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Economic Efficiency of Smallholder Peanut Farming: An Application of Data Envelopment Analysis to Smallholder Producers in the Markham Valley of Papua New Guinea

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Abstract

The study, conducted using primary data of the smallholder peanut farming in the Kaiapit District of Markham Valley, was to examine the economic efficiency of these farmers in their farm production. The input-oriented Data Envelopment Analysis (DEA) model was used to estimate technical and allocative efficiencies, the components of economic efficiency. The results establish that while about 6 percent of the farmers were both technically and allocatively efficient and therefore were economically efficient in their farming operations, the majority of the farmers were found to be economically inefficient. Decomposing technical efficiency into pure technical and scale efficiencies suggests the presence of scale inefficiency by 23 percent. This implies that the farmers were not using their inputs at optimum scale. Of the 69 percent (11 farmers) of the farmers who were found to be scale inefficient, all of them (11 farmers) were operating in the region of increasing returns to scale. Since the majority of the farmers were found to be technically and allocatively inefficient, it is useful for these farmers to shift their resources to more profitable cropping alternatives.

Key words: smallholder peanut production, economic efficiency, scale efficiency, resources allocation

Introduction

Agriculture, in Papua New Guinea (PNG), is an important sub-sector of the economy where 85 percent of the population, who dwell in the rural sector, derive their livelihood. Subsistence livelihood production systems can no longer meet the increased demands placed on them and in that perspective, their participation in the monetized cash economy is a step forward. Consistent with their desire to participate in the cash economy, the rural masses engage in various economic activities in agriculture and agriculture related production and

sales activities, both crops and livestock. Among crops is peanut, grown entirely on small scale in many parts of the country. Although a small scale activity, farm surveys (WEMIN *et al.* 2005, KOLOPEN *et al.* 2005) conducted from selected peanut growing areas indicated that it contributes as much as 70 percent of family income for families who grow it.

The domestic market value estimated for peanut produced in four provinces representing four agro-ecological zones, viz., Eastern Highlands (highlands), Markham Valley of Morobe Province (Dry Lowland), National Capital District (Dry lowland & peri-urban) and East New Britain (Wet lowlands) amounts to K29 million (WEMIN and GEOB 2004). Given that small scale peanut is produced and sold in many provinces distributed throughout the county, the market value for peanut would be significant and therefore an important smallholder cash crop.

However, there is an apparent decline in current production. For example, peanut production in 1998 was estimated to be 21,600 tonnes per annum while in 2004; it was estimated to be about 12,600 tonnes per annum (WEMIN and GEOB 2004). Production has, over the 7 year period, declined by 33 percent. This amounts to a decline of about 5 percent per annum. Such a decline in production, as a smallholder industry, is not encouraging.

The decline in production is the product of two related happenings. First, the fall in production is due to the productivity differences in the peanut growing areas. In the highlands, for example, the variations in productivity ranged between 0.6 and 1.5 tonnes per hectare (RAMAKRISHNA *et al.* 2005). WEMIN and GEOB (2004), in their cross sectional smallholder peanut production farm survey of 3 coastal and 1 highlands areas noted peanut productivity to be between 0.9 and 1.2 tonnes per hectare which are within the range estimated by RAMAKRISHNA *et al.* (2005). The variation in productivity could be due to variation in accessing suitable and improved planting seeds. Such a problem exists everywhere.

The second factor that causes a decline in production is the poor management and cultivation practices of peanut farming. The farmers' lack of these skills is the direct result of collapsed commodity extension systems, the function which has been decentralized to the provinces and provided by Provincial Departments of Agriculture and Livestock (PDAL). In sum, production declines are essentially, among others, the problem of collapsed extension systems and unavailability of suitable planting seeds in peanut growing areas.

Peanut was, up to the mid-1980s, grown on small scale commercial basis in the Markham Valley of the Morobe Province by a large number of smallholder producers. This area was where the largest concentration of smallholder production took place, in the main, to feed a peanut export processing plant established at Atzera of Markham Valley. In addition to the problems of differing productivity levels, poor access to improved planting materials, and poor management and cultivation practices, the decline in production in the Markham Valley was partly due to the closer of the peanut factory in mid-1980s.

