ASSESSMENT OF TECHNICAL EFFICIENCY OF SMALLHOLDER COFFEE FARMING ENTERPRISES IN MURANGA, KENYA

V. Kamau, J. Ateka, R. Mbeche and M. M. Kavoi
Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
Email: atekajm56@gmail.com

Abstract
The Kenyan coffee industry is a major contributor to Kenya's economy. The industry is a top foreign exchange earner coming fourth after tourism, tea and horticulture. The sector directly and indirectly supports over 6 million people, making it one of the leading sources of livelihood in the country. Despite the immense contribution, the production of coffee in Kenya has declined significantly over the past decades – associated with inefficiencies – resulting in increased poverty in coffee-dependent communities. This paper explores the determinants of technical efficiency in Murang'a County; a leading coffee producing region in Kenya. The analysis of the data followed a two-step approach following Helfand and Levine (2004). In the first step, technical efficiency measures were calculated using the non-parametric data envelopment analysis (DEA) model. In the second step, the estimated technical efficiency scores were regressed on a set of explanatory variables which included farm size, household characteristics and various indicators for institutional arrangements and adoption of technology. Results showed that the average technical efficiency was low at 54%. The findings show that farm size, coffee variety, access to credit, farmers' age and household size are critical determinants of technical efficiency in coffee farming. It is therefore concluded that adoption of improved varieties especially by youthful farmers and increased access to credit facilities which help farmers to purchase market inputs for coffee enterprise would increase TE and ultimately coffee productivity.

Key words: *Coffee production, technical efficiency, non-parametric approach, DEA.*

1.0 Introduction

Coffee is Kenya's fourth foreign currency earner after tourism, tea and horticulture. In addition, the sub-sector directly or indirectly employs about six million Kenyans in production, processing and marketing (CBK, 2011; ACP, 2015) and contributed Ksh. 10.8 billion (US$ 108 million (approximately 6%) to the GDP in 2010 (CBK, 2011).

In Kenya, production of coffee is majorly practiced by over 700,000 small-scale farmers who constitute 86.2% of the producers and operate on less than 2 hectares (ha) of land. The smallholders account for 75% of the total land under coffee, but, their production contributes about half (54%) of the total coffee production in the country. Estates, realize higher yields, perhaps due to their production approach which entails intensive application of market inputs i.e. fertilizers, pesticides, herbicides and fungicides. The smallholder producers are clustered in 450 cooperative societies. The cooperatives perform various facilitative functions including bulk supply of inputs, extension services, credit services, post-harvest handling and marketing (Karanja and Nyoro, 2005; Republic of Kenya, 2010). Critically, these cooperatives enhance the importance of small scale farmers in the value chain.

Production of coffee continues to face numerous challenges including: high cost of labour and inputs; erratic rains; high incidences of pests and diseases; competition from other farm enterprises; and poor governance of farmer organizations (USDA, 2015). The consequence has been declining productivity over the last two decades especially among the smallholder coffee farmers. Muranga County, in Kenya is one of the key coffee producing areas which has experienced decline in productivity over recent years (Republic of Kenya, 2010; Republic of Kenya, 2011). The low productivity may be attributable to inefficiencies within the production system. Based on Farrell (1957), efficiency could be attained when coffee enterprises realize maximum output by using the lowest possible input combinations. In response to the low coffee production trend in the smallholder subsector, the Kenyan government has been promoting adoption of enhanced coffee varieties and improved access to production inputs and related technologies to enhance productivity. Despite these efforts there still exist a notable yield gap between production levels by farmers and the expected yields. For example, the expected yield in Kg Cherry/ tree for Ruiru 11 cultivar is 8.39 Kgs (4.6 tons per ha) and 9.7 Kgs/ tree (5.0 tons per ha) for Batian cultivar. However, the average production levels for Kenyan small-scale farmers for the same cultivars are 1.8 tons per ha for Ruiru 11 and 3.9 tons per ha for Batian cultivars Coffee Research Institute, 2010).There is need to improve yields of existing small scale coffee farms through efficient resource utilization that would reduce poverty, ameliorate food insecurity and enhance income growth in rural areas (Linne, 2011). A study was therefore carried out to assess the technical efficiency (TE) and factors associated with TE of coffee farming enterprises in Muranga County, Kenya.

