Understanding the Effect of Land Fragmentation on Farm Level Efficiency: An Application of Quantile Regression-Based Thick Frontier Approach to Maize Production in Kenya

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Abstract

Amidst declining agricultural productivity, farm level efficiency and persistent food security problems in Africa, land fragmentation is emerging as a key empirical and policy question in the region. In this paper, a novel approach is used to estimate the effects of land fragmentation. Quantile Regression-Based Thick Frontier (TFA) is applied to show how the overall change in landholding affects production efficiency in production. Applying cross-sectional survey data from Kenya, the results showed that the least efficient group of maize farmers in Kenya were those with the small average land holding attaining a maximum output of 70% of the actual attainable output. In terms of scale of production, the least efficient group fall short by 58% compared to their large scale peers. This approach is semi-parametric requiring few assumptions with simplified figures easy for policy communication.

Keywords: Land fragmentation, Quantile Regression-Based Thick Frontier Approach, Farm Level Efficiency, Kenya

1. Introduction

Since the emergence of land reforms in the Mid-Nineteenth Century, land fragmentation has been a major concern among policy makers and economists alike. The renewed concern is as a result of the declining agricultural productivity, farm efficiency and persistent food security problem in developing countries. The nature of land fragmentation is understood and defined differently within various economic contexts and as a result, several approaches and methods have been developed and used to analyse the phenomenon. The lack of a single conventional approach has led to contradicting views and conclusions regarding whether land fragmentation should be considered as a problem or not (Demetriou, 2013). The varied multidisciplinary treatment and measurement of the phenomenon has resulted to what can be termed as a "contested causation" which has seen persistent scientific disagreement and debate.

Land fragmentation is commonly defined in the literature as the situation in which a single farm consists of numerous spatially separated parcels (Demetriou, 2013; van Dijk, 2003). Blarel et al. (1992) defined the nature of land fragmentation in Sub-Saharan Africa as a situation where a household operates more than one separate parcel of land.This definition, however, does not capture the nature of exiting land fragmentation in the region today. van Dijk (2003) distinguished four dimensions under which land fragmentations can be defined: fragmentation in ownership ; number of users (or size of use-units); internal fragmentation and fragmentation due to overlap of ownership and use. The major concern in Sub-Saharan Africa today is the declining farm sizes in both ownership and use which logically implies dis-economies of scale in food production.

To understand the long term effects of land fragmentation problem we need to identify the root causes of land fragmentation in Sub-Saharan Africa. Four factors have been identified to contribute mainly to the trend of land fragmentation: inheritance; population growth; land markets; and historical/cultural perspectives (Demetriou, 2013). The key driver behind the declining arable farm sizes in Africa is the culture of inheritance. Most societies in Sub Saharan African are characterized by a culture of *patrilineal* succession and inheritance where properties including land is successively shared among heirs or only the sons in a family (Holden and Mace, 2003). Inheritance laws facilitate or demand the subdivision of holdings into equal parts among the heirs which when the tradition continues among the subsequent generations , on the same piece of land. The trend will ensure that, as the population increases, not only does the size of holdings fall, but they are increasingly fragmented into small plots, scattered over a wide area Bizimana et al. (2004). This will ultimately result into smaller unsustainable landholding units. Coupled with this is the increasing population pressure and uncontrolled land titling leading to the growth of land markets.

The *a priori* assumption among the earlier empirical research considered land fragmentation as an indicator of inefficiency in production (Bardhan, 1973). The argument in favour of this view has been that, a consolidated land could reduce travel times, boundary waste, feasibility of larger-scale productive investment, and ease supervision of labour among other benefits (Monchuk et al., 2010). Those in favour of land fragmentation, including Blarel et al. (1992), argued that land fragmentation is beneficial to farmers in managing risk, overcoming seasonal labour bottlenecks, and in matching soil types with necessary food crops. A comprehensive review of the earlier debate on land fragmentation is contained in (Bentley, 1987). In this account policy makers took extreme view in favour of land consolidation by considering preventive legislation to reverse the land fragmentation trend, while economists adopted a balanced view arguing that land fragmentation can be adaptive under certain circumstances but may become non-adaptive with changes in technology and factor costs. This view implies that the issue of land fragmentation takes a spatial-temporal dimension requiring a context specific evaluation while considering existing local socio-economic and environmental conditions before any policy decision is made.

