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The inverse farm size productivity relationship: some new evidence from sub-Sahara African countries

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ABSTRACT

The inverse farm size productivity relationship (IR) for short implies that diseconomies of scale characterize agriculture systems for several possible reasons, including the failure of land and labor markets to equalize production efficiency across farm size distribution. From the policy perspective in turn, should smallholders be found to be more efficient, policies to facilitate the redistribution of land from large towards the small farms would be justified not only on equity but also on efficiency grounds. While many consider IR as a "stylized fact" of rural development and a guiding principle of the major land reform in the former Soviet Union, and the Eastern European countries, others find it difficult to accept without further questions for several reasons. These include the fact that in most empirical studies IR appears as smooth tendency for land productivity to decline with farm size and thus is not limited to a different pattern of resource uses between large and small farms. While different reservation wages could account for family versus non-family farms, this would not explain why land productivity appears to decline within small family farms as well. Some empirical evidence also suggests that land quality and farm size are inversely correlated, so that ignoring this relation may be the cause of a basic specification error. Finally, several studies have indicated that total factor productivity does not show any negative correlation with farm size.

In this paper, we investigate the relationship between productivity and farm size from the point of view of the option value of land and its relation with management quality and efficiency. We use LSMS-ISA national representative datasets of five sub-Saharan African countries, which provide standardized location details of sampled communities allowing the data to be linked to any other geo-referenced data . We are thus able to control for many exogenous common and comparative geo-spatial measures of land quality, infrastructure and access to markets, climate conditions, soil and topography. We also use an estimation strategy, based on quantile regressions at the household level, that allows us to test IR existence and verify signs' switches across the entire distribution of farm size, and between countries located in different agro-ecological zones. Our findings indicate that, as suggested by a model combining land option values and farm size related management quality, while IR may be important for certain ranges of farm efficiency and size, it is by no mean an ubiquitous characteristic of agriculture. Whether the relationship between productivity and size is positive or negative may thus depend crucially on other factors, including soil quality, agro-economic zones, and the efficiency of farm management.

Keywords: Farm size productivity relationship, quantile regression, sub-Saharan Africa

PAPER

1. Introduction

The finding that land productivity and size of the land operated (both owned and rented) appears are related negatively has been historically established by a variety of studies starting in the late 70s (e.g. Berry and Cline, 1979, Kutcher and Scandizzo, 1981, Binswanger et al., 1993).

The literature has emphasized different explanations for this empirical regularity:

1. factor market imperfections in land and other market such as credit and modern inputs;
2. omission of soil quality measurements that are inversely correlated with farm or plot size but positively associated with yields;
3. measurement errors in self-reported area and quantity of crop production typical of household survey agriculture data;
4. risk and uncertainty.

The finding, however robust across many studies (Bharadwaj, 1974, Carter, 1984, Feder, 1989), seems at the same time puzzling, for several reasons. First, it is not limited to small versus large farms, but in most studies, there is a smooth tendency for land productivity to decline with farm size. This result seems to contrast to the equalization of factor prices predicted by market equilibrium theory and not simply explained by lower reservation wages for family farms, because land productivity appears to decline within all ranges of family as well as non-family farms. In this respect, Feder's (1985) alternative explanation appeals to a more general transaction effect, reminiscent of Coase's theory of the firm. According to this explanation, smaller farms are based on more intense use of family labor, because of its higher efficiency and motivation than hired labor and the fact that supply of working capital is directly related to farm size. Srinivasan (1973) explains the inverse relationship by yield risk, by defining utility over income , and imposing restrictions on the coefficients of risk aversion and on how risk enters production, under constant returns. Hazell and Scandizzo (1974) provide a rationale for producers to reduce planned production in response to the negative correlation between supply and prices, and Barrett (1993) shows that IR can emerge from price risk if farmers are net buyers of the crop produced, since in this case, risk aversion implies labor overemployment to protect consumption.