2.0 Research Methodology

2.1 Study Site, Data and Variables

Data for the study were collected from a cross sectional survey of smallholder coffee producing households in Muranga County in 2015. The study area covered two coffee producing wards in Kiharu Sub-County i.e. Mugoiri and Murarandia. A total of 78 out 1,572 coffee producing households were randomly selected from the two wards (i.e. 39 from each ward) and interviewed (Republic of Kenya, 2011). The survey obtained data on land use, input use, various household characteristics, indicators for input and market access, institutional arrangements and technology adoption. The variables used in the study were computed from the data collected. The socio economic characteristics of the sampled households are presented in section 4.

2.2 Theoretical Framework

Traditional economic theory typically gives recognition to two types of production efficiencies; technical and allocative (Farrell 1957; Yotopolous and Lau, 1971; Wolgin, 1973). Allocative efficiency refers to the ability of the farm to apply optimal amounts of given resources and focuses on the adjustment of inputs and outputs to reflect relative prices. Technical efficiency is however defined in a relative sense, as the distance between observed input–output combinations and a best practice frontier (Rios and Shively, 2005; Wambui, 2005; Mugera and Langemeier, 2011). Economic efficiency is a combination of technical and allocative efficiency and it implies the least-cost method of producing a given output (Mirrlees and Little, 1974).

Empirically the estimation of efficiency in this study follows a theoretical framework developed by Farell (1957), which permits the estimation of technical and allocative efficiency. Under the assumption of constant returns to scale (CRS), the production technology of firm can be represented on an input-input space as in Figure 1.

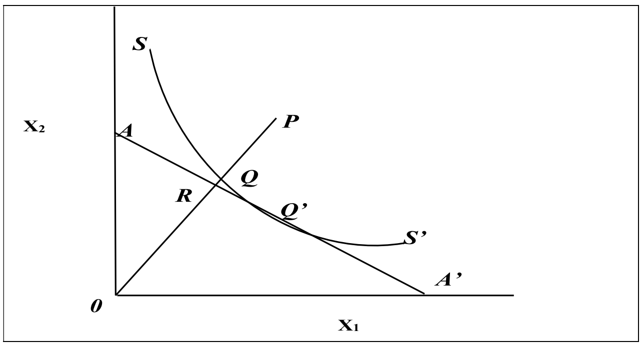

Figure 1: The relationship between Technical and allocative efficiency

In Figure 1, the point P represents the level of inputs X_1 and X_2 that a firm is observed to use to produce a unit of output. Assuming that the efficient production function is known, the isoquant, SS' represents the various combinations of the two inputs that a perfectly efficient firm can use to produce a unit of output. The point Q represents an efficient firm using the two factors in the same proportion as P to produce a given level of output. Since it can be seen that the firm producing at Q, uses only a fraction OQ/OP of each input to produce the same output as P; the ratio OQ/ OP represents a measure of technical efficiency. The ratio has the property that it takes a value of unity for a perfectly efficient firm and will be infinitely small if the amount of inputs become infinitely large. The allocative efficiency of the firm operating at point P can also be calculated by the ratio OR/OP, assuming the input price ratio represented by the line AA' is also known (Fried et al., 2008).

