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Efficiency of improved peeled longan drying technology in Thailand: A metafrontier approach

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ABSTRACT

In today's markets, for manufacturing to remain competitive and productive, development and adoption of improved technology is imperative. Energy efficiency technology is a promising candidate as it can save on energy costs, thus shortening the investment payback period. In addition, it has the added benefit of reducing carbon dioxide emissions, helping mitigate global warming. Longan, a tropical fruit grown in northern Thailand, is a popular food product peeled and dried. Peeled longan drying technology is one such manufacturing process that may potentially benefit from technology improvements. The objective of this study is to analyze the potential efficiency gains from adopting an improved drying oven. The study employed Data Envelopment Analysis to examine technical efficiency and metafrontier estimation for technological impact. Forty-four dried longan processors, using conventional drying ovens, were compared with four processors using improved ovens in Lamphun Province, Thailand. As determined by the Mann-Whitney U test, the technical efficiency of the two groups differed (at 95% statistical significance), allowing for the use of a deterministically constructed metafrontier to calculate the comparable operational efficiencies of the two different technologies. The technical efficiency of the improved technology group (TEi) was higher than the conventional technology group (TEc), 0.998 compared to 0.941, respectively. The key difference between the two drying technologies was fuel consumption (at 99% statistical significance). The improved oven technology enhanced technical efficiency by reducing fuel input by 26.1% per oven. If all 305 traditional ovens were converted to the improved technology, this would reduce fuel use by approximately 60 metric tons/day, saving over THB 70,000 per day. This fuel savings would also reduce carbon dioxide emissions by 100 tons/day.

Keywords: Metafrontier, Dried longan, CO_2 emissions, Energy reduction, Community enterprises

JEL Classification: C18

1. Introduction

Global warming, a cause of climate change affecting human livelihoods and ecological systems in a multitude of dimensions, is primarily a consequence of carbon dioxide emissions that has increased by almost 10% during 1990-1999 (Dagoumas et al., 2006). Carbon dioxide is a major greenhouse gas (GHG) constituent (Rehan and Nehdi, 2005). The main cause of rising GHG emissions is domestic consumption demand followed by increasing export production (Rhee and Chung, 2006). The Kyoto Protocol in 1997 committed signatory countries to a collective reduction of GHGs of at least 5% during 2007-2012 (United Nations, 1998). A study by Rhee and Chung on the change in the level of carbon dioxide emissions in South Korea and Japan found that improved energy-use efficiency in production could help reduce carbon dioxide emissions. Agricultural processing activities in Thailand, including wood-fueled longan drying, are significant, both economically and in their contribution to carbon dioxide emissions. If longan drying processors can improve their fuel consumption efficiency, they can become more efficient producers and help reduce carbon dioxide emissions.

Longan is a major fruit crop in northern Thailand, generating substantial employment and income. The area planted in longan trees has expanded from 88,320 hectares in 2000 to 167,097 hectares in 2009, of which 153,395 hectares were harvested yielding 598,872 tons output (Office of Agricultural Economics, 2010b). During the harvest season, the glut of output generally depresses the market price of fresh longan and hence the farm gate price. To add value to their output, longan growers have turned to drying some of the fruit, a popular export item. Thai exports of dried longan has grown from 55,904 tons in 2000 to 144,154 tons in 2009 (Office of Agricultural Economics, 2010a). This growth in dried longan exports has added value and helped counter depressed fresh longan prices due to increased crop area and output.