In the recent past, location specific peanut trials (WEMIN and GEOB 2004) have been conducted¹ with the objective of releasing better performing varieties to the farmers. The

1 Trials were conducted in Eastern Highlands, Markham of Morobe Province, National Capital District and East New Britain Provinces to assess agronomic and yield performances of 40 varieties of peanut introduced from the Centre for International Crop Research Institute of Semi Arid Territories (ICRISAT).

trials conducted were spread across major agro ecological zones of the country. Among these location trials conducted, a few were conducted in the Markham Valley of Morobe Province, where smallholder peanut production is active. These attempts to improve productivity are made in the right direction and must be done by improving extension systems to improve production and management practices.

While improving access to seeds with better management and cultivation practices are necessary steps needed to be taken to improve production, no study has, however, been conducted on the economic efficiency of smallholder peanut farming in PNG except for two studies (KWAMILON 1986, MILLICENT 2008) on allocative efficiencies of the producers. At a more general level, farmers were found to be allocatively inefficient and suggested adjustment to resources which were not used in optimal proportions. Against these findings, economic efficiency is not only influenced by allocative efficiency but technical efficiency as well. Essentially, one needs to establish a clear picture of the productive performance of the farmers and resources allocation in peanut production as a smallholder industry.

Technical and allocative efficiencies of the farms are estimated relative to, for the former, the production frontier and for the later, the cost frontier. If a farm is not located on these frontiers, it is technically and allocatively inefficient (FARRELL 1957). Since cost or economic efficiency is the product of technical and allocative efficiencies, it is economic or cost inefficient as well if it is either technically or allocatively inefficient or both.

A farm is technically efficient if it produces a given level of output at a minimum feasible level of input set or if it produces the maximum possible output with a given set of inputs. The former is estimated in the input-oriented framework while the latter is estimated in the output-oriented framework.

Although measurement approaches for estimating productive efficiency vary, they are broadly categorized into two streams; the parametric (econometric) and the non-parametric. The parametric stream requires specifying the functional forms as either deterministic or stochastic. The estimation of the stochastic frontier requires one to make appropriate distributional assumptions about the stochastic error term. This method was developed, modified and extended based on the initial works of AIGNER *et al.* (1977) and MEEUSEN and VAN DEN BROECK (1977). For the non-parametric approach to estimating efficiency, Data Envelopment Analysis (DEA) is popular and receives wide application. Unlike the parametric approach, DEA does not require one to make distributional assumptions in relation to the functional form (COELLI *et al.* 2005, HEADEY *et al.* 2010).

DEA work is based on the initial work of FARRELL (1957). CHARNES *et al.* (1978), following the work of Farrel coined the term DEA and constructed their models under the condition of constant returns to scale (CRS). The CRS DEA models developed by CHARNES *et al.* (1978) were later modified by incorporating the variable returns to scale (VRS) condition (BANKER *et al.* 1984). DEA models are formulated and analysed either in the output-oriented mode or input-oriented mode (COELLI *et al.* 2002). The former has a maximization objective while the later has a minimization objective.

Although the peanut factory collapsed, smallholder peanut production is still active and such production is distributed over most parts of the Markham Valley, particularly

areas located closer to the National Okuk Highway. Peanut production, in these areas, has become a huge cash generating activity essentially made it possible by this road not only linking buyers of Lae, the capital city of Morobe Province, but buyers from the highlands provinces as well. Essentially, there exists a vibrant informal market economy which needs to be promoted. The nature of support to be given to the farmers depends on the productive performance of these farmers and how well resources, they command, are allocated. This study² is the application of DEA to historical smallholder peanut farming data in Kiapit District of the Markham Valley to assess technical, allocative, economic and scale efficiencies of these farmers.

Methodology and Data

The DEA procedure (CHARNES *et al.* 1978, FARE *et al.* 1985, 1994) for estimating technical, allocative, cost and scale efficiency measures can be constructed in either the constant returns to scale (CRS) framework or the variable returns to scale (VRS) framework (BANKER *et al.* 1984). Except where mentioned, this study uses the input-oriented CRS DEA approach to estimate these measures.