2.3 Model Specification

This study used the Data Envelopment Analysis (DEA) to characterize the frontier of the input -output production technology, and the proportional distance of each observation from the frontier. The DEA is one of the several techniques that can be used to calculate a best practice production frontier (Coelli et al., 1998). The principal advantage of DEA, as opposed to stochastic frontier estimation (Sharma and Leung, 2000) is that it does not impose parametric restrictions on the underlying technology and is therefore less prone to misspecification (Esparon and Sturgess, 1989; Färe et. al., 1994; Talluri, 2000; Ray, 2004; Zhu, 2014). In addition, the use of the stochastic frontier was discounted on account that using it for the two step approach employed in the study will involve contradictory assumptions about the distribution of the inefficiency term (Coelli and Batesse, 1998).

The following notation is used. The production possibilities set P is the combination of all pairs of inputs X and outputs Y that are feasible, where X and Y are vectors. Inputs and outputs are assumed to be freely disposable, and P is assumed to be non-empty, closed, and convex. The output distance function D_o is

$$D_o(X,Y) = inf\left\{\theta : \left(\frac{1}{\theta}X, Y\right) \in P\right\} \quad \text{.......(1)}$$

where, θ is a non-negative scalar that measures the ratio of the observed vector of inputs to the maximum input vector required to produce output vector by the best practice farm or the frontier farm. The measure equals one for efficient firms on the frontier, and then decreases with inefficiency (Helfand and Lavine, 2004). Therefore, with N farms or decision making units (DMUs) as they are known in DEA literature, the efficiency level of the Q^{th} DMU can be computed by solving the following linear programming specification. The specification follows Charnes et al. (1978).

$$minimize_{\theta\ \lambda}\ \theta$$

Subject to;

$$-Y^q + \lambda Y \geq 0 \quad \text{...(2)}$$

$$\theta X^q - \lambda X \geq 0$$

$$\lambda \geq 0$$

where Y is a M x N output matrix, X is a M x N input matrix while λ is (λ= λ1,…, λn,) is a NX1 vector of constants that shows the intensity with which each farm is used in the construction of the frontier farm. The linear program solves for the minimum value of ϑ given the constraints that the proportionally expanded vector of outputs and the vector of inputs are in the feasible set, and that the intensity variables are non-negative. The value of ϑ represents the proportion of input bundle of the Q^{th} farm needed to produce its own output. The model is interpreted as seeking a frontier farm that can produce at least the output of the Q^{th} farm, using the smallest possible multiple of its inputs. The q^{th} farm is considered efficient if its output is best produced using all of its inputs, or inefficient if its output can be produced by the virtual farm, using a fraction ϑ of its inputs. In this case ϑ satisfies the condition

$0 \leq \vartheta \leq 1.$

3.0 Empirical Results and Discussions

3.1 Socio-economic Characteristics of Farmers

The characteristics of the sampled households are summarized in Table 1.

Table 1: Descriptive Statistics of the Study Sample

Categorical Variables			
Variables	**Values**	**Frequency**	**Percentage %**
Household	Male HH	68	87.2
Headship HH	Female HH	10	12.8
Residence of	Within Farm	62	79.5
Household HH	Away from Farm	16	20.5
Educational Level	Primary	33	42.3
	Secondary	26	33.3
	Tertiary	19	24.4
Off-Farm Activities	Yes	25	32.1
	No	53	67.9
Land Entitlement	Owned	58	74.4
	Rented	20	25.6
Coffee Variety	Ruiru 11	35	44.9
	Batian	43	55.1
Extension	Yes	65	83.3
Services:Cooperative	No	13	16.7