Dried longan takes two forms: 1) unpeeled dried longan, processed using diesel oil or liquid petroleum gas (LPG) as fuel and 2) peeled and pitted dried longan processed using longan tree wood as fuel. The latter is called golden brown dried longan, and is the subject of this study. After peeling and pitting, the longan flesh is placed in trays for drying in an oven for 12-14 hours, producing the golden brown color prized by the market. The drying oven is built following traditional techniques; it is a 4.0×2.5×3.0 meter, galvanized iron, open chamber heated by the external burning of old and unproductive longan tree fuelwood. The heat is transmitted through a connective tube and fan-circulated in the chamber. Longan fuelwood is relatively scarce, with the price increasing from THB 0.75 per kilogram in 2007 to THB 1.50-2.00 in 2009-2010 (from survey data). Fuelwood burning not only creates public health hazards but also contributes to environmental problems like smoke and increased carbon dioxide emissions that can add to global warming (Arnold et al., 2006).

Lamphun province has 43,889.28 hectares of land devoted to longan production, second only to Chiang Mai Province in northern Thailand, producing 173,243 tons, or 36% of northern Thai output. Six Tambons produce dried golden brown longan, collectively using 356 ovens (Dried Golden Brown Longan Flesh Processing Community Enterprises Network, 2011). Tambon Makuajae is the most prominent, with 305 ovens, only 4 of which are the improved version. In the improved version, the conventional design has been modified for fuel is saving and productivity enhancement by installing a cavity door to prevent heat dissipation when kept closed, installing an automatic temperature control device, and lining the oven walls with insulation. In contrast, the conventional oven has no cavity door, no temperature control device, and no heat insulator.

For drying golden brown peeled and pitted longan, this study compares the group operational efficiency of 44 processors utilizing the conventional ovens and that of 4 processors using the improved ovens through the application of group frontier estimation and Data Envelopment Analysis. If using the improved oven can increase production efficiency, then policymakers should provide supporting measures to encourage the adoption of this new technology – not only to enhance production efficiency but also to reduce fuel consumption, lowering carbon dioxide emissions and mitigating global warming.

2. Theoretical and conceptual frameworks

An early concept of efficiency study was advanced by Farrell (1957) to analyze production or economic efficiency, using three components: EE for technical efficiency; TE for the capability of a producer to maximize output within the production input constraint; and AE, or allocative (or price) efficiency, for the capability of a producer to allocate resources appropriately given prevailing input prices. Battese (1992) undertook a survey on the application of the production frontier for the analysis of technical efficiency in agricultural production for the reason that the production frontier approach does not allow for analysis of technological differences (Battese et al., 2004), and thus the metafrontier concept was developed to analyze production efficiency where technological heterogeneity exists. Efficiency analysis can be performed using two popular approaches: 1) Stochastic frontier analysis (SFA) in the works of Thiam (2001), Azadeh et al. (2009), Dong-hyun (2010), Villano (2010), Yi-Ju Huang (2010), and Lee & Hwang (2011); and 2) Data Envelopment Analysis (DEA) in the works of Assaf (2010), Kontolaimou & Tsekouras (2010), Portela & Thanassoulis (2010), Luou & Wu (2011), Sala-Garrido et al. (2011), and Tiedemann (2011). SFA is a parametric approach. DEA is a non-parametric approach, and as such widely applied. The recent introduction of the metatechnology concept dealing with technological differences in a production sector and the metafrontier analytical approach have enabled the study of relative efficiency across different technologies (Battese, 2002; Battese et al., 2004).

3. Literature review

The metafrontier function has been widely applied for studies in various fields and industries including agriculture (Battese and Tessema, 1993; Chen and Song, 2008; R. Villano, 2010; Thiam et al., 2001), football (Torben Tiedemann, 2011), banking (Bos and Kool, 2006; Kontolaimou and Tsekouras, 2010), the hotel industry (Assaf et al., 2010), communications (Lee and Hwang, 2011), energy and environment (Dong-hyun, 2010; Kounetas et al., 2011; Liou and Wu, 2011; Sala-Garrido et al., 2011), electricity