As Savastano and Scandizzo(2009) have shown, a relationship between productivity and operated area may arise because of the investment required by the decision to increase one's farmland . Under dynamic uncertainty, in fact, the amount of land operated by a farmer will depend on the timing of the exercise of the option to invest in land development. With decreasing returns to scale, this will imply a non monotonic relationship between revenue per ha and operated land. If land is available on the market in fixed quantities (i.e. supply of plots for rents or sale , or entire farms of discrete size), and/or investment is lumpy, small farms will exhibit lower revenue thresholds for investment, and thus lower revenues per ha than larger farms. This implies, in particular, that the relationship between productivity and size may exhibit turning points, as farmers switch from one type of investment to another (e.g. from land improvements to irrigation) as their operating land increases as a result of previous investment decisions.

Some empirical evidence (Bhalla, 1979, Bhalla and Roy 1988, Benjamin, 1995, Dyer, 1997), suggests an inverse correlation between land quality and farm size, so that ignoring this relation may be the cause of a basic specification error. This implies that if various characteristics of land such as fertility, water and nutrient availability, soil structure and composition are taken into account, the negative correlation between average land productivity and size might be drastically altered or disappear. In an insightful study on the impact of Kenya extension service, Evenson and Mwabu (1998) found that productivity response to acreage, measured through quantile regression, was not significantly different across quantiles, but displayed a concave shape, first rising and then falling with the size of the cultivated area.

More recently, other studies suggest that correcting for land and crop quantity measurement errors strengthen the IR (Carletto et al., 2013; Deininger et al., 2012). Finally, several studies have indicated that total factor productivity does not show any negative correlation with farm size, and results, if anything, seem to suggest a tendency toward increasing with the scale of the enterprise.

The contribution of our paper to the existing literature is threefold:

1. We analyze the existence of the IR in a cross-country context making use of comparable national representative surveys.

2. We avoid the problems posed by the endogeneity of key farm variables, by using a number of exogenous variables available in the geo-referenced dataset of the LSMS-ISA project. For example, instead of controlling for soil quality self-reported information of farmer, we use exogenous soil quality variables.

3. We control for other omitted variable bias and measurement errors in self-reported area of farmers by using the GPS information of land area collected by the enumerators.

Our results , using evidence for five sub-Saharan African countries (Malawi, Niger, Nigeria, Tanzania and Uganda) suggest the following conclusions:

- Consistently with findings of the existing literature, land quality and its components appear to be significant explanatory variables of land productivity, and so are several other exogenous variables linked to urban and market influence, such as distance from the roads, temperature and rainfall.
- Effects of farm size on average land productivity remains significant across all specifications.
- However, this relationship is both nonlinear and switches signs across farm size groups. More specifically, average land productivity (ALP) exhibits an inverted U-shaped relation with farm size for the first three deciles of the land productivity distribution, with ALP first rising and then falling after a threshold farm size. Vice versa ALP shows the opposite pattern of a U-shaped relationship for the rest of the distribution, first decreasing and then increasing after reaching a lower threshold.
- This pattern is confirmed by quantile regression and by testing the ALP – farm size relationship within and across quantile groups.
- Farms in the lower tail of the ALP distribution thus experience IR only once they have reached a critical size. Vice versa, farms at the upper end of the distribution experience IR only if they are below a critical size, which, in general, tends to be larger (and some time much larger) than the critical size of the lower end farms.
- Thus, small and large farm behavior tend to diverge, since farms in the lower deciles of the land productivity distribution experiment the IR for a smaller range of farm sizes than farmers of the higher deciles.

2. Conceptual Framework

The agricultural enterprise poses two different problems to the theory of the firm. First, contrary to reasonable expectations on the division of labor and the role of capital, in most cases the family farm appears to be the dominant form of organization of the productive unit in agriculture. Second, similarly, but more dramatically than for the other types of firms, the existence of profit represents a puzzle for the family farm, since its determination as a residual in a highly competitive market does not follow a clear economic logic . Perhaps the best discussion of this twofold question, within a more general framework of the fundaments of the theory of the firm is the treatment by Demsetz (1995), who discusses the issue of the existence of the firm by contrasting Coase's transaction theory with its own. Demsetz aptly starts its treatment by noting that rather than with the existence of the firm, the early literature was concerned with a related, but separate event, the existence of profit in a perfectly competitive market. Given that profit existed, the institutional theory tried to find a justification in the entrepreneur. In two significant cases, that of Frank Knight (1925) and Ronald Coase (1937). Both these authors laid the foundation of a productivity theory of the firm, based on the idea that the reason for the firm's existence was to increase productivity by providing managed coordination, thereby reducing risk in the case of Knight and reducing transaction costs for Coase. Demsetz's own theory is based on two related concepts: specialization and interdependence, where the development of a business firm is seen as a process of specialization that separates production from consumption, thereby creating interdependence with other firms and households.