Extension	Yes	33	42.3
Services:MoA	No	45	57.7

Continuous Variables

Variable	Mean	Minimum	Maximum	Std. Deviation
Age	36.55	19	59	7.740
Household Size	6.13	1	11	3.055
Farming Experience	20.46	5	43	7.744
Farm Size (Acres)	3.8577	1.50	14.20	2.75938
Land Size undercoffee (Acres)	2.3756	.60	7.50	1.48238
No of coffee stands/acre	992.88	210	3000	660.555
Farm Labour (Man-Days/acre)	158.35	36	483	105.894
Herbicides Use (Litres/acre)	12.13	1	38	9.606
Pesticides Use (Litres/acre)	18.12	4	55	12.757
NPK Fertilizer (Kgs/acre)	202.40	25	600	138.259
Urea Fertilizer (Kgs/acre)	154.95	25	700	113.611
Early Crop (Kgs/acre)	481.61	78	2400	402.967
Late Crop (Kgs/acre)	1703.87	215	6900	1255.040
Output (Kgs/acre)	2185.48	378	7500	1540.065
Output per Stand (Kgs)	2.3959	0.50	6.34	1.10620

Source: Authors' Survey in Murang'a County, 2015

As shown in table 1, majority of the sample households (87.2 %) were male headed; a result that was expected since most households in Sub Saharan Africa are male headed (waGithinji et al., 2011). The survey results further showed that 79.5% of the household heads resided within the village, implying therefore that they were available to make important tea farming decisions. All the household heads had attained formal education: 42.3% primary attended school, 33.3% secondary and 24.4% attained tertiary education. The attained levels of education provide an indication that most of the sample households had the requisite capacity on human capital necessary in the adoption of recommended coffee husbandry practices (Nyangena and Ogada, 2014). The average land area under coffee enterprise was 2.38 acres out of the mean land size of 3.86 acres. 74.4% of the land was owned by the household and 25.6% was leased. The area favoured production of high quality Arabica cultivars i.e. Batian and Ruiru 11 with proportions of 55.1% and 44.9% respectively. The average number of coffee stands per household was 992. About 44.9% of the coffee stands had been sourced as seedlings from the local coffee cooperatives, who oversaw planting, spacing and crop husbandry.

The results of the survey indicated that most of the farming households had received extension information and advisory services in the 2014-2015 growing season, majority of them (83.3%) from the cooperatives. In addition, the cooperatives supplied farms inputs (chemical top-dress fertilizers, pesticides, and herbicides) to the farmers. Only 46.2% of the farms had opted for local arrangements to source inputs from private Agro-Vets.

With regard to input use, the survey revealed that the farms recorded an average of 158 Man-Days/acre (both family and hired), 12 litres of herbicides, and 18 litres of pesticides/acre as well as mean top-dress fertilizer use of 202 Kgs/acre for NPK (20.20.0) and 154 Kgs/acre for Urea. A mean production of 2.40 Kgs was observed per coffee stand for the year. The average output for the early crop was at 481.61 Kgs/acre, with the minimum output at 78 Kgs/acre and 2,400 Kgs/acre for the maximum. Equally, the late crop recorded a mean output of 1,703.87 Kgs/acre, with a minimum of 215 Kgs/acre and a maximum of 6,900 Kgs/acre. Overall the results show that the achieved levels of output were below the recommended levels.

3.2 Estimated Results of Technical Efficiency

Following the linear programming model in equation 2, TE was estimated under assumptions of constant returns to scale. The results showed that the mean TE_{CRS} score or index was 0.54, with a minimum TE_{CRS} score of 0.11 and a maximum TE_{CRS} of 1.00. Figure 1 shows the distribution of the TE scores for the sample households.

