Global Journal of Business, Economics, and Management: Current Issues

Volume 11, Issue 3, (2021) 235-253

www.wjbem.eu

Impact of Land Fragmentation on Rice Production Efficiency: Comparative Study of Upper and Middle Sindh Province of Pakistan

Mansoor Ahmed Koondhar[a *], College of Management, Sichuan Agricultural University, Chengdu, 611130, China. lihoujianguoying@126.com
Houjian Li [b], College of Economics, Sichuan Agricultural University, Chengdu, 611130, China. prema924266501@foxmail.com https://orcid.org/0000-0003-4852-8042
Mumtaz Ali Joyo[c], Department of Agricultural Economics, Sindh Agriculture University Tandjam.Pakistan. joyoali@gmail.com https://orcid.org/0000-0003-0921-6812
Faiza Ahsan[d], College of Management, Sichuan Agricultural University, Chengdu, 611130, China. Socialist.mansoor@gmail.com https://orcid.org/0000-0003-3130-2151

Suggested Citation:
Koondhar, M., Li, H., Joyo, M.A. & Ahsan, F. (2021). Impact of Land Fragmentation on Rice Production Efficiency, Comparative Study of Upper and Middle Sindh Province of Pakistan. *Global Journal of Business, Economics, and Management: Current Issues. 11*(2), 235-253. https://doi.org/10.18844/gjbem.v11i3.4694.

Received from July 19, 2021; revised from September 13, 2021; accepted from November 25, 2021.
Selection and peer-review under responsibility of Prof. Dr. Andreea Iluzia IACOB, Bucharest Academy of Economic Studies, Romania.

Abstract
There is a risk involved in measuring the impression of land fragmentation on productivity at the micro-level. The impression of this study is to investigate the correlation of land fragmentation and rice production efficiency into two different major rice cropping zones, which are mostly in the middle and upper part of the Sindh province, Pakistan. For this study, random data of 450 rice growers were collected from 5 major growing districts *(Dadu, Naushahroferoze, Sukkur, Larkana, and Shikarpur)* of Sindh province Pakistan, 432 respondents were analyzed out of 450. Cob Douglas and the censored normal Tobit model were analyzed by using SPSS and E-views. According to the results, the production function opined that the production can be increased owing to the increase in family income, ploughing, planking, and irrigation. It also confirmed that the reduction in land rent, temporary labor with fertilizer usages such as urea, DAP, and chemical spray would cause a production increase in the middle part of Sindh. The results policy suggested the assurance of land fragmentation and distance from homestead to farm has a significant correlation with rice production.

Keywords: Rice, production, fragmentation, Policy, Sindh.

* ADDRESS FOR CORRESPONDENCE: Mansoor Ahmed Koondhar[a *], College of Management, Sichuan Agricultural University, Chengdu, 611130, China
E-mail address: lihoujianguoying@126.com

1. Introduction

Nguyen, Cheng et al. (1996) from 1993-94 have data collected from 1200 respondents from Jilin, Shandon, Jiangxi, Sichuan, and Guangdong provinces of China to analyze the land fragmentation impact on the productivity of wheat, rice, and maize. The results showed a positive and statistically significant impact on production with the corresponding total farm size. Similarly (Wan and Cheng 2001), discovered the correlation between land fragmentation and return to scale in the Chinese farming system, by using the same primary data, the major findings were that the 1% land fragmentation increase can reduce the 9.8% and 2% in the tuber, root crops respectively. Also, research was done by Fisher and Liu(1992), who collected household survey data from 1987-1988 of 1200 respondents from Jilin, Jiangsu, Henan, Heibei, and Jiangxi provinces of China to examine the land fragmentation effect on productivity owing to the number of parcels. The results found that the number of parcels rejected the null hypothesis with the inverse sign of the coefficient.

An early study was taken by Wadud and White(2000) to compare the land fragmentation and rice production efficacy in Bangladesh and Pakistan, the results declared that land fragmentation reduces rice production efficiency in Pakistan and Bangladesh. Kiplimo and Ngeno(2016) researched the understanding of the relationship of land fragmentation with farm-level productivity by using 200 survey primary data of the Trans-Nzoia area of Kenya. The major findings revealed that small farm and once piece holding growers get more production followed by the large farm holding with more parcels growers.

Currently, Feng has researched the impact of land rental market participation and off-farm employment owing production efficiency, choose 52 respondents from three villages of Jiangxi province of China, included distance from the homestead to farm and number of parcels as control variables. His major finding reveals that the number of parcels has a positive and significant relationship, but the distance from homestead to farm does not show any correlation with production efficiency. The parametric and non-parametric model was used commonly to distinguish the results of efficiency analysis. For the empirical analysis of agricultural productivity and grower efficiency both parametric stochastic frontier production function and non-parametric model non-parametric model DEA, Data envelopment analysis are used from the abundant(Bravo-Ureta and Pinheiro 1993; Coelli 1995; Audibert 1997; Kebede 2001; Yang and Chen 2009).

Since the last decade, many researchers have used it as a key model to examine production efficiency (Huang, Tang, et al. 1986; Kalirajan and Shand 1986; Taylor and Shonkwiler 1986; Koondhar, Qiu, et al. 2016). Similarly Zhuo and Shunfeng(2008), meta-frontier function to examine the gap between the agro-based technology and efficiency in China. Research has investigated rice production and efficiency which was analyzed by Daryanto et al (2002). Likely (Coelli, Rahman, et al. 2002; Daryanto, Battese, et al. 2002), applied the non-parametric method to estimate rice producer's efficiency in Bangladesh. Amongst the many studies, only some have taken land fragmentation into account. Research by Hazarika and Alwang(2003) has declared the positive and significant impact of plot size on tobacco cost efficiency in Malawi. Similarly, a study from Bangladesh by Wadud and White (2000) showed average growers cultivated more than one plot of land at a great level of practical and allocate efficiency. On other hand, land fragmentation measured with parcel numbers and distance from homestead to farm found no statistically significant correlation with rice producer's efficiency in Nepal (Kebede 2001).

1.1. Purpose of study

This paper aims to analyze rice production efficiency level with the impact of land fragmentation besides objective to estimate up to what extent rice production can be enhanced rice production under existing inputs. There is a risk involved in measuring the impression of land fragmentation on productivity at the micro-level. Already many researchers have researched land fragmentation and crop production, every researcher has chosen a different area, model, crop, and intention. These researchers have examined efficiency by using limited measures and failed to declare the productivity effect of land fragmentation and other inputs i.e., the respondent age, experience, education, and farmer health condition. The statistical model can deal with these inputs to get better results of the land fragmentation impacts on production efficiency.