(Yi-Ju Huang 2010), and industry (Battese et al., 2004; Christopher J. O'Donnell, 2008; Kounetas et al., 2009). It can be used to estimate comparative efficiency at the national level like in the work of Christopher J. O'Donnell et al. (2008) as well as at the regional level like in the study by George E. Battese (2004) that estimated the technical efficiencies and technology gap for garment production firms in five different regions of Indonesia. Zhuo Chen and Shunfeng Song (2008) used the metafrontier approach to study efficiency and the technology gap in Chinese agriculture while Alexandra Kontolaimou (2010) used it for analysis of European banking efficiencies. R. Sala-Garrido et al. (2011) estimated a DEA metafrontier model for comparing the efficiency of four wastewater treatment technologies. Villano et al. (2010) conducted a study to verify whether metafrontier analysis was appropriate for estimating the varietal effect on technical efficiency of three different pistachio varieties in Iran. The findings revealed very slight differences in technical efficiency among the three varieties, as the study did not take into account the production constraints beyond the capability of the growers to improve production efficiency or adopt a better technology. The authors also pointed out that it would be misleading to compare varietal differences on the criteria of output per area unit alone.

In the present study, where the dried longan processors used improved ovens equating to a change in production technology, measurement of technical efficiency was not made solely in terms of yield per oven but extended to cover efficiencies in fuel consumption, raw material input, and labor usage. No constraining factor is likely to exist to prevent the processors from adopting the new technology because the cost for oven modifications is relatively low compared to the overall business investment. The present DEA model takes the form of variable returns to scale (VRS) developed by Banker, Charnes and Cooper (1984), because the alternative constant return to scale (CRS) form is limited by its inability to separate technical efficiency from scale efficiency; therefore, use of a VRS DEA model can avoid the problem of compounding effect (Chaovanapoonphol et al., 2009).

4. Methodology

Measurement of relative efficiencies involves comparing the calculated efficiency of a production unit with benchmarks or the efficiencies of the best practice production units on the frontier. Other production units are relatively inefficient compared to the best practice combinations on the production frontier generated by the Data Envelopment Analysis (DEA), which is a linear programming solving technique using input and output data of various production units. Any production unit having the input combinations on the frontier will be the most efficient producer. The present study employed an input-oriented method as the adopters of the improved ovens tried to minimize input use while keeping the output unchanged. The development of the improved oven implies a change in dried golden brown peeled longan processing technology; thus, a metafrontier – a new production frontier – can be constructed by pooling the data of processors using the improved ovens and conventional ovens for calculation and evaluation as to whether the average production efficiency changes at a statistically significant level.

The construction of the production frontier using the DEA method is based on the input and output units of a homogenous set of decision making units (DMUs). If there are k groups of DMUs using heterogeneous technology, and each group contains L_k producers, then the variable returns-to-scale DEA model can be solved using an input-oriented linear programming procedure as follows:

$$\begin{aligned} & \text{Min}_{\theta,\lambda}\ \theta \\ \text{s.t.}\quad & -yi + \mathbf{Y}_k\lambda \geq 0, \\ & \theta x_i - \mathbf{X}_k \lambda \geq 0, \\ & N1'\lambda \leq 1 \text{ and} \\ & \lambda \geq 0. \end{aligned} \qquad (1)$$

where

yi = M×1 vector of output quantities for the ith producer

x_i = N ×1 vector of input quantities for the ith producer

Y_k= M×L_k matrix of output quantities for all the L_k producers

X_k= N×L_k matrix of input quantities for all the L_k producers

N1= L_k×1 vector of 1

λ = L_k×1 vector of weight given to i producer and

θ = scalar matrix

θ Values are solved by linear programming with respect to equation (1). Since θ represents the ratio of the decrease in input use by i producer and the unchanged output, the value of θ obtained will be the efficiency score for the ith producers. It will satisfy $\theta \leq 1$, with a value of 1 indicating a point on the frontier. The value of θ will be the input-oriented measurement of technical efficiency.