In the wake of dwindling land holdings and intensification, especially in developing countries, there is a renewed interest in attempt to understand and resolve the controversy surrounding the impact of land fragmentation on food production (Demetriou et al., 2013; Monchuk et al., 2010; del Corral et al., 2011; Wan and Cheng, 2010; Sauer et al., 2012). The major concern in Africa today is the declining mean farm size over time within densely populated smallholder farming areas where more than half of rural farm households control less than one hectare of land (Jayne et al., 2012). The disparity of landholding cast doubt to the sustainability of food production sufficient for household subsistence and market surplus.

The major contribution of this study is to present an approach that to explain the effects of land fragmentation differently. Understanding the effects of land fragmentation in a theoretically consistent way provides a convenient way to compare the effects attributed to land fragmentation overtime. What should be seen as land fragmentation in this context can also provide a new and unexpected implications not only for theoretical approach, but more significantly for long term impacts in food production and policy decision.

The main objective of this study is to estimate the impact of land fragmentation on farm level production efficiency using a quantile regression approach. Specifically the paper analyses the relationship between farm level technical efficiency and the overall land ownership. The remainder of the paper is organized as follows: Section two delves deeper into the land fragmentation problem, Section three reviews the previous studies on the effects of land fragmentation, Section four presents the empirical approach used while Section five discusses the results and Section six concludes the paper.

2. The Land Fragmentation Problem

Global population is projected to grow by nearly 2.3 billion people by the year 2050 with the fastest growth expected to come from Sub-Saharan African region (FAO, 2009). The major challenge for global agriculture today is how to produce food that will meet demand for the growing population. Increased population will imply increased pressure on limited natural resources including land and water. Market demand for food and animal feed is expected to reach 3 billion tonnes, up from todays nearly 2.1 billion tonnes (FAO, 2009). Coupled with food demand is the emerging demand for feedstock driven largely by demand for biofuels (Popp et al., 2014).

The current food security debate has now shifted to the Africa's food security paradox. Despite Africa's huge potential, owing to its vast natural resources and large areas of arable land and water resources, food security in the region remain elusive (UNDP, 2012). The region has consistently recorded low productivity and low technology adoption hindering sufficient food production. Currently, Sub- Saharan Africa's yields reach about 25 percent of its potential, comparatively, yields in Central America, Central Asia, Eastern Europe, and the Russian Federation reach approximately 40 percent of their potential (Global Harvest Initiative, 2012). It is estimated that about 60 percent of the worlds arable land is in Africa AGRA (2013), however, given the present trends, the continent can only produce 13 percent of its food needs by 2050. Historical accounts of increase in agricultural output in Africa is mainly attributed to expansion of cultivated area rather than intensification of cultivation with rising yields per hectare (Wiggins, 2014).

Africa with a huge potential to feed itself requires sustainable and efficient utilization of resources in order to increase agricultural productivity thus addressing persistent food security threat in the region. It is argued that that there are only two possible options left to increase food production; either increase yield per hectare or expand the amount of land to be cultivated or both (Hofstrand, 2012). Expansion of agricultural land area is, however, not feasible technically since arable land is limited; the latter remains the only viable option. Increasing productivity could, however, further pose a major environmental threat since most technologies adopted often involve intensive input application, including fertilizers and agro-chemicals, which may impact negatively on the environment.