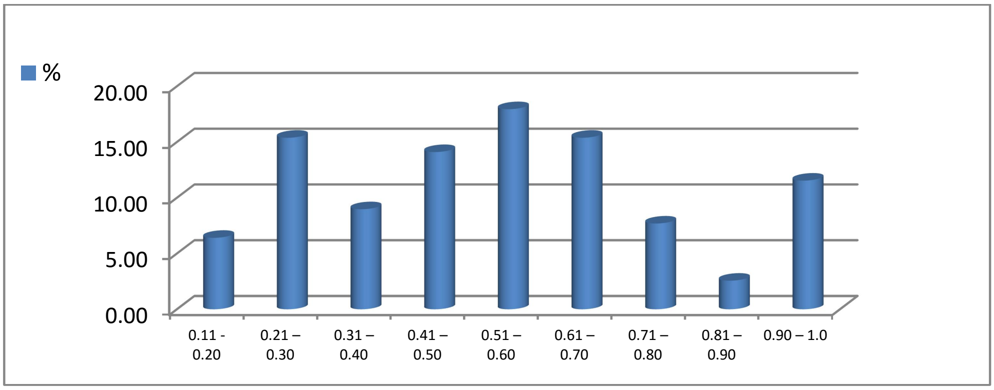

Figure 1: Distribution of TE scores for the various coffee households

The study found that only 12% of the households were highly efficient; and were within the range of 90 and 100% technical efficiency. The coffee enterprises (DMUs) operating at less than the mean technical score of 0.54 accounted for 44% of the sample. Twenty three percent of the households were deemed to be relatively technically efficient because they operated between 0.61-0.70 and 0.71-0.80. These results implied that there is still an opportunity amounting to 46% which is untapped and can be exploited to improve coffee production through efficiency gains.

3.3 Determinants of TE in Coffee Production

The estimated technical efficiency scores were regressed on a set of explanatory variables which included farm size, household characteristics and various indicators for institutional arrangements and adoption of technology (Table 3). The findings show that farm size, coffee variety, access to credit, farmers' age and household size are critical determinants of technical efficiency in coffee farming. Among the observed household characteristics, age of a farmer negatively and significantly influenced efficiency while household size positively influenced TE. This implies that as the age of the farmers increase, the farm TE declines. This observation could be explained by the fact that coffee farms in Kenya have been undergoing a transition. Farmers have been adopting new coffee varieties to improve productivity. However, older farmers have been slow to adopt them (ACP, 2015).These results are corroborated by Murthy *et al.* (2009) who studied TE of tomato production in India and observed that farms managed byrelatively younger farmers were more efficient.

Table 3: Determinants of technical efficiency in Murang'a County

Variable	Coefficient	t ratio	P value
(Constant)	1.932***	2.745	0.008
Age of Farmer	-.028***	-3.943	0.0003
Household Headship	-.076	-.694	0.491
Household Size	.006***	6.433	0.000
Residence of Headship	-.100	-1.163	0.250
Land Size	.002	.058	0.954
Land Entitlement	.058	.769	0.445
Farm size under Coffee	-.147***	-2.772	0.004
Coffee Variety	.062***	2.828	0.001
Farming Experience	.028	.936	0.354
Non Farming Activities	.020	.262	0.795
Farmers	-.070	-.959	0.342
Cooperatives	.050	.519	0.606

MoA	-.024	-.356	0.723
Credit Access	.006***	2.861	.003

Source: Authors' Survey in Murang'a County, 2015.

The household size positively and significantly influenced TE scores. This could be explained by the fact that coffee is a labour intensive enterprise and many households in Muranga employ family labour in their coffee farms. An increase in the household size therefore increases access to family labour which in turn improves TE scores. While we are not suggesting an increase of household size, the importance of this variable should be looked at from the context of supplying labour to smallholder, often, family farms. A decline in household sizes often associated with rural urban migration of young people might be a set back to the coffee industry going forward (see, Poudel *et al.*, 2012).

The area under coffee had a negative and significant (p=0.004) influence on TE. This can plausibly be explained by the fact that farmers with large farm sizes have a crop diversification tendency of investing in other agriculture ventures for example maize, horticulture and sheep rearing. The inverse plot size and TE relationship may be explained by the more intensive use of labour in small farms than larger farms as reported in Kiani (2008) and waGithinji *et. al.* (2011). Coffee variety had a positive and a significant (p=0.001) influence on TE. In recent years, high yielding and disease resistant Arabica coffee varieties have been promoted in the area (ACP, 2015) and their adoption has been associated with increased TE scores.