This research has mentioned the data of household, crop, and plots, as well as used other controlling variables like availability of facilities at the village level to examine the factors affecting rice production and production efficiency with the help of frontier production function and censored normal Tobit model. The major difference between present research and previous studies is that our research area, units of the inputs, i.e. land preparation, fertilizer, chemical spray and application of the irrigation, and other factor are mentioned above. Control variable soil quality is included based on the perceptions of the grower. For reminding, this paper is organized as follows, Section 2 describes the methodology, data sampling procedure, and technical analysis. Section 3 is listed with empirical results. Section 4 is indicated by conclusion and policy recommendations and the last one is the reference.

2. Methods

Concerning the methodology, three key problems will be discussed, 1st the selection among parametric and non-parametric approaches, 2nd the selection of a functional form for the production function and 3rd is the choice of model estimation. The 1st issue is discussed in sections 2.1 and 2nd and 3rdare given in 2.2

2.1. Data collection

The field survey was carried out in the Sindh province of Pakistan due to its high degree of land fragmentation. Sindh province is located in the southeast of Pakistan, and Sindh is rich in Indus. Indus is located in arable and fertile land. The total land area of Sindh province is 54,407 square meters which cover 17.7% of the total area of Pakistan (supporting data). Owing to the increase of Indus delta cultivation area is growing, nowadays the arable land of Sindh is 40% and 5% is rangeland. The total cropped area of Sindh is 3.10 million hectares out of 5.88 million hectares of cultivated area. There are two cultivating seasons, Kharif and Rabi. Kharif spans from June to October and Rabi from October to

March. Field crops are cultivated on almost 68% of the cropped area in Sindh, and the main crops of Sindh's are cotton, wheat, rice, and sugarcane. In addition, Sindh contributes 35% of rice, 28% of sugarcane, 20% of cotton, and wheat 12% in the total production of Pakistan. In this paper, we focus on rice production.

2.2.Sample

Total randomly 450 respondents were selected from 5 districts including Shikarpur, Sukkur, Naushahroferoze, Larkana, and Dadu, and 90 samples were collected from each district. These are the major rice-growing areas of Sindh and they are also called rice-wheat cropping areas of Sindh. Two talukas per district are chosen and 3 villages per taluka are selected, with 15 respondents randomly selected from each village. 432 out of 450 samples (96%) are used for empirical analysis. Analyzed samples and total samples are mentioned in table 1.

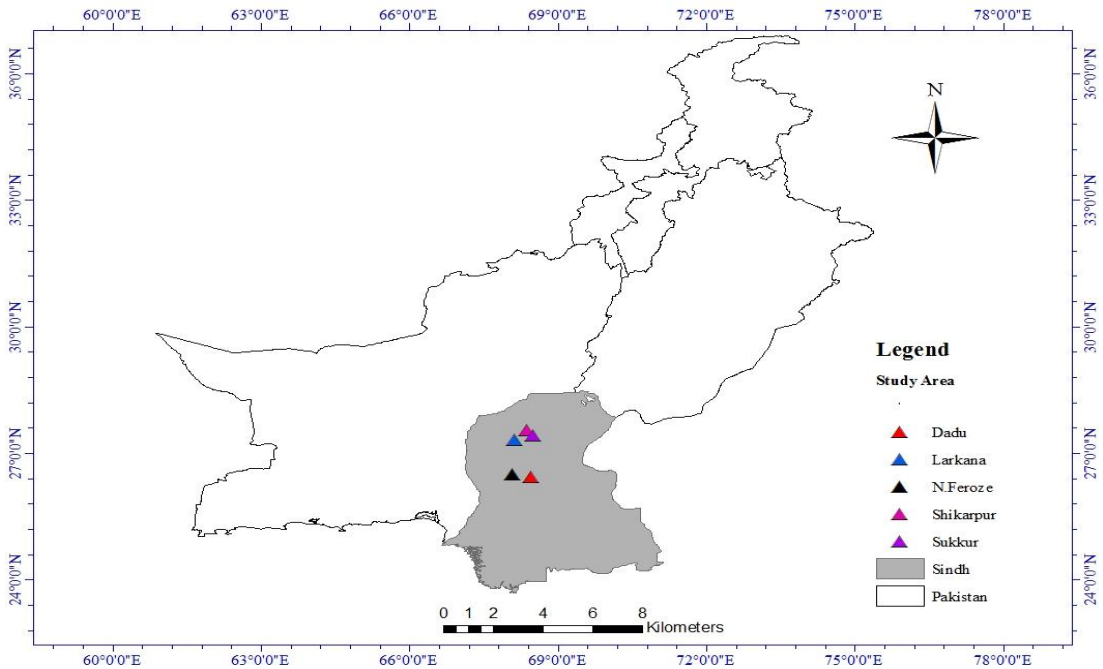

Figure 1 Area selected

2.3.Key Model selection

Selection among non-parametric and parametric to measure production efficiency has been contentious: both have their strengths and weaknesses (Coelli 1995). The parametric examination cops with stochastic noise and let hypothesis testing to production efficiency and structure. Therefore, this model has to stipulate a functional form for the frontier of production and Levis a distributional hypothesis in the terms of efficiency. The non-parametric analysis could not levy such barriers but it imposes the missing sampling errors. The selection of the parametric and non-parametric hypothesis can be contingent on the research key objective, the variable types, methods, and data availability. In

this article, we selected the stochastic frontier production function as a parametric hypothesis to analyze the land fragmentation impacts on rice production efficiency. The key factor of selection this method is to the rice production of Sindh has upregulated and downregulated changes which might be due to climate variations and other environmental changes i.e. soil quality, the slope of the land, and irrigation accessibility. Moreover, all respondents may not give a response exactly, due to the heterogonous acuities that may affect the measured efficiency (Chen, Huffman, et al. 2003). The stochastic frontier function was established autonomously by (Meeusen and van Den Broeck 1977)Ainger, Lovell, and Schmidt (1977). Jondrow et al (1982) lengthy it by joining producer-specific efficiency effects. Greene (2008) estimated different stipulations for the distributional hypothesis. Following Coelli and Rahman et al(2002), assuming a half-normal distribution of the one-sided error, the basic structure of the model for a cross-sectional data set can be expressed as

$$Pi = f(X_i;\beta) + \varepsilon_i (i = 1,2,3,4.....N)$$

Where: P_i Denotes the production of I-th farm, N refers to the household farms numbers, $\beta = (1\times j)$ is the vector of Unidentified parameters, $X_i = (j \times 1)$ Pathway of the input numbers of i-th farms, $f(.)$ Signifies the production frontier function, and ε is the composed error term that could be decomposed like:

$$\varepsilon_i = S_i - \mu_i$$

Where: V_i symbolizes the stochastic random error that is supposed to be independently and identically distributed (iid) such as $N(0,\sigma_s^2)$ an independent of the μ_i;

μ_i Known as undesirable random error interpretation for production efficiency (PIE) those are expected to be iid as semi-standard $N^+(0,\sigma_\mu^2)$.