CRS DEA for Technical Efficiency

Under the CRS DEA framework, the technical efficiency (TE_{CRS}) measure, also known as the “overall” TE_{CRS} measure (OTE), can be derived as:

$$\min_{Q,\lambda} Q$$

Subject to

$$-y_i + Y\lambda \geq 0 \quad (1)$$

$$Qx_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

Where each farm of the study sample of n farms produces a single output by using m inputs. Thus, y_i is the output produced by the i^{th} farm, x_i is the $(m \times 1)$ vector of inputs used by the i^{th} farm, Y is the $(n \times 1)$ vector of outputs produced by the n farms, X is the $(m \times n)$ matrix of inputs used by the n farms, and λ is the $(n \times 1)$ vector of weights attached to each of the efficient farms. The DEA in equation (1) is estimated n times, one for each farm and therefore, Q is a scalar and provides a measure of TE for each farm under CRS (TE_{CRS}). If $Q=1$, the farm is on the frontier and is technically efficient. If on the other hand, $Q < 1$ the

² The study derives the input-output data from Mr Kwamillon's MPhil Thesis completed in the Department of Agriculture, University of Technology in 1986. The historical data is used to benchmark productivity analysis. Presently, input-output data are being collected to assess productivity changes since 1986.

farm does not lie on the frontier and is thus technically inefficient.

CRS DEA for Cost Efficiency

When input prices are available, one runs the CRS cost minimization DEA model (FARE *et al.*, 1985, 1994) as:

$$\min_{\lambda, x_i^*} w_i' x_i^*$$

Subject to

$$-y_i + Y\lambda \geq 0$$

$$x_i^* - X\lambda \geq 0 \quad (2)$$

$$\lambda \geq 0$$

Where, w_i =vector of input prices for the i^{th} farmer, x_i^* is the cost minimizing vector of input quantities for the i^{th} farm, given the input prices w_i and output levels, y_i .

The CRS cost efficiency (CE_{CRS}) or economic efficiency (EE_{CRS}) measure is then estimated as the ratio of minimum cost to the observed cost. Thus:

$$EE_{CRS} = w_i' x_i^* / w_i' x_i \quad (3)$$

Allocative Efficiency

The allocative efficiency (AE_{CRS}) index can then be calculated residually from the TE_{CRS} measure estimated in equation (1) and EE_{CRS} index estimated in equation (3) as:

$$AE_{CRS} = \frac{EE_{CRS}}{TE_{CRS}} = \frac{w_i' x_i^*}{w_i' TE_{CRS}} \quad (4)$$

where $TE_{CRS} = \theta_i^{CRS}$ and $w_i' TE_{CRS} = w_i' (\theta_i^{CRS} X_i)$. If $AE_{CRS} = 1$, the farms are allocatively efficient. If on the other hand, $AE_{CRS} < 1$, the farms are allocatively inefficient, suggesting they are not on the cost frontier.

Input Use Ratios

For each farm, the cost minimization DEA model in (2) produces the cost efficient input quantities (x_i^*) while the TE_{CRS} DEA model in (1) produces the technically efficient input (Qx_i) levels (COELLI *et al.* 2002). Given these efficient input quantities, one can estimate the farms extent of input use in peanut farming by constructing the input use ratios (IR) (COELLI *et al.* 2002) as:

$$IR = \frac{Qx_i}{x_i^*} \quad (5)$$

By using equation (5) one can investigate, for each farm, if it either over or under utilize the resources used in its farming operations. An $IR < 1$ suggests underutilization of

inputs while an $IR > 1$ suggests over use of inputs.