4.1 Metafrontier construction

The metafrontier was constructed using a DEA model based on the pooled data for all producers in all groups. A total of $L=\Sigma_k L_k$ producers are solved by linear programming using the data of all producers as follows:

$$
\begin{aligned}
&\text{Min}_{\theta^*, \lambda^*} \ \theta^* \\
\text{s.t.} \quad & -y_i + \mathbf{Y^*}\lambda^* \geq 0, \\
& \theta^* x_i - \mathbf{X^*}\lambda^* \geq 0, \\
& N1'\lambda^* \leq 1 \text{ and} \\
& \lambda^* \geq 0. \qquad (2)
\end{aligned}
$$

where

y_i = M×1 vector of output quantities for the i^{th} producer

x_i = N ×1 vector of input quantities for the i^{th} producer

Y*= M×L matrix of output quantities for all the L producers

X*= N×L matrix of input quantities for all the L producers

N1= L×1 vector of 1

λ*= L×1 vector of weight given to i producer and

θ^*= scalar matrix

4.2 Input distance function

Let $D^k(x,y)$ denote the input distance function for group k technology. It is defined by:

$$D^k(x,y) = \sup_{\lambda} \{ \lambda > 0 : (x/\lambda \in L^k(y)\}. \qquad (3)$$

4.3 The metafrontier

Let x and y be nonnegative real input and output vectors of dimension N×1 and M×1, respectively. The metatechnology set contains all input-output combinations that are technologically feasible, or formally as follows:

$$T = \{(x,y) : x \geq 0; y \geq 0; x \text{ can produce } y\}. \qquad (4)$$

The input sets are defined for any output vector, y, as:

$$L(y) = \{x : (x,y) \in T\} \qquad (5)$$

Let D (x,y) denote the input distance function for the input metadistance function. It is defined by:

$$D(x,y) = \sup_{\lambda} \{ \lambda > 0 : (x/\lambda \in L(y)\}. \qquad (6)$$

4.4 Group frontier

If all producers can be grouped into k different technological groups due to their differences in terms of resources, determining factors or other environmental factors, the group frontier function can be defined as follows:

$$T^k = \{(x,y) : x \geq 0; y \geq 0; x \text{ can be used by firms in group k to produce } y\} \quad (7)$$

Within a specific technological group, the representative input set can be expressed as:

$$L^k(y) = \{x : (x,y) \in T^k\}, k=1,2,\ldots,K; \text{ and} \quad (8)$$

$$D^k(x,y) = \sup_\lambda \{\lambda > 0 : (x/\lambda \in L^k(y)\}, \quad k=1,2,\ldots,K. \quad (9)$$

The boundaries of the group-specific input sets are referred to as the group frontier. If the input sets, L^k (y) k=1,2,…,K, satisfy standard regularity properties, then the distance functions, D^k (x,y), k=1,2,…,K, also satisfy standard regularity properties. Irrespective of the properties of these sets and functions, it is clear that:

1) If $(x,y) \in T^k$ for any k then $(x,y) \in T$;
2) If $(x,y) \in T$ then $(x,y) \in T^k$ for some k;
3) $T=\{T^1 \cup T^2 \cup \ldots \cup T^k\}$; and
4) $D^k(x,y) \geq D(x,y)$ for all k=1,2,…,K.

4.5 Technical efficiencies and metatechnology ratios

From equation (4) and (6), the measurement of technical efficiency by an input-oriented approach of input-output combinations under a metatechnological frontier is denoted by:

$$T(x,y) = D(x,y) \quad (10)$$

Similarly, the following expression measures the technical efficiency of group k by input-oriented approach:

$$T^k(x,y) = D^k(x,y) \quad (11)$$

From 4), the distance function of group k, $D^k(x,y)$ will have a value not below that of the metadistance function, D(x,y). With the envelopment of the metafrontier over the group frontier, the following expression determines the metatechnology ratio (MTR) (Christopher J. O'Donnell, 2008) or technology gap ratio (TGR) (Battese et al., 2004):

$$MTR^{k}(x,y) = \frac{D(x,y)}{D^{k}(x,y)} = \frac{T(x,y)}{T^{k}(x,y)} \quad (12)$$