Donor supported agricultural development policies in developing countries focused on programs supporting smallholder farmers who have since remain trapped in a vicious cycle of subsistence production due to the nature and scale of farm operations. Currently, smallholder farmers in Africa are increasingly becoming dependent on the markets for food access and income. Increasing integration of these farmers into regional and international markets, however, has made them more vulnerable to volatile market prices and other uncertain global exogenous shocks. Small scale farming inherently limit the sustainable food production options subsequently increasing dependence on uncertain and poorly developed markets for livelihoods.

Although extensive research has been carried out on land fragmentation in Eastern Europe and Asian countries, limited studies in Africa exists which adequately address the phenomenon within the current emerging farming situations.

2.1. Land Fragmentation in Kenya

Major land reforms in Kenya took place in 1960s as Kenya was attaining its independence from British colony where Africans were allowed to buy land from Europeans (**?**). Rift Valley, the Kenya's bread basket as is currently referred to is part of the formerly exclusive European-owned, large-scale farms and ranches, dubbed 'White Highlands' where a massive programme of land transfer was undertaken to convey some 1.2 million acres into the hands of African smallholders (Leo, 1978).

In 1961 Kenya embarked on a program of agricultural reform called the Million Acre Settlement Scheme providing for the transfer of ownership of land in the Rift Valley from outgoing white settlers to 35,000 African families. The Government of Kenya would buy land (with British funds) from departing European settlers, which would be resold as small-holdings to Africans. These new settlers were given loans for their purchase of land and development from international aid agencies to cover the cost of the purchase of their plots and of certain development inputs (Leo, 1978; Harmsworth, 1974). It is notable that decolonization of the British Empire in Kenya marked the beginning of land fragmentation in Kenya.

Kenya's post-colonial agricultural history was characterized by a rapid expansion in the quantities of commodities produced for both the local and export markets, especially tea and coffee (Njonjo, 1981). Colonial Kenya's agricultural economy was divided into two radically distinct sectors - the European-owned White Highlands and the African Reserves, now commonly refereed as large scale and small scale farmers. Table 1 shows the distribution of large scale farms in post-colonial Kenya in terms of farm sizes.

Table 1: Size Distribution of Large Farms in 1970: in Numbers, Hectares and Percentages Area

Size (ha.)	Number	%	Area in 1000ha	%
0-19	417	13.1	4	0.2
20-49	324	10.2	11	0.4
50-99	304	9.6	23	0.8
100-499	1,156	36.5	320	11.9
500-999	498	5.7	373	13.9
1000-3,999	350	11.0	685	25.4
Total	3,175	100	2,690	100

Source: ILO (1972:367) cited in Njonjo (1981)

Clearly from the table the average landholding among the large scale farmers was about 850 hectares or about

2000 acres. This figures represent the distribution countrywide with majority of landholding in the White Highlands of Rift-valley. About 50 years now since Kenya's Million-Acre Settlement Scheme the average land holding-Although comparative figures for the current distribution are not available-landholding in acres for Uasin Gishu and Trans-Nzoia Couties stands at about 10 acres and 7 acres respectively. These are the figures obtained from the cross-sectional survey data used in this study.

Kenyas 2009 National Land Policy emphasizes the need to allocate and use land in an economically viable, socially equitable and environmentally sustainable way. According to World bank datasets, about 10% of land in Kenya is considered arable and with the current population of about 45 million, the population is expected to grow by 2050 up to 55 million, further increasing pressure on land. Traditions, customs and formal succession laws promote and regulate the transfer of property from one generation to another. The new constitution of Kenya may further compound this problem of land fragmentation since legally daughters married-off to another family can now come back and claim inheritance and succession in the property sharing including land. Land control Act in Kenya does not define the minimum land size considered economically viable but the Land Control Boards are left to determine the viable land sizes. There is an urgent need to inform policy on the most sustainable way to guide land use in Kenya in the midst of increasing population and declining scale of food production and farm level productivity.

