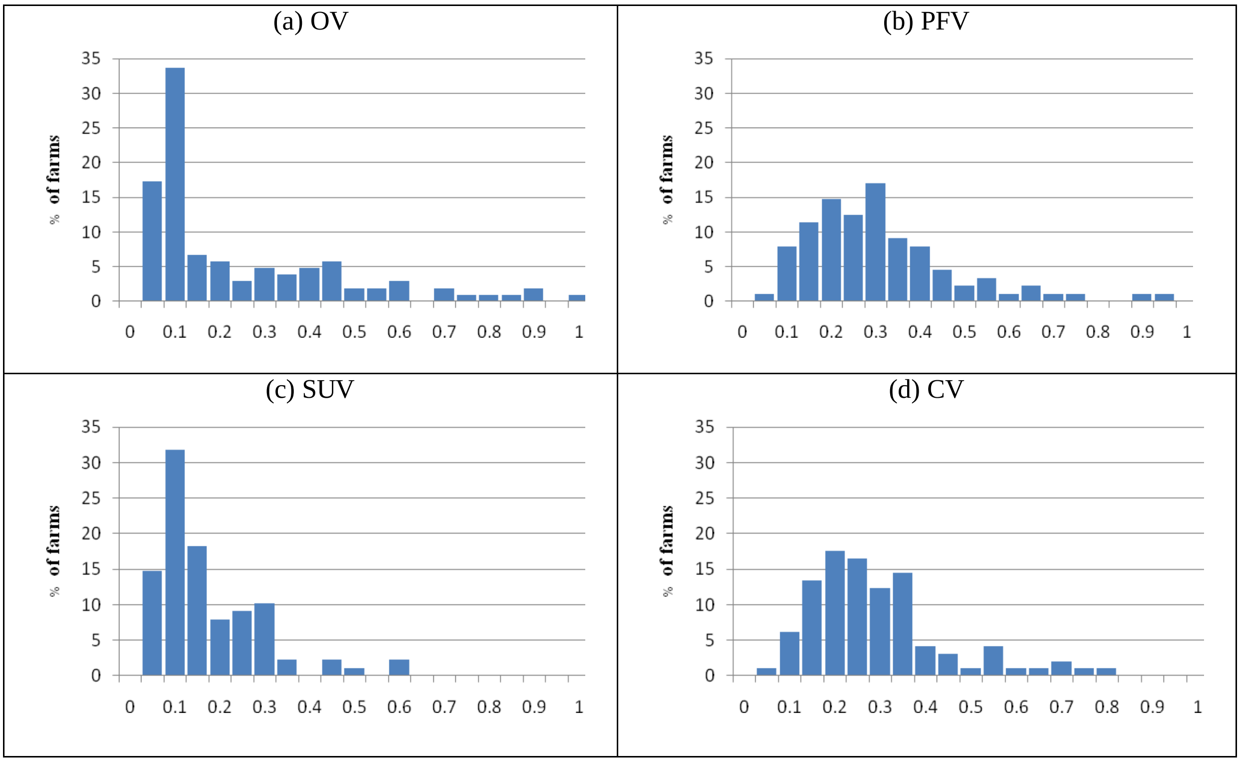

Figure 7 Density of farm-level technical efficiencies with respect to the metafrontier

complex cropping patterns used in vegetable production compared with livestock and cereal production. Technical efficiency with respect to the metafrontier implies that the technology gap ratios of 'clean and safe' farmers are significantly lower than those of conventional farmers where the mean TGR was 0.802. Hence, conventional technology has a higher production capacity but lower efficiency in transforming inputs into outputs. For 'clean and safe' farms, production technology constraints were highest on organic and safe-use farms, for which mean TGRs were 0.446 and 0.387, respectively. Technology constraints are lower on pesticide-free farms, where the mean TGR was 0.642. The fact that safe-use vegetable farms are found to have the lowest mean technology gap ratios is interesting in that synthetic chemical use is expected to improve output capacities. Restrictive regulations can be a major technology barrier since safe-use farms, like organic farms, are required to conform to strict standard practices. The farms are inspected both on farming practices and for the issuance of produce qualifications and were expected to have the lowest mean TGR.

Despite the low mean TGRs on 'clean and safe' farms, all four farming systems were found to have at least one farm that lay on the metafrontier. This result means that at least some farmers practising different methods are able to eliminate technological constraints to achieve the highest possible output regardless of the technology used.

Famers' abilities to operate vegetable farms efficiently can be improved by paying attention to the effects of the inefficiency variables. There are different factors influencing inefficiencies in the four farming methods. Assistance provided by NGOs is found to have large and positive impacts on efficiency levels on organic vegetable farms. As mentioned before, organic farms in northern Thailand follow two different strategies: predominantly self-sufficiency and commercial farming. The first strategy, also called traditional or sustainable organic farming, was initially implemented by NGOs. The system commonly has no use of any synthetic chemicals and farmers are encouraged to have the ability to operate their farms using internal inputs rather than purchase them from input markets. Farming assistance is commonly transferred through farmer groups and networks. The second strategy is applied on farms receiving advice and assistance from private organisations. Here, conversion to organic practices is in an early stage on these farms. Farmers operate their farm depending substantially on external inputs such as commercial alternative pesticides and fertilisers. Practically, to achieve 'clean and safe' practices organic farmers need relevant support on production, postharvest and marketing practices, particularly during the conversion period (Kramol *et al*. 2005; Lorlowhakarn *et al.* 2008; Kramol *et al.* 2009). For these reasons, factors affecting the provision of farmer assistance need to be identified to improve organic farm efficiency. In addition, direct and practical support from NGOs through participatory and community-based training methods (Lorlowhakarn *et al.* 2008) should be considered to enhance the process of technology transfer.