Input Slacks

Inputs slacks appeared to be handled in two different ways. The first approach is to treat the slacks as the source of technical inefficiency (ALI and SEIFORD 1993). The second way is to treat the slacks as the source of allocative inefficiency (FERRIER and LOVELL 1990, SHARMA *et al.* 1999). In the later approach, equation (2) accounts for the input slacks that were not captured by equation (1). This procedure suggests that slacks occur due to inappropriate input mixes used in production and therefore it is considered as a source of allocative inefficiency. This paper followed the later approach to account for input slacks

DEA for Scale Efficiency

In the situation where the TE_{CRS} index, Q is less than 1, farms are not operating at the optimal scale. In this case one needs to estimate the extent of scale efficiency (SE), often done, by estimating TE under the condition of variable returns to scale (TE_{VRS}). Essentially, to account for TE_{VRS} , the CRS model in equation (1) was modified by adding convexity constrain; $NI'\lambda = 1$ (BANKER *et al.* 1984). Thus:

$$\min_{Q,\lambda} Q$$

Subject to

$$-y_i + Y\lambda \geq 0$$

$$Qx_i - X\lambda \geq 0 \tag{6}$$

$$NI'\lambda = 1$$

$$\lambda \geq 0$$

The DEA specification in equation (6) eliminates the scale inefficiency component from the TE_{CRS} estimate derived from the CRS DEA model. Essentially, SE is derived residually as:

$$SE = TE_{CRS} / TE_{VRS} \tag{7}$$

A farm is scale efficient if its SE index = 1. In this case, the farm is operating in the region of CRS. On the other hand, if $SE < 1$, the farmer is scale inefficient.

In the case where the farmers are found to be scale inefficient, a further VRS DEA analysis can be conducted with the non-increasing returns to scale (NIRS) restriction ($NI'\lambda \leq 1$) imposed on equation (6) by replacing the convexity constraint; $NI'\lambda = 1$ with $NI'\lambda \leq 1$. Now let the estimated TE measure under the non-increasing returns to scale (NIRS) as TE_{NIRS} . It follows that if $TE_{NIRS} = TE_{CRS}$, increasing returns to scale exists. If on the other hand, $TE_{CRS} < TE_{NIRS}$, the farms are operating under decreasing returns to scale. These situations

indicate that scale inefficiency arise only if the farmers were operating in the regions of increasing and decreasing returns to scale (COELLI *et al.* 2005, KUMAR and GULATI 2008).

Sample and Data

The input-output data was collected from 17 farmers located in Atzera, Amari, and Lower Yaros in the Kaiapit District. The inputs were farm size measured in hectares, family labor in man-days of work, and hired labor in man-days of work and seeds in kilograms and capital in Kina³. The output, measured in kilograms, was sold as dried pods packed in 50 kg bags. The smallholder farms varied in sizes between 0.1 and 1.2 hectares. Peanut seeds and outputs were valued at market prices. Capital tools such as spades and bush knives were valued at cost price.

The farmers have easy access to the Okuk Highlands Highway which connects Lae, the Capital City of Morobe Province and the provinces of the highlands region. Essentially, the farmers grow and sell peanut on a regular basis to road side buyers in the production locations.

Peanut can be grown twice in a year. This study conducted the productive performance analysis of the farmers using the aggregated data covering both production cycles. Due to the geographical spread of the farmers, a sample of 30 farmers was randomly selected. At the time of interview, 13 farmers were not available and due to time and resources constraints, 17 farmers were actually interviewed. To remove the influences of outliers, one farm was dropped in the actual DEA analysis as it has contained input-output which were abnormally high.

Results and Discussion

The summary statistics of inputs and output of the average farm in the study sample are presented in Table 1. This farm cultivates 0.265 of a hectare of land to produce 279 kg of peanut. This production required an average of 62 man-days of labor, 17kgs of seed, and costs K13.81 for tractor hire services and K2.09 for the purchase of farm tools. Farm work was done by family members and hired hand of which hired labor contributed about 22 percent of the man-days of work.

Table 1. Summary statistics of inputs and output.

Variables	Minimum	Maximum	Mean	Standard Deviation
1. Output				
Peanut Output (Kgs)	48	660	279.06	160
2. Inputs				
Land planted (ha)	0.068	0.44	0.265	0.103
Labour (man-days)	19.7	137.48	61.778	34.645
Seed (kgs)	7.3	27.89	17.092	6.665
Tractor	6.76	24.89	13.811	5.073
Tools	0.77	3.33	2.099	0.664

3 A PNG Kina is worth about AU\$ 0. 43

Table 2. Distribution of estimated technical, allocative and cost efficiencies.