Parameters β, σ_v and σ_μ Production efficiency (PE) for the individual firm could be estimated for getting the desired results. Formerly, technically efficiency with PE=1-PIE could be used for this research, normally, to check the virtual significance of the land fragmentation. So, the equation was drawn as follow:

$$PE_i = m_1\delta + \eta_1$$

Where: PE_i is already mentioned above, m_i signifies the $(1\times k)$ pathway of variables that might affect the farm efficiency such as land fragmentation in our circumstance δ symbolize the $(k\times 1)$ undefined variables and η_i is a random disturbance term presumed to be iid such as $N^{+}(0,\sigma_{\mu}^{2})$

2.4. Model selection and estimation

The selection of functional form in the parametric method has likely been a theme to debate (Bravo-Ureta, 1993). Binominal production function, translog, and Cobb-Douglas are usually used to analyze the production function. Few researchers i.e. Kopp and Smith(1980), contend that log as an interest rate on efficiency measuring, but it does not show the same interest rate on the general structure of production technology. The Cobb-Douglas production function runs a satisfactory picture of the production technology. Therefore we choose Cobb-Douglas due to the straightforwardness, it's a seemingly good fit for all kinds of data (Fleisher and Liu 1992; Nguyen, Cheng, et al. 1996).

Characteristic agricultural inputs such as household characteristics, farm characteristics, land, labor, capital, material i.e., fertilizer, seed, irrigation, pesticide, weedicide used to cultivate rice to get the production. All are key variables and included in our model. Farm and household characteristics signify the soil quality, age, education, and health of the household. The key principle of Cobb-Douglas is to use the value of input variables should not be zero. Capital suspected land rent, and capital refers to the machinery of land management, i.e. plowing and planking, labor included permanent and temporary labor. In Pakistan, commonly used fertilizers are DAP, Urea, and NAP in rice crops, sometimes SOP, MOP, and Sodium Potash are used, based on the requirements and quality of the land.

We analyzed the model with the binomial approach. Firstly, we approximate the frontier method by presumptuous a half-normal distribution inefficiency term to forecast the production efficiency scores and assess them $\beta^{'}s$; afterward, we analyzed the factors of production efficiency by the Tobit method. Because individual step model could be used, which includes farm-specific determinants, to check its influence on the production efficiency in the approximation production frontier efficiency (Huang, Tang, et al. 1986; Coelli, Rahman, et al. 2002).

2.5. Description of the production frontier function

The production frontier model could be specified like:

$$Ln(Y)=\beta_{0i}+\beta_{1i}\ln(AGE)+\beta_{2i}\ln(EDU)+\beta_{3i}\ln(EXP)+\beta_{4i}\ln(LR)+\beta_{5i}\ln(FS)+\beta_{6i}\ln(FM)+\beta_{7i}\ln(FI)$$
$$+\beta_{8i}\ln(PL)+\beta_{19i}\ln(PLG)+\beta_{10i}\ln(PLK)+\beta_{11i}\ln(SR)+\beta_{12i}\ln(TP)+\beta_{13i}\ln(URA)+\beta_{14i}\ln(DAP)+\beta_{15i}\ln(NP)$$
$$+\beta_{16i}\ln(CS)+\beta_{17i}\ln(IRI)+\beta_{18i}\ln(HL)+\beta_{19i}\ln(SLP)+\beta_{20i}\ln(SQ)+v-\mu$$

Where: ln(Y) symbolizes the yield of rice crop from upper and middle Sindh and all the abbreviated variables in the equation which are available in table No.1. Data for land rent was collected annually but we have subtracted the data to half-year because the rice crop stands on the field for about 4 months. Family income is included all kinds of income such as income from the crop, livestock,

nonfarm income, remittance, zakat, etc. Sometimes if the farmer's family size is small or they are working in another industry as a job, shopkeeper, or so on, farmers need to hire more labor during planting of rice from one place to another, harvesting and threshing. Therefore, we included permanent and temporary labor separately. The chemical spray includes weedicide, fungicide, and insecticide. V and μ symbolize the error term as mentioned in the equation.

Table 1

Description of variables for production function frontier

Variables	Identifications	Unit	Expected Sign
Land rent **(LR)**	Continuous	Rs/half year	+/-
Family income **(FI)**	Continuous	Rs/annual	+
Permanent labor **(PL)**	Continuous	Nos/Ac	+
Temporary labor **(TL)**	Continuous	Nos/Ac	+/-
Plough **(PLG)**	Continuous	Nos/Ac	+
Planking **(PLK)**	Continuous	Nos/Ac	+
Seed rate **(SR)**	Continuous	Kg/Ac	+
Urea **(URA)**	Continuous	Bags/Ac	+
DAP	Continuous	Bags/Ac	+
NP	Continuous	Bags/Ac	+
Chemical spray **(CS)**	Continuous	Nos/Ac	+/-
Irrigation (**IRI)**	Continuous	Nos/Ac	+
Slope **(SLP)** (0=steep,1=Moderate 2=Good)	Dummy	0.00	-
Soil quality **(SQ)** (1=Good, 0=Normal)	Dummy	0.00	+

Input in the method of Cobb-Douglas is included with the expectations of positive and negative, some inputs have both expectations may it has a positive or negative relationship with yield.

2.6. Description of the production efficiency equation

The used variables for analyzing production efficiency are age, education, farmer's health, family members, farm size, experience, and other factors like information, which may affect the capability of the producer to use the available resources. The indicators selection for a model depends upon research type, area, and accessibility of data. Likely in our research, we choose the variables.

Respondent's characteristics: age, education, experience, family size, farmer's health.

Farm characteristics: Farm size, land rented in, land rented out, shared land in, shared land out, land fragmentation, several parcels, distance from homestead to farm, tractor ownership.

Respondent has the same facilities like extension service, bank, market, school, etc. in the village, still the situation is not likewise in different areas like upper and middle Sindh. So, we have tried our best to explain the situation as much as we can. Therefore, we have used area (Middle and upper Sindh) as dummy variables to show the figure of the current situation and explain why there is a difference.

$$PE = \partial_{0i} + \partial_{1i}AGE + \partial_{2i}EDU + \partial_{3i}EXP + \partial_{4i}OL + \partial_{5i}RIL + \partial_{6i}ROL + \partial_{7i}SIL + \partial_{8i}SOL + \partial_{9i}LR + \partial_{10i}LF + \partial_{11i}FS$$
$$+ \partial_{12i}FM + \partial_{13i}FM + \partial_{14i}DIS + \partial_{15i}TO + \partial_{16i}HL + \partial_{17i}Bank + \partial_{18i}MAK + \partial_{19i}EXT + \partial_{20i}SCH + \partial_{21i}MS + \partial_{22i}US + \eta_{Li}$$

All the equations mentioned abbreviated variables can see detailed in Table 2.