For Boserup (1965), Binswanger and Rosenzweig (1986) , and Binswanger and McIntyre (1987), the process of agricultural development is characterized by population pressure which brings about the family farm system, chiefly because of hired labor transaction costs that create diseconomies of management. The family farm, in other words, while equally productive in reducing other transaction costs external to the firm (a la Coase) is superior in increasing productivity by internalizing labor supervision costs without increasing transaction costs internal to the firm. According to the family farm theory (Roumasset, 1995), in particular, it is the very organization of the farm that is determined by labor transaction costs, rather than by any technical economy of scale. On the other hand, Eastwood, Lipton, and Newell (2010), henceforth ELN, on the basis of a simple maximization model, with homogenous farmers, claim that development will bring about an increase in family reservation utility and thus in equilibrium farm size, but the increasing availability of cheaper capital and technological progress can go either way. Moreover, removal of any of the hypothesis of the simple model (e.g. infinite supply of family farmers, homogeneity of land etc.) tends to open the way for different results, pointing to the impossibility of a unique prediction on the effects of development on the farm size. A similar conclusion can be reached for the relationship between efficiency and farm size, with a plurality of possible outcomes, depending on the various components of scale economies and diseconomies, including indivisibilities and transaction costs, that may directly and indirectly interest the farm.

While the outcomes of increasing farm size may be many, it seems legitimate to ask whether there is a fundamental tendency, as postulated by Coase (1937), for the farm to grow in response to the need to reduce market transaction costs and, if not, why or because of which fundamental constraints or counter-tendencies. This question is dictated by the general issues considered by Coase , but also by the seemingly ubiquitous finding of an inverse relationship (IR) between land productivity and farm size. The answer to the above question, however, requires an answer to a more general question, namely: is the farm , and the family farm in particular, defined by its relationship with transaction costs, within the bigger picture of the relationship between the firm and the market? In this respect, most of the literature cited, with the partial exception of ELN, appears to regard transaction costs as an element of possible scale diseconomies in determining the optimal size of the farm, and not as a constitutive element of the productivity mission of the firm as an institutional agent, as claimed by the institutional economic literature . Rather than asking whether small farms reduce transaction costs, for example, Pingali (2010) focuses on the opposite question on whether and how to reduce the transaction costs faced by small farms. On a different note, ELN note that there is no theory that predicts optimal farm size to minimize unit transaction costs, because of multiple equilibria, deriving from non convexities of the transaction cost functions. They claim that these multiple local optima may give rise to sudden jumps from self cultivation to much larger forms of operations, in effect , because labor transaction costs become less important than capital transaction costs.

These arguments seem also to exclude a tendency toward an optimal farm size, but rely on a particular interpretation that essentially assimilates transaction costs to the costs of accessing factor markets and managing factor usage. A more general interpretation, however, considers transaction costs all costs related to ex ante and ex post exchange , including the choice of the trade partners, bargaining, monitoring and enforcing the related contracts. For Coase (1972), the firm acts as an agent capable to reduce these costs by substituting a structure of command and control to the decentralized structure of the market , and by appropriately standardizing the contracts themselves.

Within this interpretation, as a nexus of contracts, the family farm presents different organizational features from a commercial farm which may indeed reveal a tendency to settle around an optimal size , that , if not reached , or once reached, may give rise respectively to scale economies and diseconomies . The organization of the family farm , in fact, is based on a structure of implicit contracting grounded in familiarity (in the literary sense) , trust and mutual exchange, with community monitoring and enforcement, a strong role for tradition procedures, routines and rights, and equal importance of utilitarian exchange and ritualized gift giving. As Demsetz (1995) argues, furthermore, the family farm is also typically organized in a way that promotes a certain degree of self-sufficiency, and thus tends to substitute the contracts between producers and consumers with a standard in house arrangements, which often include family and non family labor.