Distributions	TE _{CRS}	AE	CE
< 0.500 (%)	25.00 (4)*	12.50 (2)	62.50 (10)
0.500 – 0.599 (%)	12.50 (2)	37.50 (6)	18.75 (3)
0.600 – 0.699 (%)	18.75 (3)	18.75 (3)	6.25 (1)
0.700 – 0.799 (%)	12.50 (2)	18.75 (3)	6.25 (1)
0.800 – 0.899 (%)	-	-	-
0.900 – 0.999 (%)	-	6.25 (1)	-
1.000 (%)	31.25 (5)	6.25 (1)	6.25 (1)
Minimum	0.348	0.347	0.139
Maximum	1.000	1.000	1.000
Mean	0.708	0.642	0.461
Standard Deviation	0.235	0.167	0.212

*Figures in the brackets are number of farms located in that category of distribution.

Table 3. Input use ratios.

	Land	Labour	Seed	Tractor	Tools
Minimum	0.937	0.786	0.690	1.000	0.659
Maximum	3.356	3.424	5.411	18.433	11.959
Mean	1.674	1.615	2.278	4.426	2.702
Standard Deviation	0.737	0.743	1.447	4.362	3.024
Over using farms (%)	87.50 (14)*	87.50 (14)	81.25 (13)	93.75 (15)	75.00 (12)
Under using farms (%)	11.76 (2)	11.76 (2)	11.76 (2)	-	23.53 (4)

*Figures in the brackets indicate the number of farms who over or under use the indicated farm inputs.

The DEA models described in the previous section were estimated using the program DEAP 2.1 (COELLI 1996). The results on technical, allocative, cost and scale efficiencies estimated from these models and together with their frequency distributions are summarized in Table 2. The efficiency measures are observed to vary substantially among the sampled farmers. Technical efficiency (TE_{CRS}) varied between 0.348 and 1.000 with a mean of 0.708. This indicates that the average farm has produced less than the potential total output by about 29 percent. Of the 16 farms, 5 (31.25%) of them were technically efficient.

Allocative efficiency (AE_{CRS}) varied between 0.347 and 1.000 with a mean of 0.642. This index suggests that these farms, on average, need to reduce costs by 36 percent and given their prices that can be done by realigning the input mixes in the production process. Of the 16 farms, only one farm was price efficient.

Economic or cost efficiency is the product of combining the TE_{CRS} and AE_{CRS} (found at the tangency point of iso-cost and iso-product curves). Cost efficiency (CE_{CRS}) varied between 0.139 and 1.000 with an average of 0.461, suggesting that the average farm is cost inefficient by 54 percent. Of the 16 farms, one farm was found to be technically and allocatively efficient and thus cost efficient. In sum, the foregoing DEA analysis suggests the existence of substantial inefficiencies in smallholder peanut.

Allocative inefficiency suggests that the average farm did not equate the value of marginal product of inputs to their respective acquisition prices. Essentially, the extent to which the inputs were used was investigated by constructing the input use ratios (COELLI *et*

Table 4. Distributions of technical, pure and scale efficiencies.

Distribution	TE _{CRS}	TE _{VRS}	SE
< 0.500 (%)	25.00 (4)	-	23.53 (4)
0.500 – 0.599 (%)	12.50 (2)	-	-
0.600 – 0.699 (%)	18.75 (3)	-	6.25 (1)
0.700 – 0.799 (%)	12.50 (2)	12.50 (2)	12.50 (2)
0.800 – 0.899 (%)	-	31.25 (5)	18.75 (3)
0.900 – 0.999 (%)	-	-	6.25 (1)
1.000 (%)	31.25 (5)	56.25 (9)	31.25 (5)
Minimum	0.348	0.756	0.343
Maximum	1.000	1.000	1.000
Mean	0.708	0.922	0.768
Standard Deviation	0.235	0.095	0.234
IRS (%)	-	-	68.75 (11)
DRS (%)	-	-	0
CRS (%)	-	-	31.25 (5)