3. **Results**

The empirical results of production efficiency usually take farm-scale as solitary explanatory variables. In this research, we decomposed the farm size into parcels and the size of the average parcel. In the case of average plot size, the plot number measures the scale effect. Although, the average size of the plot imprisons the knowledge of land fragmentation. In this case, the average size of the plots is estimated to have a positive and significant correlation with production efficiency. In this era, many of the technologies are not suitable to be used in small farms and farms away from the homestead. This shows the inconvenience in farm management, so we expect it would have a negative and significant relationship with production efficiency. When a household head has its tractor, it might be easier to manage the field on time and also save them money. Therefore, we expect that has a positive relationship with production efficiency.

If the bank is available in the village, it could be possible and easier for a farmer to access the credit on time, when he needs to buy inputs. Thus, we realize that there are chances to be a positive and significant relationship. Availability of market for farm inputs and outputs at the village becomes the easier for the farmer to go market and buys inputs and sells output which may show positive relationship because if the market is far away he needs to spend more time to go market to buy input. He may also spend a lot of money on transport. Extension service can help the farmers to increase production by information regarding management and applying the applications of inputs. Thus, we expected that it would be possible to show a positive relationship.

Dummy variables of areas (upper and middle) Sindh are included to compare the infrastructure of the village and production efficiency. Upper Sindh may show high productivity as compared to the middle because of the selected respondents from upper Sindh which are located at the river bank. Still, in some cases, we are not sure it will be a positive or negative relationship, but somehow we are sure that in middle Sindh there will be a negative sign. Although, middle Sindh is rich and highly fertile land for the cultivation of rice, sugarcane, wheat, and cotton. But due to a shortage of water in rice crops, farmers can't get higher yields as compared to upper Sindh. Therefore farmers prefer to cultivate cotton or sugarcane. All the variables along with the expected sign are available in table 2.

Table 2

Description of variables for production efficiency

Variables	**Identifications**	**Unit**	**Expected Sign**
Age	Continuous	Years	+
Education **(EDU)**	Continuous	Years	+
Experience **(EXP)**	Continuous	Years	+
Owned land **(OL)**	Continuous	He*	+
Rent inland **(RIL)**	Continuous	He*	+

Rent out Land **(ROL)**	Continuous	Hec*	+/-
Share inland**(SIL)**	Continuous	Hec*	+/-
Share out land **(SOL)**	Continuous	Hec*	+/-
Land fragmentation**(LF)**	Continuous	Nos	+
Farm size **(FS)**	Continuous	Hec*	+
Family size **(FM)**	Continuous	Nos	+
Distance from Homestead to farm (**Dis**)	Continuous	KM	+
Tractor Ownership (**TO**) (0=Yes, 1=No)	Dummy	If 0=Yes	+/-
Health **(HL)** (0=Average, 1= Healthy	Dummy	If Healthy	+
Bank at village**(Bank)** (0=Yes,1=No)	Dummy	If 0=Yes	_
Market (**MAK**) (0=Yes, 1=No)	Dummy	If 0=Yes	+/-
Extension service (**EXT**) (0=Yes, 1=No)	Dummy	If 0=Yes	+
School (**SCH**) (0=Yes, 1=No)	Dummy	If 0=Yes	-

Hac* acquire the sign of numbers of Hectares, Nos refers to the numbers of family members, KMis the symbol of kilometers, means how many kilometers are far away from the homestead.

3.1. Descriptive analysis

Table 3 shows the results of descriptive analysis of our proposed variables, which are compared with the middle and upper parts of Sindh province, Pakistan. In the case of land rent (LR), an average land rent of Rs.56251.28 pays more in contrast to the middle part of Sindh. On the other hand, the upper part pays fewer Rs, 53971.7 for land rent. Still, there is not much difference may it's because the middle part of Sindh province land is more fertile, their farmers can cultivate sugarcane, rice, wheat, and cotton. On the other side, in the upper part just we can cultivate rice and wheat, according to cultivation diversity there should be a huge difference is expected between upper and middle Sindh, but found little because of the availability of irrigation water. The upper part of Sindh is located at the Basin of Sindh River, there is no shortage of irrigation as in the middle Sindh. Followed by the farm size the grower of the upper part has 15.7 hectares of the land as compared to middle Sindh grower has less than 9.68 hectares.

An average earning of the family income is more to the farmer of upper Sindh as compared to the farmer of the middle part of the Sindh. In the case of land management practices such as plowing, planking, permanent labor, and temporary labor, there is not much difference which can be seen in table 3. But there is a little bit difference in seed rate usage to the farmer of middle Sindh is more as compared to upper Sindh, as we mentioned there can be cultivated four crops and a shortage of irrigation, so the soil become hard, therefore, farmers put more seed to get high germination and production. Corresponding with fertilizer (i.e. Urea, DAP, NP) the farmer of upper Sindh applies more applications of fertilizer to get the high production due to soil quality. The same thing happens in chemical spray, due to more irrigation unwanted grass, fungus appeared in the field of rice crop. So, the farmer from the upper part of Sindh needs to apply more application of chemical spray to get more production and to save the rice quality.

All results can be seen in table 03.

Table 3

Descriptive analysis of the variables of Production Function frontier

Variable	**Middle Sindh**				**Upper Sindh**			
s	**Mini**	**Max**	**Mean**	**Std. D**	**Mini**	**Max**	**Mean**	**Std. D**

LR	4680.00	140400.00	56251.28	27223.6	7020.0	117000.0	53971.7	27046.4
FS	2.00	200.00	22.65	38.48	1.0	972.0	36.9	112.5
FI	34000	3280000	599751	532343	118000.0	9320000.0	848367.7	1270009.7
PL	1.00	8.00	2.79	2.26	1.0	8.0	2.6	2.6
TL	2.00	60.00	11.78	11.35	1.0	50.0	11.9	10.2
PLG	2.00	4.00	2.58	0.78	2.0	4.0	2.8	0.7
PLK	1.00	2.00	1.21	0.41	1.0	2.0	1.4	0.5
SR	5.00	50.00	21.28	10.92	1.0	40.0	18.2	11.9
UREA	1.00	4.00	2.09	1.02	1.0	8.0	2.8	1.5
DAP	0.05	3.00	1.05	0.47	1.0	3.0	1.2	0.5
NP	1.00	2.05	1.18	0.43	1.0	2.0	1.3	0.5
CS	1.00	4.00	1.97	0.98	1.0	4.0	2.1	0.9
IRI	2.0	26.0	11.7	5.8	3.00	30.00	12.89	5.94
SLP	1.00	1.00	1.00	0.00	1.0	1.0	1.0	0.0
SQ	1.00	1.00	1.00	0.00	1.0	1.0	1.0	0.0

The full names of abbreviated variables are available in Table 3.