3. Estimation Approach and Data

Measuring Land Fragmentation

The literature on land fragmentation shows a variety of indices and approaches used to measure and estimate the land fragmentation effects on farm productivity. Several indices used to measure to measure land fragmentation are documented by Demetriou (2013). Most measures of land fragmentation have considered land fragmentation as a spatial problem where the concern is the geographical scattering of farm lands in terms of dispersion of parcels per ownership and the shape of parcels and non-spatial factors such as the type of ownership and the existence of accessibility of a parcel to a road.There is no single objective measure of land fragmentation (Bentley, 1987). Notable studies in Africa include Bizimana et al. (2004) where they estimate the impact of land fragmentation on economic efficiency in terms of geographic dispersion of plots (i.e. number of arable plots cultivated and distance travelled by farm operators from the farm house)

The major concern in Africa today is the effects of decreasing absolute landholding size on farm level efficiency in production. A measure of land fragmentation should capture at least one of the six parameters if not all, which include farm size, plot number, size, shape and spatial distribution (Bentley, 1987). No single index takes into account all of the above mentioned factors. The key issues in Kenya is the need to understand the effects of land fragmentation on productive efficiency of the farmer. Our key assumption is that decreasing scale of production -as a result of transfer of ownership from one generation to another or land markets- decreases the technical efficiency of individual farm owner operating under smallholding. In this study we use the farmer with large holding size as our counter-factual to the to measure the effect of fragmenting land into smallholding.

3.1. The Empirical Approach

Farm level efficiency can be estimated using a stochastic frontier model with either output-oriented or input oriented technical inefficiency. However, the rational behaviour of the farmers in developing countries cannot be captured fully by the classical technical cost minimization and profit maximization since they do not participate fully in the input and out markets (Kumbhakar, Subal C. Hung-Jen Wang, 2015).

Following Michler et al. (2015) and Dawson et al. (1991), a stochastic production function can is defined as

$$y_i = f(x_{ki,\beta})e^{\epsilon_i} \tag{3.1}$$

where y is observed output, x is a vector of inputs, β is a vector of corresponding coefficients and ϵ is an error term. Aigner, Lovell, and Schmidt; and Meeusen and van den Broeck specify the error term as being composed of two independent elements as shown in equation 3.2.

$$\epsilon_i = v_i - \mu_i \tag{3.2}$$

The distribution of v is assumed to be i.i.d $N(0, \sigma_\mu^2)$ while μ reflects technical efficiency relative to the technical frontier. The assumption is that every farm potentially produces less than it might due to a degree of inefficiency so that the farm is attaining less than optimal output possible from a given input level. When $\mu = 0$, output lies on the frontier while $u > 0$ reflects production below the frontier.

Various methods have been developed to estimate parameters of the production frontier $f(x)$ parametrically and to estimate the inefficiency levels (Kumbhakar, Subal C. Hung-Jen Wang, 2015). But the choice of the method will depend on whether distributional assumptions on the error components are made or not.

In this study we use a distribution free approach to show the impact of land fragmentation on farm level efficiency. One approach is the Thick Frontier Approach(TFA) proposed by Berger and Humphrey (1991). This approach, however, has several drawbacks. First, the frontier function cannot be distinguished from the inefficiency effect of the model when using cross-sectional data. Secondly the the function is estimated using subsets only of the available data only, hence a major constraint for smaller datasets. To mitigate the drawbacks of TFA, **?** proposed Quantile Regression Approach which allows observations to lie above the fitted curve as a result of pure chance Liu et al. (2008). From the fitted quantile equation the estimate of the production frontier are assume that observations on or above it are efficient and that ones lying below it are likely to be inefficient, and use some measure of the distance from observations below the frontier to the frontier itself as the measure of their inefficiency.Unlike the TFA in which regression uses observations from the sub-samples only, the quantile regression uses all the available data estimation such that each regression uses all the data by putting different weights based on the choice of quantiles. A detailed practical applications of the two approaches are documented in by Kumbhakar, Subal C. Hung-Jen Wang (2015). Since quantile regression based TFA is a semi-parametric approach,which requires an assumption about the functional form of the frontier we use Cobb-Douglas (CD) production function with multiple inputs. The CD function is commonly used and its restrictions are not major concerns in the current estimations.:

$$y_i = \alpha x_{ji}^{\beta} e^{v_i - \mu_i} \tag{3.3}$$

The random error term, v_i assumed to be normally distributed as before while the technical efficiency term, μ_i is assumed to follows the half normal distribution. Quantile regression approach has been shown to performed more reliably better than either other approaches Liu et al. (2008).