Credit access is the only institutional factor that had positively and significantly (p= 0.003) affected TE scores in this study. It implies that an additional unit of this factor elicits a significant marginal increase in the TE score. Coffee production does require a number of inputs including seedlings, pesticides and herbicides. Hence improved access to credit which most farmers obtain from cooperative societies where they are members would enable them to access market inputs (fertilizers, herbicides, pesticides etc.) for increased productivity and ultimately technical efficiency. The importance of credit provision follows findings of Poudel *et al*., (2012) who studied technical efficiency of coffee farming enterprises in Nepal. The finding is however inconsistent with Ogada *et.al.* (2014) who found the access to credit was inversely related with TE.

3.4 Conclusion

This study has revealed that smallholder coffee farmers are technically less efficient. The estimated technical efficiency scores ranged from 0.11 to 1.00 with a mean of 54.4%. Implicitly, there is an evident and ostensible opportunity for these coffee farming enterprises to enhance their technical efficiency and productivity. On average, these enterprises had a potential to enhance their coffee productivity by an average of

46% from the existent levels of input utilization. This could be achieved through increased adoption of improved varieties and improved farm management practices especially by the youthful farmers. Coffee production requires a number of inputs including seedlings, fertilizers, pesticides and herbicides. Hence improved access to credit which most farmers obtain from cooperative societies where they are members would enable them to purchase market inputs for increased productivity and ultimately technical efficiency. However, there is need to pursue other types of efficiency studies including allocative, scale and economic efficiencies in the smallholder coffee sub-sector.

References

Africa Caribbean Pacific, ACP. (2015). Boosting coffee productivity in Kenya and Malawi through better access to and use of modern technologies and innovations. Available at http://acp-st.eu/sites/all/files/projects-factsheet/ACP-330-219_PRINT.pdf.

Coffee Board of Kenya, CBK (2011). Liberalization and the Privatization of the Coffee Industry. Nairobi: CBK.

Charnes, A., Cooper, W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444. http://dx.doi.org/10.1016/0377-2217 (78) 90138-8

Coffee Research Institute, (2010). Annual Report: Climate Change Hits Coffee Industry. Www.coffeeresearch.org. January 2016.

Coelli T, Prasada R, and Battese G.E. (1998). An Introduction to Efficiency and productivity Analysis, Kluwer Academic publisher, Boston.

Esparon, N., and Sturgess, N. (1989). The Measurement of Technical Efficiency Using Frontier Production Functions of Rice Farms in West Java 1. Bulletin of Indonesian Economic Studies, 25(3), 99-119. http://dx.doi.org/10.1080/00074918912331335659.

Fare R. S. Grosskopf and Lovell C. A. Knox, (1994). Production Frontiers. CambridgeUniversity Press.

Farrell, M. (1957).The Measurement of Productive Efficiency. Journal of the Royal Statistical Society Series A (General), 120(3), 253. http://dx.doi.org/10.2307/2343100

Fried, H., Lovell, K., & Schmidt, S. (2008). The Measurements of Productive Efficiency and Productivity Growth. New York: Oxford University Press, USA.

Republic of Kenya (RoK),(2010). Economic Review of Agriculture (p. Murang'a District Farmers Statistic Records.Murang'a District Agricultural Office, Murang'a, Kenya.

Republic of Kenya (RoK), (2011).Murang'a District Farmers Statistic Records). Nairobi: Ministry of Agriculture, Nairobi, Kenya. Government of Kenya.

Helfand S. M. and Levine E. S. (2004).Farm Size and the Determinants of Productive Efficiency in the Brazilian Center-West." Agricultural Economics 31:241-249.