Table 4 also shows the descriptive results of the variables which were selected for normal censored Tobit model analysis. The average age, education, and experience of upper Sindh farmer variables are more than the middle Sindh. The upper part of the Sindh is near the Sukkur which is the 3rd largest city of Sindh, and division city of middle Sindh. So, the education ratio is higher in the upper part of Sindh. An average of own land was recorded more in upper Sindh farmer in the contrast of the middle Sindh who has less. But mostly middle Sindh farmers rent land from others for cultivation. Therefore, the results in the table show the rent in the land is higher as compared to upper Sindh.

In the case of shared land shared in or shared out means if farmers have a large size of the farm, he will share his land with other farmers for cultivation, the farmer will pay 50% of the inputs and get 50% of the output. The average rate of shared land is 3.93 hectares acres in middle Sindh and 3.90 hectares in upper Sindh. The trend of shared out land is more in the upper part of the Sindh so the results show an average rate of shared out land in upper Sindh is 13.96 hectares which is much more than middle Sindh. As I mentioned upper part is near Sukkur, many businessmen buy and rent the land from others and give farmers 50% production sharing. With the corresponding land fragmentation, the average rate of middle Sindh is 6.2, which is a little higher than in upper Sindh. In the case of an average farm size family members and distance from homestead to farm, results showed that the average distance from homestead to farm, family members, and farm size is more in the middle part of the Sindh.

Table 4

Descriptive analysis of the variables of Production efficiency land information data is given in acres

Variables	**Middle Sindh**				**Upper Sindh**			
	Mini	**Max**	**Ave**	**Std. D**	**Mini**	**Max**	**Ave**	**Std. D**
Age	20.0	75.0	43.5	11.3	20.00	80.00	44.48	13.64

EDU	2.0	20.0	10.6	4.5	1.00	18.00	11.06	4.56
EXP	2.0	60.0	20.6	11.0	5.00	50.00	21.77	10.98
OL	1.00	180.00	22.44	36.20	1.0	200.0	26.8	36.9
RIL	2.0	100.0	21.5	27.6	4.00	92.00	18.65	21.07
ROL	2.0	100.0	21.5	27.6	4.00	92.00	18.65	21.07
SIL	2.0	32.0	9.2	7.8	2.00	25.00	9.14	6.64
SOL	2.0	150.0	12.3	26.7	3.50	150.00	32.66	36.63
LF	2.0	74.0	6.2	6.8	2.00	12.00	5.77	2.05
FS	1.0	972.0	36.9	112.5	2.00	200.00	22.65	38.48
FM	2.0	20.0	8.24	3.34	3.0	22.0	8.1	3.5
Dis	1.0	50.0	11.9	14.4	1.00	71.00	9.33	10.38
TO	1.0	2.0	1.6	0.5	1.00	2.00	1.55	0.49
HL	1.0	1.0	1.00	0.00	1.0	1.0	1.0	0.0
Bank	1.0	2.0	1.9	0.3	1.00	22.00	1.99	1.73
MAK	1.0	2.0	1.9	0.3	1.00	2.00	1.78	0.42
EXT	1.0	2.0	1.9	0.3	1.00	2.00	1.88	0.33

The full names of abbreviated variables are available in Table 4.

3.2.Results of the frontier production function

The empirical results of the frontier production analysis are available in table 5. Land rent has a highly significant impact on rice production but the coefficient sign of middle Sindh is negative. This depicts that if the land rent reduces to 1% in the production, then the yield will be increased up to 4.932%. But the upper Sindh reject the null hypothesis with a positive and highly significant sign, which means the yield of rice can be increased up to 0.965% with an increase of 1% in land rent. Family income rejects the null hypothesis in middle Sindh with a positive sign of the coefficient, which seems that the rice production could be increased 2.063% with the increase of 1% in the family income as compared to middle Sindh. Upper Sindh doesn't have any relation between family income and rice yield. It happens because the middle part of the Sindh is less developed as compared to the upper part. Therefore, farmers are not aware to access the credit easily from banks or government institutions and they get the credit from local traders *(Biyapari)* in terms of products i.e. fertilizer, chemical spray, at high-interest rates.

If a farmer has more savings, they can buy inputs on time with good quality, therefore the results showed a positive and significant impact on rice production. In the case of permanent labor, the middle part of the Sindh shows no relationship, but the upper part of the Sindh shows there is a positive and significant impact on rice production that means if there is a 5% increase in permanent labor, the rice production will be increased 0.725%. The middle part of Sindh farmers work on his land with their family, therefore there is no impact and in the upper part, the education ratio is higher, which means the family members of farmers move from villages to cities for higher education and another kind of business so he needs to increase the permanent labor on his farms to increase the production. The Part of the middle Sindh rejects the null hypothesis in the case of temporary labor with a 1% significant value but the sign of the coefficient is minus, which means the production of rice will be increased to 2.344% owing to a 1% reduction in temporary labor. The upper part of the Sindh does not show any relation, it could be possible the family member of the middle part of the Sindh are actively participating in agricultural activities so they need to reduce the temporary labor.

In the case of land management (i.e. ploughing and planking), both the upper and middle of the Sindh reject the null hypothesis with a positive sign of the coefficient and 1% significant level. It means that there is a chance to increase the yield of rice by increasing the 1% ploughing and planking. Land management practices are the basic application for good production. If the land is hard and does not ploughed deeply or does not level properly, it will affect negatively production. Followed by the seed rate found negative and significant impact in the middle part of Sindh, positive and significant impact showed in the upper part of the Sindh. It seems, in middle Sindh, if the farmer reduces 1% of the seed rate, the production will be increased up to 2.344%. But in upper Sindh, it is inverse, if the grower will increase the seed rate the production will be increased by 0.001%. It could be possible that as we mentioned above the soil quality of middle Sindh is more fertile as compared to upper Sindh, when the farmer use more seed on fertile land, the healthy plants will be grown and there will be no space among plant to plant. Hence results showed that the seed ratio should be reduced in the middle part of the Sindh and should be increased in the upper part to increase the production level.

In the case of fertilizer (i.e. Urea, DAP&NP), the middle part of the Sindh claims to reject the null hypothesis with a 5% significant level in Urea and 1% in DAP but the coefficient of both variables have a negative sign, which means production can be increased by 5% and 1% decrease in the applications of Urea and DAP fertilizer. In the upper part, Urea and NP claim to reject the null hypothesis at 5% and 1% of a significant level. From the observational data and analysis, we can say that soil of the middle part of the Sindh is fertile so there is a need to reduce applications of fertilizer and increase the application of healthy soil in the upper Sindh part to get good productions.