We also generated results from a stochastic frontier approach for comparative purposes only. The farms are hypothesized to use a constant returns-to-scale technology, but the farm sizes of the firms differ. Such that the variation in size will introduce heteroskedasticity into the idiosyncratic error term, we estimate the parameters of a CobbDouglas production function. We use a conditional heteroskedastic half-normal model, with the ordidanal variable of the quantiles of scale of production being the explanatory variable in the variance function for the technical efficiency term. In the Quantile regression we used a novel approach of landholding size variable to divide the sample among the large scale and small scale. Here we attempt to use the scale of operation as a determinant of efficiency such that the efficiency levels obtained reflects what those farmers in the upper quantile achieve compared to those bellow.

3.2. Data

Cross-sectional data collected through a multi-stage random sampling from farm households in Trans-Nzoia County. The survey took place during after the harvest season of 2013 in he Months of December and January. The data was part of the value chain assessment study commissions by the County of Trans-Nzoia in Kenya with the support from USAID. Questionnaire interview was administered to over 200 households. After data cleaning we retain 186 sample size for the present analysis. We use household and farm characteristics including the amounts of inputs used in maize production and the cost of labour and inputs used. Land use information was also collected capturing the landholding size, farm production under different farm enterprises. A desk review of existing studies were used to triangulate the primary data and information obtained from the survey.

Results and Discussions

Table 2 below shows the summary of variation in mean farm sizes and the average maize output in 90Kg bags/acres among the various scales of production of the sample. The subdivision was obtained from the four quantiles generated from the sample.

Table 2: Size Distribution of Land holdings, maize Farm Size and Maize Output

Quantile	No. of Obs.	Land Holding Size	Maize Farm Size	Bags/Acre
1	54	1.51	2.05	14.75
2	35	2.90	3.01	15.23
3	37	5.28	4.57	17.50
4	42	19.83	17.63	17.03
Total	168	7.2	6.69	16.02

Source: Authors Survey Data

From the table we observe that there is a close correlation between the total mean land holding, average scale of production and the resulting average output of farmers within the four quartiles.

3.3. OLS Regression Model

Table 3 shows the regression results obtained from the estimated Cobb-Douglas production function used in the quantile regression. The results shows that the cost of fertilize and chemicals used, cost of land preparation,

Table 3: Cobb-Douglas Regression Coefficients of the Variables used

lny	Coef.	Std. Err.	t
Fertilizer/Chem Cost	.1056254	.0352543	3.00***
Quantity of Seeds	.0111108	.0420349	0.26
Land Operation Cost	.0972186	.0457072	2.13**
Scale of Prod			
2	.6238806	.0566586	11.01***
3	.9551558	.0585234	16.32***
4	1.237234	.0676389	18.29***
Gender			
Female	-.1236659	.0503431	-2.46**
Level of Educ			
Sec./vocational	-.0536456	.0505524	-1.06
Post-sec./college/ Univ	-.1072289	.0607928	-1.76*
cons	.6738238	.4378589	1.54
$R^2 = 81\%$	$\overline{R^2} = 79\%$	$*P < 0.10$,	$**P < 0.05, ***P < 0.01$

Source: Authors Survey Data, Table showing significant variables only

scale of production and gender of the head of household were all significant at explaining the variation in average maize output produced. There was

3.4. Quantile Regression Results

Table 4 shows the technical efficiency estimates from a quantile regression output showing the variations in the level of efficiencies as the land size increases both in the size of land holdings and scale of maize production.