Karanja, A. M. and Nyoro J. K. (2005). Coffee Prices and Regulation and their

Impact on Livelihoods of Rural Community in Kenya, Tegemeo Institute of Agricultural Policy and Development, Egerton University, Kenya

Kiani A. K (2008). Farm Size and Productivity in Pakistan. European Journal of Social Sciences – Volume 7, Number 2 (2008)

Linne, K. (2011) 4C Climate Code: additional, verifiable, voluntary. Climate Change Adaptation and Mitigation in the Kenyan Coffee Sector. German Society for International Cooperation (GIZ), Eschborn, Germany.

Mirrlees, J.A., and Little L.M.D (1974). Project Appraisal and planning for Developing Countries. Heinemann, London

Mugera W. K. and Langemeier M. R. (2011). Does Farm Size and Specialization Matter for Productive Efficiency? Results from Kansas, Journal of Agricultural and Applied Economics, 43, 4 (November 2011):515–528. Southern Agricultural Economics Association

Murthy D. S., Sudha,M. ,Hegde M.R. and Dakshina V. M. (2009).Technical Efficiency and its Determinants in Tomato Production in Karnataka, India: Data Envelopment Analysis (DEA) Approach. Agricultural Economics Research ReviewVol. 22 July-December 2009 pp 215-224

Nyangena W. and Ogada M.J. (2014). Impact of Improved Farm Technologies on Yields.The Case of Improved Maize Varieties and Inorganic Fertilizer in Kenya. Environment for Development Discussion Paper Series January 2014.

Ogada M. J., Muchai, D., Mwabu G. & Mathenge M. (2014).Technical Efficiency of Kenya's Smallholder Food Crop Farmers: Do Environmental Factors Matter? Environment, Development and Sustainability; a Multidisciplinary Approach to the Theory and Practice of Sustainable Development; Volume 16, Number 5.Springer.

Poudel, K. L., N. Yamamoto, and Thomas G., (2012).Comparing technical efficiency of organic and conventional coffee farms in Nepal using data envelopment analysis (DEA) approach. Selected Poster prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

Ray, S. C. (2004). Data Envelopment Analysis: Theory and Techniques for Economics and Operations Research. New York: Cambridge University Press

Rios A. R. and Gerald E. Shively (2005).Farm size and Nonparametric Efficiency Measurements for Coffee farms in Vietnam. Selected Paper Prepared for Presentation at the American Agricultural Economics Association. Annual Meeting, Providence, Rhode Island, July 24-27, 2005

Sharma, K., & Leung, P. (2000). Technical efficiency of carp production in India: a stochastic frontier production function analysis. Aquaculture Research, 31(12), 937-947. http://dx.doi.org/10.1046/j.1365-2109.2000.00521.x

Talluri, S. (2000). Data Envelopment Analysis: Models and Extensions. International Journal of Production Economics, 37(13), 8-11.

USDA (2015).Coffee Annual 2015.Global Agricultural Information Network Report. Available at:

http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Coffee%20Annual_Nairobi_Kenya_5-14-2015.pdf

waGithinji, M., Konstantinidis, C., and Barenberg, A.,, (2011). "Small and as Productive: Female Headed Households and the Inverse Relationship between Land Size and Output in Kenya" (2011). Economics Department Working Paper Series, No. 139. Available at: http://scholarworks.umass.edu/econ_workingpaper/139

Wambui, B. (2005). Technical Efficiency in Kenya's Maize Production: An Application of the Stochastic Frontier Approach (MSc. Thesis Department of Agricultural and Resource Economics). Colorado State University Fort Collins, Colorado: USA.

Wolgin, J. M. (1973). Farm Response to Price Change in Smallholder Agriculture Kenya. An ExpectedUtility Model.Unpublished Ph.D. Thesis, Yale University.

Yotopolous, P. A. and L. P. Lau.(1971). A Test for Relative Efficiency and Application to Indian Agriculture, American Econ. Review: 94-109.

Zhu, J. (2014). Quantitative Models for Performance Evaluation and Benchmarking, International Series in Operations Research & Management Science 213, DOI 10.1007/978-3-319-06647-9-2. Springer, International Publishing Switzerland.