Family farms may thus be more effective in enhancing productivity, than other types of organizations, especially when market transaction costs are high, and they pursue their mission with a panoply of instruments, characteristic of traditional societies, some of which survive within "familistic" cultures also in more advanced and indeed non agrarian urban contexts (Putnam, 1967). We should expect their contribution to productivity increases , however, to be uneven, and led by different drivers, depending on the features of the environment that they face, their different objectives, and the relative importance that the instruments at their disposal assume . Management ability is certainly a component of a successful performance, but a number of family characteristics may conjure up to determine winners and losers including the human and non human capital (Sen's re-known "capabilities") with which the family is endowed.

Classes of different performances may thus emerge across the spectrum of family farms , depending on the fact that they may have diverse subsistence and marketing goals and because of characteristics that may be at the same time too many and too subtle to observe. Within each class, a tendency to optimize may be present, with several local optima that determine local IRs in different intervals of productivity and farm sizes. In more dynamic terms , the implications of development and transaction costs for the family farm may be rather different than those of the firm. In both cases an increase in market transaction costs (MTC) may increase the incentives to internalize the production of goods and services, but while this typically means a more vertically integrated enterprise for the firm, it will simply tend to enhance the push for self sufficiency for the family farm and thus increase its optimal size. Symmetrically, an increase in internal transaction costs (ITC) , such as information and supervision, will reduce the incentive to integrate the value chain for a firm that is already well positioned in the market, while it may reduce optimal farm size by increasing specialization and market dependence for the family farm.

Decisions about family size are also likely to be affected by transaction costs, so that the family farm, unlike the firm, may react to changes in MTCs and ITCs with two instruments, i.e. the number of people in the family and the scale of operations. Thus increases in the ratio between MTCs and ITCs may be expected to encourage larger family sizes, because a higher degree of self-sufficiency requires larger operating sizes, higher diversification and more general skills, with factors somewhat trapped within the farm or its quasi market circle of mutual help of extended family systems . Here, we should expect first a direct relationship between productivity and farm size and then IR emerging in response to excessive increases lead by the forces unleashed by the harder drive toward self sufficiency. Vice versa a decrease in the MTC- ITC ratio will encourage smaller and more specialized enterprises, higher integration with the market and higher factor mobility, with IR pushing toward a contraction of farm sizes along these lines. Thus, even though consistent with the Coasian premises, the process of de-agrarianization may be itself a cause of the IR, since it is to some extent the opposite of the process originally described by Coase, with many different types of smaller farm- firms emerging from the rather homogenous population of traditional family farms to exploit the reduction in market transaction costs made possible by development.

Because the family farm has low supervisory costs from higher motivation of its members (Feder, 1985) and of the gratuities that they can experience as parts of an extended family business, the reduction in external transaction costs may be expected to have different effects on differently performing farms. For highly productive family farms, that are performing better than their peers because of higher quality management or other non observable farmers' abilities, increases in marketable surplus and development of commercial agriculture may be a chance to be exploited immediately, even before undergoing a transformation to more specialized units, operating exclusively for the market. While increasing farm size may be necessary to exploit the new market opportunities, increasing internal transaction costs (ITC) should be expected with negative effects on productivity until a certain threshold of successful transformation into commercial farming has been achieved.

For the less productive family farms , on the other hand, the opportunities created by lower MTCs may be met with size expansion without major increases in supervision costs at first, either because of underemployed family labor, or because of other benefits from MTC reduction, such as access to modern inputs, extension and better prices. Beyond a certain threshold of expansion, nevertheless, it is reasonable to expect that ITCs will become prevalent again and that larger farm sizes will be associated with lower productivity.

These considerations also suggest that farmers may operate in different ways, especially in the extreme distribution of farm productivity residuals, due to unobserved cognitive and physical abilities (Evenson and Mwabu, 1998), previous experience with investment or other performance- related characteristics. Thus, for example, at the low extreme of the productivity distribution (or the distribution of its residuals after accounting for the exogenous variables), productivity could increase as farmers take advantage of larger operating areas to overcome other performance disadvantages due to low endowments of skills and knowledge. At the high extreme, on the other end, supervision costs may become more important and larger sizes may reduce the competitive advantage of abilities and motivation of family farmers (Feder, 1985).