The results of chemical spray (*pesticide& weedicide*) in the middle part of the Sindh rejects the null hypothesis rather accept the null hypothesis at a 5% level with the coefficient of negative sign, and the upper part of the Sindh province accepts the null hypothesis rather reject the null hypothesis, this shows no any significant change in rice production. This means that the rice production can be increased by 1.685% by the reduction of 5% in the chemical spray. Applications of irrigation influence are positive to the rice production in the middle part of Sindh and negative in the upper part of Sindh, production of rice can be increased by enhancing the irrigation application in middle Sindh and by reducing the applications of irrigation in the upper part. This will help to increase the yield by 2.685% and 1.212%, as we mentioned above there is a shortage of irrigation in the middle part of Sindh, the farmers face problems but on the other side upper part has special rice canals, which flow just in rice cultivation season, farmers do not pay attention to the weather and soil quality, it increases the waterlogging and salinity, thus we found both results positive and negative to increase the production. The marginal productivity of N shows a positive relationship in the middle part of the Sindh but shows no relation in the upper part. Similarly, the productivity of P shows the positive sign in the upper part and does not show any sign in the middle Sindh. Although the marginal productivity of K has a positive relation in middle Sindh.

Table 5

Results of the frontier production function

Variables	**Middle Sindh**			**Upper Sindh**		
	Coeff	**Std.Err**	**Sign**	**Coeff**	**Std.Err**	**Sign**
Yield	4.932	1.411	0.001***	5.214	1.914	0.000***
Land rent	-1.359	-.1452	0.009***	0.965	0.562	0.008**
Family income	2.063	0.3324	0.001***	0.0365	0.065	0.125

Permanent labor	.0599	0.056	0.280	0.725	0.321	0.009**
Temporary labor	-2.344	0.245	0.000***	0.958	0.7851	0.249
Plough	0.283	0.128	0.012***	1.953	0.798	0.000***
Planking	1.252	0.259	0.000***	3.4513	1.409	0.000***
Seed rate	-2.058	1.185	0.001***	1.925	0982	0.001***
Urea	-0.526	0.325	0.018**	0.805	0.282	0.024**
DAP	-2.105	1.256	0.000***	.070	.108	0.523
NP	.058	.142	0.686	.151	.040	0.000***
Chemical spray	-1.6581	0.958	0.056**	.007	.046	.877
Irrigation	2.685	1.985	0.000***	-1.212	-0.824	0.000***
Ln σ_v^2	-15.165	-4.259	0.000***	-13.156	-3.195	0.000***
Lnσ_μ^2	-11.282	-3.241	0000***	-10.392	-2.714	0.000***
σ_v	0.45			0.65		
σ_μ	0.189			0.305		
Log-Likelihood	42.85			8.80		
Likelihood test ration of $\sigma_\mu = 0$	3.91			8.14		
Probably≥chibar2	0.000			0.002		

Data Source: Primary data collected and analyzed by Author using SPSS20.0. *** indicates the rejection of null hypothesis at 1%, **Highlighted to null hypothesis rejection at 5% significant level, the *null hypothesis is rejected at 10% level of significance.

3.3. Results of rice production efficiency

Table 6 precise the results of the production efficiency score gained from the frontier model. An average score of the technical efficiency for the upper part of Sindh is 0.64 as compared to the middle Sindh which has 0.72 and this is higher than the upper part. The results summarized that an average of the rice yield 0.72% can get from per hectare by applying the above applications of inputs in the middle part of the Sindh and the upper part of the Sindh can be increased 0.64% per hectares. Similarly, it is suggested that in the short run, substantial room exists to rally the rice production for farmers. The minimum production efficiency in the middle part of the Sindh could be increased to 0.86% and 0.64% can be increased in the upper part of the Sindh. For the farmer with the lowermost efficiency level, the considerable increasing output can be reached to the quantity by using currently the inputs. Furthermore, the results of the frequency distribution are available in table 6. In the case of middle Sindh, more than 45% of the respondent has a production efficiency score between 0.90-1, in addition, 44.5% of farmers' score is under 0.80-90, and the rest of the farmers' score is under 0.65-090. Considerably, the upper Sindh has about 47.5% of the farmers' production efficiency score which is between 0.80-90.

Table 6

Results of rice production efficiency

Sat	**Middle Sindh**				**Upper Sindh**			
	Mini	**Max**	**Mean**	**Std. D**	**Mini**	**Max**	**Mean**	**Std. D**
	0.86	1.0	0.72	0.007	0.67	1.00	0.64	0.007
Score	**050-**	**0.65-**	**0.80-**	**0.90-**	**050-**	**0.65-**	**0.80-**	**0.90-**

range	**0.65**	**0.80**	**0.90**	**1.00**	**0.65**	**0.80**	**0.90**	**1.00**
Cases	0	21	94	96	4	31	105	81
Percentage	0	10	44.5	45.5	1.81	14.03	47.51	36.65

Data Source: Primary data collected and analyzed by Author using SPSS20.0.

3.4. Results of Tobit model for production efficiency

Table 7. Shows the results of the Tobit model, this model was analyzed for production efficiency, age in both cases upper and the middle part. This shows the positive and significant impact on rice production efficiency, and results have declared that production of rice up to 0.625% in middle and up to 0.710% in upper Sindh can be increased by the decrease of 1% in the ages of the respondent. It seems, if the farmer is aged he can't work efficiently in his field, but on the other side, the young farmer can work harder than an old farmer. In the case of education, results showed a positive and significant relationship with rice production efficiency. From the results, we can explain that rice production up to 0.163% can be increased by increasing 1% in education, the upper part does not show any impact of education on rice production efficiency. It is possible if the farmer is more educated he can learn and adopt advanced technology for rice cultivation. The experience also showed interesting results in both the upper and middle part of the Sindh, where coefficient has a positive and significant impact at 5% level, means the production will increase up to 0.589% in middle Sindh and up to 0.725% in upper Sindh by the increase 5% inexperience. It is common that if the experience is higher the results will be satisfactory.

Considerably, the own land results showed in the middle of Sindh the rice production can be increased by increasing by 1% inland, it happens because in the middle Sindh has a feudalism system, the farmers can't adopt new technologies to cultivate with his experience. The results showed if the farmer has their land he can buy and adopt technologies that he wants. In the case of rented or shared inland, there is a positive impact on rice production efficiency in upper Sindh, but neither any impact in middle Sindh nor shows the relationship of shared land with rice production efficiency. The results of land fragmentation are quite interesting, results in middle and upper Sindh have rejected the null hypothesis at 1% and 5% significant level rather than accept the null hypothesis. It means the production of rice can be increased up to 0.952% and up to 0.125% by reducing land fragmentation by 1% and 5% in the middle and upper part of the Sindh respectively.

From the results, we can conclude that more parcels of the land disturb farmers moving from one place to another. In both cases, farm size rejects the null hypothesis at 1% and 5% levels in the upper and middle parts of the Sindh respectively. Possibility to increase the rice production to to151% and 0.458% in upper and middle Sindh respectively by increasing of 1% and 5% in the farm sizes accordingly. If the farm size is large, the farmer can adopt modern technologies and it will be easier for him to manage the farm.