Results from the quantile regression-based TFA shows that generally the level of efficiency increases with the scale of land holding in production. Specifically, the results indicates that for the least efficient group of maize farmers in Kenya, the maximum output per acre is about 70% of the actual attainable output of their large scale peers. There is a linear trend showing increase efficiency as both the average size of landholding and production scale increases. The trend continues with the third quantile group of farmers falling short of the actual attainable output by about 8% only. By scale, however the least efficient group could only attain upto 42% of the possible output.

Table 4: Efficiency Levels between land Land holdings, maize Farm Size and Maize Output

Quantile	No. of Obs.	Mean TE at holding scale	Mean TE at Output Scale	Mean Land size at Output scale (Acres)
1	61	70%	70%	42%
2	20	83%	84%	87%
3	35	92%	91%	94%

Source: Authors Survey Data

Conclusions

The issues of land fragmentation remain a key empirical question in Africa with the need for more comprehensive datasets to evaluate it exhaustively. Continuous decline in farm size will is likely to negatively impact on farm level efficiency especially food production. Understanding the land fragmentation within context specific and using consistent empirical approach will serve as a guide and solution to the key policy decisions in agriculture. Quantile Regression-Based Thick Frontier Approach gives a new insight to the land fragmentation issue relevant in Africa today. This approach is a semi-parametric requiring few assumptions with simplified figures easy for policy communication.

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Appendix A. Stochastic Frontier Production Function Results Table

```
Stoc. frontier normal/half-normal model         Number of obs      =        147
                                                Wald chi2(3)       =      19.80
Log likelihood =  6.5025121                     Prob > chi2        =     0.0002

------------------------------------------------------------------------------------------
                     lny |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------------------+----------------------------------------------------------------
lny                      |
                    lnX1 |   .1379437   .0334229     4.13   0.000     .0724361    .2034513
                    lnX2 |   .0792055   .0391116     2.03   0.043     .0025482    .1558627
                    lnX4 |    .067538   .0392497     1.72   0.085      -.00939     .144466
                   _cons |   1.554386    .454151     3.42   0.001     .6642665    2.444505
-------------------------+----------------------------------------------------------------
lnsig2v                  |
                       Z2 |
                  Female |  -1.673636   .5255666    -3.18   0.001    -2.703728   -.6435445
                         |
                       Z3 |
       Off-farm business |    -.26509   .6303041    -0.42   0.674    -1.500463    .9702834
    Off- farm employment |  -2.657965   .9214009    -2.88   0.004    -4.463877   -.8520522
                         |
                   _cons |  -3.224435   .2028658   -15.89   0.000    -3.622045   -2.826826
-------------------------+----------------------------------------------------------------
lnsig2u                  |
                  gindex |
                       2 |  -2.040158   .3609948    -5.65   0.000    -2.747695   -1.332621
                       3 |  -4.904339   .6351172    -7.72   0.000    -6.149145   -3.659532
                       4 |  -43.38375   9284.547    -0.00   0.996    -18240.76    18153.99
                         |
                       Z1 |
           36 - 45 years |   .0285128   .5963143     0.05   0.962    -1.140242    1.197267
           46 - 60 years |    .357329   .5361388     0.67   0.505    -.6934836    1.408142
                Above 60 |  -.0703956   .6841196    -0.10   0.918    -1.411245    1.270454
                         |
                       Z4 |
 Sec./vocational training |   .2942508   .4124361     0.71   0.476    -.5141091    1.102611
 Post-sec./college/ Univ |   .5575503   .4803031     1.16   0.246    -.3838265    1.498927
                         |
                   _cons |  -.2862995   .5812485    -0.49   0.622    -1.425526    .8529266
------------------------------------------------------------------------------------------

.
. test _b[lnX1] + _b[lnX2] + _b[lnX4] = 1

 ( 1)  [lny]lnX1 + [lny]lnX2 + [lny]lnX4 = 1

           chi2(  1) =   94.34
         Prob > chi2 =    0.0000
```