Equation (12) can be rearranged to find the technical efficiency of an input-output combination as follows:

$$T(x,y) = T^{k}(x,y) \times MTR^{k}(x,y) \quad (13)$$

4.6 Data for the study

The field data were collected from golden brown peeled longan driers identified by simple sampling technique in the purposively selected area of Tambon Makuajae, Muaeng District, Lamphun Province, Thailand as it is the largest area of dried golden brown peeled longan production. The study included 48 samples, 44 producers using conventional technology and only 4 using improved ovens. The input variables included: Input1 – value of fresh longan (THB/oven); Input2 – labor cost for peeling and pitting longan fruits (THB/oven); Input3 – fuelwood volume for longan drying (kg/oven); and Input4 – electricity cost for longan drying (THB/oven). The potential input factors of oven size (all identical size), labor attending the oven (one person per oven in all cases), and fuelwood moisture content (all completely dry as purchased at least six months prior to use) were omitted as explanatory variables from this study because they did not vary across the producers. The output variable was the value of the dried longan (THB/oven).

5. Results

The study found that the 44 longan driers using conventional technology achieved an average output of 24,548 THB/oven, with a range of 16,975-37,200 THB/oven, and the 4 using improved technology achieved an average output of 33,323 THB/oven, with a range of 19,074-48,248 THB/oven (Table 1). For raw material input (Input1), the conventional technology users used fresh longan of 17,686 THB/oven on average, with a range of 12,015-23,400 baht/oven, while the improved technology users used fresh longan valued relatively higher at 22,550 THB/oven on average, with a range of 15,712-31,391 THB/oven. For labor input (Input2), the improved technology users spent 5,839 THB/oven on average, with a range of 3,848-8,346 THB/oven, while the conventional technology users spent relatively less at 4,108 THB/oven on average, with a range of 3,270-6,351 THB/oven. For fuelwood input (Input3), conventional technology used an average of 739 kg/oven, with a range of 525-1,041 kg/oven, much higher than the volume used by the improved technology, which was in a much narrower range of 505-573 kg/oven, or 546 kg/oven on average. Similarly, for energy input (Input4), electricity costs for the conventional technology was 179 THB/oven on average, with a range of 100-300 THB/oven, while the corresponding cost for the improved technology averaged 130 THB/oven, with a range of 120-150 THB/oven. The test of the difference in input use extent between the two sample groups indicated fuelwood consumption was different at the 99% statistically significant level ($p = 0.005$) between the conventional and improved technology; and the labor input and electricity costs were different at the

90% statistically significant level (p = 0.067 and p = 0.056, respectively). However, there was no statistically significant difference between the conventional technology and the improved technology in terms of fresh longan raw material input in value terms and dried longan output in value terms. From the test results, the improved technology can effectively lower the use of fuel wood, labor and electricity inputs relative to conventional technology (at statistically significant levels).

TABLE 1. Summary statistics of data on firms processing golden brown dried longan.

Variable	Conventional technology (44 observations)	Improved technology (4 observations)	Mann-Whitney (MW) U test	Pooled data (48 observations)
Output (total revenue)				
Mean (THB)	24,548	33,323	MW = 55.0	25,278
Std dev	3,955	13,362	ρ value = 0.218	5,631
Max (THB)	37,200	48,248		48,248
Min (THB)	16,975	19,074		16,975
Input1 (fresh longan)				
Mean (THB)	17,686	22,550	MW = 70.0	18,091
Std dev	2,492	7,709	ρ value = 0.495	3,364
Max (THB)	23,400	31,391		31,391
Min (THB)	12,015	15,712		12,015
Input2 (labor)				
Mean (THB)	4,108	5,839	MW = 39.0*	4,252
Std dev	515	2,151	ρ value = 0.067	878
Max (THB)	6,351	8,346		8,346
Min (THB)	3,270	3,848		3,270
Input3 (fuel wood)				
Mean (kg)	739	546	MW = 14.5***	722
Std dev	136	29	ρ value = 0.005	140
Max (kg)	1,041	573		1,041
Min (kg)	525	505		505