In the case of distance from homestead to farm, results show distance has a negative and significant impact on rice production in both cases. This means it would be possible to increase 0.352% and 0.312% of the yield by reducing 1% of the distance from homestead to farm because the faraway farm farmer faces many challenges such as time-consuming, disturbance to travel, cost increasements and difficulty in managing the farm. Healthy farmers can work efficiently on their farms, so the results are also in favor of the farmer is healthy the production of rice can be increased up to 0.152%. The results of the market show a positive and significant relationship with rice production efficiency. The rice yield can be increased up to 0.201% by the increase of 5% in market availability at middle Sindh as

compared to the upper part similarly production will be increased up to 0.524% by establishing the markets near to the farm. This market will help the farmer in getting inputs, and selling outputs as well, a farmer can save time and transportation costs.

Furthermore, considerable the Agricultural education extension service has a positive and significant impact on rice production efficiency at 10% significant level, means the rice production will be increased up to 0.341% by increasing 10% agricultural education extension service but the upper part of Sindh doesn't show any correlation with rice production. It implies that education extension services played an important role in aware the farmer's concerns about the facilities, credit, modern technologies that can help the farmer to increase production. Availability of school at village level shows the positive correlation with rice yield, possibility rice production will be increased up to 0.968% by the increase of 1% in school availability at the village because the family members (*i.e. Children*) do not go to school at middle Sindh, they are lacking behind in knowledge about farming and other activities. If the school is available at the village level, young farmers can go to school in the morning or any other available time and can work with parents in the evening time at the farm.

Table 7
Results of Tobit model for production efficiency

Variables	**Middle Sindh**			**Upper Sindh**		
	Coeff	**Z-stat**	**Sign**	**Coeff**	**Z-Stat**	**Sign**
Yield	0.985	35.252	0.001***	0.6214	22.114	0.000***
Age	-0.625	5.242	0.009***	0.710	4.625	0.000**
Education	0.163	2.652	0.001***	0.051	0.098	0.114
Experience	0.589	3.256	0.007**	0.725	0.321	0.009**
Owned land	2.344	0.245	0.000***	0.004	0.085	0.249
Rent in land	0.082	0.778	0.261	0.102	0.925	0.008**
Rent out Land	0.020	0.955	0.295	0.004	0.078	0.231
Share in land	0.080	1.185	581	0.010	0.061	0.105
Share out land	0.40	0.711	0.476	0.805	0.282	0.024**
Land fragmentation	-0.952	-4.521	0.000***	.-0.125	0.825	0.005**
Farm size	0.458	1.142	0.005**	.151	.040	0.000***
Family size	0.028	0.852	0.393	.007	.046	.877
Distance	-0.352	6.824	0.000***	-.312	-1.259	0.000***
Tractor Ownership	0.321	2.524	0.000	0.025	0.098	0.125
Health	0.152	4.221	0.010*	0.072	0.082	0.271
Bank at village	0.025	0.125	0.352	0.007	0.081	0.452
Market	0.201	0.825	0.004**	0.524	3.721	0.000***
Extension service	0.341	2.824	0.021*	0.017	0.087	0.421
School	0.968	7.621	000***	0.061	0.098	0.242
Likelihood	4.51			3.11		

*Data Source: Primary data collected and analyzed by Author using SPSS20.0. *** indicates the rejection of null hypothesis at 1%, **Highlighted to null hypothesis rejection at 5% significant level, the *null hypothesis is rejected at 10% level of significance.*

4. Discussion

For the analyzing impact of land fragmentation on rice production efficiency, crop and plot-level data was collected from Sindh province of Pakistan, a total of 450 respondents were selected from the major five rice-growing districts of Sindh, 432 samples were analyzed for the results remaining 18 samples found errors in data. The stochastic frontier function was analyzed to explain the rice productivity and efficiency and the censored normal Tobit model was analyzed for explaining the production efficiency which is affected by factors.

The results of the frontier function showed the land rent has a significant and negative impact on rice production in middle Sindh as compared to the upper part which has a positive and significant relationship with rice production efficiency. The results of family income reject the null hypothesis at a 1% significant level in middle Sindh rather than accept the null hypothesis, but in the upper part of Sindh, family income does not show any impact on rice production. Permanent and temporary labor show interesting results, temporary labor shows a negative and significant impact on rice production efficiency in middle Sindh but permanent labor only shows a positive and significant impact on rice production efficiency.

The results are inverse to each other, it happens because of the education in middle Sindh as compared to the upper Sindh, and the education ratio is relatively lower. Here, we can say family members are engaged in direct or indirect activities for rice production (Carnahan, 2002). The applications of inputs ploughing, planking, Urea, and DAP, have interesting results, where all these variables rejected the null hypothesis at a positive and significant level of 1% and 5% respectively in upper Sindh. Only seed rate, urea, and DAP have a negative and significant impact on rice production. What's more, the application of irrigation of inputs in upper and middle Sindh shows a negative and positive correlation with rice production.

In addition, the average rice production of middle Sindh is higher than upper Sindh, middle Sindh efficiency score is 0.72 and the upper Sindh is 0.64. The score range of the middle Sindh is 96 which means farmers are in the 0.90-1.00 range as compared to upper Sindh where the score range is 0.80-0.90. Furthermore, the results of the Tobit model show the age has a positive correlation in upper Sindh and negative in middle Sindh on production efficiency. In the case of education, there is no relationship with production efficiency in upper Sindh but there is a significant and positive impact on rice production in middle Sindh. Experience and own land showed interesting results, experience has a positive and significant impact on rice production efficiency in the booth part of Sindh, but own land just has a positive and significant impact on rice in middle Sindh but there is no sign in upper Sindh. Property rights, i.e. land rented in, rented out, shared in, and shared out, only shared in and shared out reject the null hypothesis at a 5% significant level. Land fragmentation and farm size also showed very interesting results, both variables show a significant relationship with rice production efficiency, land fragmentation coefficient has a negative sign but the coefficient of the farm size has a positive sign.

5. Conclusion

The distance from homestead to farm rejects the null hypothesis at a negative and 1% significant level. Availability of market, school, and extension service at village level have a positive and significant correlation with production efficiency in middle Sindh at 1, 5, and 10% significant level. But in middle Sindh, only the market variable showed a positive and significant impact on production. It may be because of the education ratio that is already higher in upper Sindh as compared to the middle Sindh, as we already have mentioned above the sample area of upper Sindh is near to the division of the province so farmers do not face any problem to sell out products and buy input as compared to middle Sindh farmers, who have to face many problems along with the consumption of the time and money.