On the contrary, production inefficiencies of pesticide-free farms are lower than for organic farms, especially those located at an altitude of at least 750 metres. Pesticide-free farmers who implement sustainable farming concepts on their farms have higher farm efficiencies. The idea of sustainable farming concept on pesticide-free farms is relevant to that of traditional organic farming which focuses on farm diversification because the only obvious disparity between organic and pesticide-free farms is that pesticide-free farmers are allowed the use of synthetic fertilisers.

Safe-use and conventional farms show fairly similar results on the factors affecting their technical inefficiency. Higher farmer education is found to reduce inefficiency for farms in both groups. Inefficiency on conventional farms could also be reduced by greater specialisation in vegetable production. Planting fewer vegetable species reduces time and cost in production and marketing. In addition, farms located at an altitude below 750 metres improve efficiency on conventional farms because the farms are closer to markets (the central city). On safe-use farms, results show that support from government organisations can reduce technical inefficiency. This suggests that training farmers in production skills and marketing arrangement enhances their abilities to increase their farm efficiencies. Low technical inefficiency on conventional farms could be explained by low or lack of production and marketing support.

The estimated technical efficiency and technology gap ratios in this study could illustrate expected farm performances among vegetable farming systems. Relative to their own technology, farms with ‘clean and safe’ practices commonly show higher technical efficiency than conventional farms. This might be due to the support from a number of organisations in northern Thailand. The government could consider providing greater assistance to conventional farmers to help them improve their technical efficiency to levels achieved by farms with ‘clean and safe’ practices. On the other hand, technology gap ratios indicate that ‘clean and safe’ farming methods have higher production constraints than conventional farms. However, all farming systems have at least one farmer located on the metafrontier, implying that all practices are able to reduce constraints to achieve maximum attainable productivity. In other words, the development of vegetable farms in terms of productivity is achievable for all farming practices.

In order to strengthen ‘clean and safe’ farm productivity, internal and external constraints on farmers need to be overcome through collaborative assistance and support from relevant organisations in both the public and private sectors. The factors include:

The effectiveness and availability of **production technologies** to deal with agronomic constraints, especially crop protection and nutrient management, is fundamental. The technology improvement should be relevant to particular farms’ circumstances, conditions and logistical systems. The technologies applied on the farm following the directions given by different assistance providers have their own strengths and weaknesses that should be considered.

The ‘clean and safe’ industries need **supply chain development** to manage the marketing of farmers’ produce. Marketing infrastructure (e.g. processing facilities, labelling schemes) and supply chains (for both farmers and marketing intermediaries) are important factors influencing farm efficiency, profitability and technology adoption.

Improvement of **farmer capacity** in managing their farms for both production and marketing is needed. Farmers’ knowledge and perceptions about ‘clean and safe’ agronomic practices and supply chain involvement are important factors for on-farm efficiency, profitability and technology adoption.

Technology transfer processes should be considered in order to improve innovation and adoption. ‘Clean and safe’ farming technologies are complicated and have less economic benefit, particularly in the conversion period. Although there are a number of assistance providers, agencies and projects supporting farmers, improving the relevance and effectiveness of their technology transfer strategies is required.

7. Conclusions

This paper provides a comparative analysis of production performance in three ‘clean and safe’ vegetable faming systems and a conventional vegetable faming system. The technical efficiencies and technology gaps of organic, pesticide-free, safe-use and conventional farms are analysed using stochastic frontier analysis and metafrontier analysis, respectively. The technical efficiencies with respect to individual frontiers show that all group frontiers have low mean technical efficiencies. For conventional farms, technical efficiencies with respect to their frontier are lower than those for other groups. In contrast, the estimates of technology gap ratios for conventional farms are significantly higher than those for 'clean and safe' farms.

The group frontiers of all farming systems are found to touch the metafrontier, meaning that all farming systems have the potential to reduce their technology constraints to achieve the highest available productivity level. On this basis, appropriate support services should enable 'clean and safe' vegetable farms to reach productivity levels at least equivalent to those achieved by conventional farms.

The wide range of technical efficiencies and TGRs of farms in all farming systems suggests that farm performance can be improved by the provision of assistance services. But the vast differences in production performance among farmers indicate that the extent and forms of assistance are likely to vary among members in each group. Organisations and projects providing assistance for 'clean and safe' farming methods that influence vegetable production in northern Thailand still have a lot of work to do if farmers engaging in these practices are to achieve their full potential.

Various factors, including forms of support provided by different organisations, were found to improve technical efficiency, but their impacts were not consistent across farming systems. The inefficiencies of all individual farming systems are influenced by different factors such as effective assistance providers, farm location, farmer education and number of vegetable species grown. Specifically, improvements are needed for agronomic technology, supply chains, farmer capacity in production and marketing, and effectiveness of technology transfer processes.

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