Variable	Conventional technology (44 observations)	Improved technology (4 observations)	Mann-Whitney (MW) U test	Pooled data (48 observations)
Input4 (electricity)				
Mean (kg)	179	130	MW = 37.5*	175
Std dev	56	14	ρ value = 0.056	55
Max (kg)	300	150		300
Min (kg)	100	120		100

Source: Calculation
Notes: ***sig at level 0.01 for 2-tail test
** sig at level 0.05 for 2-tail test
* sig at level 0.10 for 2-tail test

Before estimating the metafrontier function, it is necessary to test the statistical difference between the two variable sets. The present study employed the Mann-Whitney U test (Pereira and Leslie, 2010) for comparison between two independent groups only, with one group having a sample size less than 30 and for data which are not normally distributed (Sala-Garrido et al., 2011), with the following hypothesis:

$$H_0: TE_i = TE_c$$

$$H_1: TE_i \neq TE_c$$

Hypothesis testing by Mann-Whitney U criteria (31.50) proved there exists a difference in technical efficiency between the two groups at the 95% (p=0.032) statistically significant level (Table 2), and thus a metafrontier can be constructed for comparing the technical efficiencies of the conventional and improved technologies. The technical efficiency of the conventional technology group in relation to the group frontier was 0.946 on average, with the most inefficient producer in this group having a TE value of 0.777 (Table 3). Fourteen of the producers (31.8%) operated on the frontier and the remaining 30 (68.2%) performed below the group frontier. In contrast, the four producers using improved technology group had an average TE value of 1.00, as they all operated on the group frontier.

In relation to the metafrontier, the conventional technology producers had an average TE value of 0.941 with the most inefficient producer having a TE value of 0.777. Twelve producers (27.3%) in this group operated on the metafrontier, while the remaining 32 (72.7%) performed below the metafrontier. For the improved technology group, the average technical efficiency was 0.998, with the most inefficient producer having a TE value of 0.992 and the other three producers (75%) operating on the metafrontier. When combining all producers from both groups together, 15 (31.2%)

operated on the metafrontier (Figure 1), while the other 33 (68.8%) performed below the frontier, with the most technically inefficient producer having a TE value of 0.777. The metatechnology ratio (MTR) of the conventional technology group was 0.995, implying that its input use efficiency was 99.5% of the potential maximum, while the MTR of the improved technology group was 0.998, meaning that on average, every producer in this group utilized inputs very close to the maximum technical efficiency. The gap (0.3%) between the conventional and improved technology producers in their technical efficiencies is very small given the same types of input and under the same metafrontier.

6. Discussions

The improved longan drying technology, through modifying the conventional oven by installing a cavity door, insulation, and a temperature control device, is barely superior to the conventional technology in terms of technical efficiency, when the performance is assessed using a metatechnology approach. However, input use of fuelwood, labor and electricity is significantly more efficient for the improved technology.

Financially, the investment to modify an oven costs 27,050 THB/oven, reducing fuelwood consumption from 741 kg/oven/day for the conventional oven to 546 kg/oven/day for the modified oven, or 195 kg/oven/day. With fuelwood costing 1.20 THB/kg (2011 price) and a production period of 45 days/year, this would require just over two years to payback the investment.

This improved technology not only contributes to higher technical efficiency but also reduces fuelwood burning, helping to cut carbon dioxide emissions. If the 44 conventional producers with 305 total ovens in this study modified their ovens, over the 45-day operating year, they would reduce the volume of fuelwood input by 59,475 kg/day, saving 71,370 THB/day, and mitigating carbon dioxide emissions by 100,070 kg/day, or approximately 100 metric tons/day (Lu et al., 2009; MacCarty et al., 2008; Maru et al., 2007).