al. 2002) and these results are presented in Table 3. The mean input use ratios of the inputs are greater than one, suggesting considerable overuse of these inputs. The overuse of seeds was not expected as they were required to be bought from established sellers. By using their own seeds, farmers used more seeds than needed to ensure adequate germination. Of the 16 farms, 13 used more seeds than they actually needed. Farm labor used was higher than normally required and this could possibly be due to farms providing prepared meals to hired hand in addition to making, on occasions, a one of cash payment for a particular activity that ought to be completed. The easy to attract hired hand for meals may suggest disguised unemployment, a situation prevailing in most rural village communities. Of the 16 farms, 14 used more labor than they actually need. The overuse of tools may be expected. The probable cause of this was the difficulty involved in apportioning tools to different and varied farming activities performed in a given production cycle. Farm size and tractor hire were inputs requiring adjustments as well. For tractor hire, the rate of hire may need to be reviewed, if at all, possible.

Mean scale efficiency (SE) score of 0.768 were estimated and this result is given in Table 4. The score suggests that the average farm need to increase scale efficiency by 23 percent. The mean TE_{CRS} score was reported to be 0.708 and the mean TE_{VRS} score was reported to be 0.922. If by improving SE by 23 percent, TE_{CRS} can be increased to 0.922, a substantial gain in technical efficiency of 21.4 percent. These results suggest that technical efficiency can be improved by adjusting the scale of farm size to operate in addition to paying attention to improving allocative efficiency of peanut farming. Furthermore, of the 16 farms, 5 farms had constant returns to scale while the remaining 11 farms had increasing returns to scale. In sum, the farms are essentially small and need to be increased to reduce costs and improve profitability of peanut farming.

Given the above results, it is useful to highlight that the relevance of these results are limited by two factors. First, the results were obtained from a study sample of 16 farms which is less than 30 farms, the minimum required for statistical analysis. Thus the results

may not be representative of the peanut farming population. Secondly, the use of historical data may not provide the correct picture of the current productive efficiency of peanut farming in the study area. It is therefore suggested that further research should be conducted to validate these results and to provide information on productivity changes that might occurred over the past 30 years.

Conclusions

The paper analyzed, by using DEA, the technical, allocative, cost and scale efficiencies of smallholder peanut farming in the Markham Valley of Papua New Guinea. The DEA analysis using historical production data was done not only to get some understanding of the productive efficiency of farms that prevailed then but it can also become useful for comparing productivity changes that might have occurred since 1986.

The findings indicate that technical, allocative, cost and scale efficiencies estimated varied substantially among the sampled farms. The average TE_{CRS} for the sampled farms was estimated to be 0.708 which suggest that farms need to reduce inputs by 29 percent. Allocative efficiency estimated amounts to 0.642 which suggest that farms, on average, need to reduce cost by 36 percent. Of particular interest is the over use of labor which may indicate disguised unemployment problem in the farming areas. The overuse of seed can be addressed by using reliable seeds for planting while tractor hire rate may be appropriately reviewed. The overuse of tools was expected as it was not possible to apportion their use in other farming activities.

The farms, moreover, were scale inefficient by 23 percent. Given the average TE_{CRS} of 0.708 and TE_{VRS} of 0.922 and by improving scale efficiency by 23 percent, TE_{CRS} can be increased to 0.922, a massive gain of 21.4 percent in technical efficiency. Essentially, technical efficiency can be improved by adjusting the scale of farm size while simultaneously making adjustments to inputs to improve allocative efficiency in peanut farming. While adjustments in the use of inputs are necessary to improve technical and allocative efficiencies, 96 percent of the farmers were economically inefficient in their farm operations. Given that farmers have other production activities in addition to peanut; it might be useful for them to shift resources to these alternatives which may be more profitable. Moreover, given the small sample size and historical data used, further research is required to validate the findings of this study and examine the extent of productivity change that might have occurred since 1996.

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