The long-term increase in the production of rice is predictable to be accomplished by using biotechnologies and management of integrated less potential varieties, which have resistance about pest control, it can give potential yield in poor soil. It is abundant with weather changes, mechanization, and water conservations. All the measures can't be implemented until the land fragmentation ratio is severe. If the above technologies can be implemented very easily on land consolidation. Reduction of land fragmentation could be a sign of increasing rice production which will increase the international exports to reduce the poverty level.

Reference

Audibert, M. (1997). "Technical inefficiency effects among paddy farmers in the villages of the 'Office du Niger', Mali, West Africa." Journal of Productivity Analysis 8(4): 379-394. https://link.springer.com/article/10.1023/A:1007767508848

Bravo-Ureta, B. E. and A. E. Pinheiro (1993). "Efficiency analysis of developing country agriculture: a review of the frontier function literature." Agricultural and resource economics Review 22(1): 88-101. https://www.cambridge.org/core/journals/agricultural-and-resource-economics-review/article/efficiency-analysis-of-developing-country-agriculture-a-review-of-the-frontier-function-literature/9F5FB5B35C8DE12797588E3B5B41CF44

Chen, A. Z., W. E. Huffman, et al. (2003). Technical efficiency of Chinese grain production: A stochastic production frontier approach. American Agricultural Economics Association Annual Meeting, Montreal, Canada. https://ageconsearch.umn.edu/record/22116/

Coelli, T., S. Rahman, et al. (2002). "Technical, Allocative, Cost and Scale Efficiencies in Bangladesh Rice Cultivation: A Non-parametric Approach." Journal of Agricultural Economics 53(3): 607-626. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1477-9552.2002.tb00040.x

Coelli, T. J. (1995). "Recent developments in frontier modelling and efficiency measurement." Australian Journal of Agricultural and Resource Economics 39(3): 219-245. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8489.1995.tb00552.x

Daryanto, H., G. Battese, et al. (2002). Technical efficiencies of rice farmers under different irrigation systems and cropping seasons in West Java, University of New England. Asia Conference on Efficiency and Productivity Growth. Retrieved April. https://www.academia.edu/39577332/Technical_Efficiency_Of_Paddy_Farming_Under_Major_Irrigation_Conditions_In_The_Dry_Zone_Of_Sri_Lanka_A_Parametric_Approach

Fleisher, B. M. and Y. Liu (1992). "Economies of scale, plot size, human capital, and productivity in Chinese agriculture." Quarterly Review of Economics and Finance 32(3): 112-124. https://go.gale.com/ps/i.do?id=GALE%7CA13884538&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=10629769&p=AONE&sw=w

Greene, W. H. (2008). "The econometric approach to efficiency analysis." The measurement of productive efficiency and productivity growth 1: 92-250. https://books.google.com/books?hl=en&lr=&id=djMh3iuB1EIC&oi=fnd&pg=PA92&dq=Greene,+W.+H.+(2008).+%22The+econometric+approach+to+efficiency+analysis.%22+The+measurement+of+productive+efficiency+and+productivity+growth+1:+92-250.&ots=XH1nfGLuO4&sig=tfsBz2bo5EP_yD4Y4ApJWlZLTrc

Hazarika, G. and J. Alwang (2003). "Access to credit, plot size and cost inefficiency among smallholder tobacco cultivators in Malawi." Agricultural Economics 29(1): 99-109. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1574-0862.2003.tb00150.x

Huang, C. J., A. M. Tang, et al. (1986). "Two views of efficiency in Indian agriculture." Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie 34(2): 209-226. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1744-7976.1986.tb02203.x

Jondrow, J., C. K. Lovell, et al. (1982). "On the estimation of technical inefficiency in the stochastic frontier production function model." Journal of econometrics 19(2-3): 233-238. https://www.sciencedirect.com/science/article/pii/0304407682900045

Kalirajan, K. and R. T. Shand (1986). Estimating location-specific and firm-specific technical efficiency: an analysis of Malaysian agriculture, Australian National University, National Centre for Development Studies. http://jed.or.kr/full-text/11-2/8.pdf

Kebede, T. A. (2001). "Farm household technical efficiency: A stochastic frontier analysis." A study of Rice producers in Mardi Watershed in the Western Development Region of Nepal, A Masters Thesis Submitted to Department of Economics and Social Sciences, Agricultural University of Norway. https://agris.fao.org/agris-search/search.do?recordID=NO2002000053

Kiplimo, L. and V. Ngeno (2016). Understanding the Effect of Land Fragmentation on Farm Level Efficiency: An Application of Quantile Regression-Based Thick Frontier Approach to Maize Production in Kenya. 2016 AAAE Fifth International Conference, September 23-26, 2016, Addis Ababa, Ethiopia, African Association of Agricultural Economists (AAAE). https://ageconsearch.umn.edu/record/249280/

Koondhar, M. A., L. Qiu, et al. (2016). "Comparing economic efficiency of wheat productivity in different cropping systems of Sindh Province, Pakistan." Journal of the Saudi Society of Agricultural Sciences. https://www.sciencedirect.com/science/article/pii/S1658077X1630114X

Kopp, R. J. and V. K. Smith (1980). "Frontier production function estimates for steam electric generation: A comparative analysis." Southern Economic Journal: 1049-1059. https://www.jstor.org/stable/1057240

Meeusen, W. and J. van Den Broeck (1977). "Efficiency estimation from Cobb-Douglas production functions with composed error." International economic review: 435-444. https://www.jstor.org/stable/2525757

Nguyen, T., E. Cheng, et al. (1996). "Land fragmentation and farm productivity in China in the 1990s." China Economic Review 7(2): 169-180. https://www.sciencedirect.com/science/article/pii/S1043951X96900073

Taylor, T. G. and J. S. Shonkwiler (1986). "Alternative stochastic specifications of the frontier production function in the analysis of agricultural credit programs and technical efficiency." Journal of development economics 21(1): 149-160. https://www.sciencedirect.com/science/article/pii/0304387886900441

Wadud, A. and B. White (2000). "Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods." Applied Economics 32(13): 1665-1673. https://www.tandfonline.com/doi/abs/10.1080/000368400421011

Wan, G. H. and E. Cheng (2001). "Effects of land fragmentation and returns to scale in the Chinese farming sector." Applied Economics 33(2): 183-194. https://www.tandfonline.com/doi/abs/10.1080/00036840121811

Yang, C.-H. and K.-H. Chen (2009). "Are small firms less efficient?" Small Business Economics 32(4): 375-395. https://link.springer.com/content/pdf/10.1007/s11187-007-9082-x.pdf

Zhuo, C. and S. Shunfeng (2008). "Efficiency and technology gap in China's agriculture: A regional meta-frontier analysis." China Economic Review 19(2): 287-296. https://www.researchgate.net/publication/222865839_Efficiency_and_Technology_Gap_in_China's_Agriculture_A_Regional_Meta-frontier_Analysis