TABLE 2. Different technical efficiency test between two groups.

Groups	Observations	Mean	Std Dev	Mann-Whitney U test	$\rho - Value$
Conventional Technology (TE_c)	44	0.91954	0.085928		
Improved Technology (TE_i)	4	1.000	0.000	31.500**	0.032

Source: Calculation
Notes: ***sig at level 0.01 for 2-tail test
** sig at level 0.05 for 2-tail test
* sig at level 0.10 for 2-tail test

TABLE 3. Technical efficiency and metatechnology ratio.

Groups	Mean	Std Dev	Maximum	Minimum	Dried longan efficiency (%)
Conventional technology					
Group efficiency (TE^k)	0.946	0.062	1.000	0.777	31.8
Metafrontier efficiency (TE)	0.941	0.061	1.000	0.777	25.0
MTR^k (TGR)	0.995	0.017	1.000	0.919	
Improved technology					
Group efficiency (TE^k)	1.000	0.000	1.000	1.000	100.0
Metafrontier efficiency (TE)	0.998	0.004	1.000	0.992	75.0
MTR^k (TGR)	0.998	0.004	1.000	0.992	

Source: from calculation

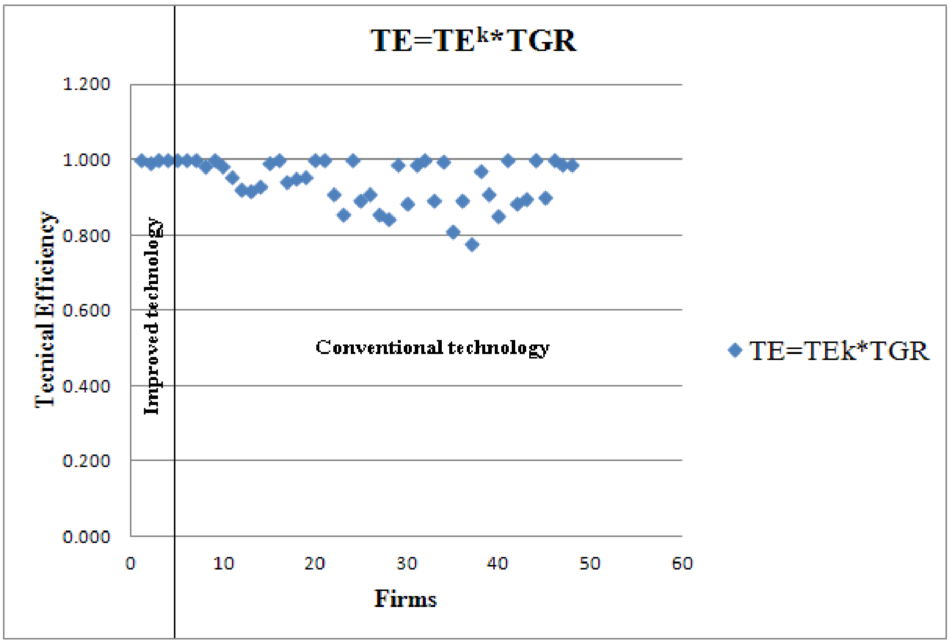

Figure 1. Metafrontier of 48 firms.

7. Concluding remarks

The findings from the present study indicate the technical efficiency of improved technology for golden brown peeled longan drying is superior to that of conventional technology at a statistically significant level. The improved technology involves modifying the conventional oven by installing a cavity door to prevent heat dissipation, insulation material, and an automatic temperature control device; thus the reduction in fuelwood input use. Given the benefits, including reduced carbon dioxide emissions, measures should be devised, namely a low interest loan program or government compensation for material costs for oven modifications, to encourage processors to adopt the improved technology.

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