If factor productivity is distributed normally, with a constant variance, aside from identification problems, OLS will generally provide an estimate of the relationship based on mean response. In other words, OLS will allow us to estimate a response coefficient that will quantify the average response of the dependent variable (e.g. land productivity) to farm size increases. If the distribution of the response around the mean , estimated according with OLS, is not satisfactorily described by a single variance, however, quantile regression (Koenker and Basset, 1978) promises a more robust and appropriate estimate, especially if variance is systematically related to the increase in the response variable (heteroscedasticity). We can also conjecture that the relationship between productivity and alternative measures of size (land available, land under cultivation etc.) may be considerably different for farmers who, for various reasons that cannot be captured by the econometric model, have to operate at low productivity levels, with respect to farmers that operate at high productivity levels.

3. The Option Model

We follow Savastano and Scandizzo (2009) and assume that landowners hold the option to invest in additional land i q at a given rate $r^* = \frac{r}{\rho}$. Yield is assumed to follow a Brownian process as identified by the equation:

$$(1)\quad dy = \alpha y dt + \sigma y dz$$

Assume that the farmer contemplates the possibility of investing in farmland q_i, Farm operating profit from developing land, π, is determined according to the following equation :

$$(2)\quad \pi_i = \frac{y}{\delta} f(q_i;m_i) - \frac{c}{\rho} f(q_i;m_i)(1-e^{-\rho T})$$

In (2) , $\delta = \rho - \alpha$, and without loss of generality, we set $\frac{c}{\rho}(1-e^{-\rho T}) = r$ and consider only land a decision variable. Revenue per unit of output, i.e. the random variable y is supposed to follow a geometric Brownian motion as described in (1). In addition, $f(q)$ is a neoclassical production function with the standard properties $f_i > 0$, $f_{ii} < 0$, $i = q,m$, with management m positively related to both average and marginal productivity : $f_{qm} > 0$, $f_{qqm} < 0$. We also make also the following assumptions: (1) the production function is linear homogenous in the two inputs of land and management ability, (2) management is exogenously given for the farmer, (3) the farmer can develop land at the cost c , which includes all on farm investment. This cost is sunk and the investment is irreversible, (4) the operating profit flow is such that the farmer does not have the option to suspend or abandon the cultivation.

The objective of the farmer is to maximize the expected present value of profit. The discount rate is given and equal to ρ . The farmer cultivates his own original plot of land, given his endowment of management capabilities, and has to decide whether to develop land on the basis of costs and benefits of cultivating additional pieces of land.

Given these conditions, as shown more generally by Dixit and Pyndick (1994), the optimal policy is described by an upward-sloping threshold curve $y = y(q, m)$. In the region above the curve, it is optimal to develop more land in a lump to move immediately to the threshold curve. In the region below the curve, inaction, and therefore, cultivating the previous amount, is optimal. The farmer waits until the stochastic process of y moves vertically to $y(q)$, and then develops land just enough to keep from crossing the threshold. Assuming that there is a continuous supply of land, the farmer cultivates his own initial level and has the option of develop additional pieces of land. As shown by Savastano and Scandizzo (2009), the threshold value of production at which the farmer will invest in additional land development is:

$$(3) \qquad \frac{y^*}{\delta} = \frac{\beta_1}{\beta_1 - 1} \frac{r}{f_q(q_i;m)}$$

The parameter $\beta_1 > 1$ derives from the solution of the dynamic problem of the farmer under uncertainty and is an inverse function of the variance of the process in equation (1). Thus, equation (3) simply states that the threshold of investment will be at a level of marginal productivity of land that significantly exceeds its development costs.

Since the production function is homogenous of degree one, we can write:

$$(4) \quad f_q(q_i;m_i)q_i + f_m(q_i;m_i)m_i = Q_i$$

(5) Thus, average land productivity (ALP) for the new developed area can be computed as follows:

$$(6) \quad ALP_i = \frac{Q_i}{q_i} = [f_q(q_i;m_i) + f_m(q_i;m_i)\frac{m_i}{q_i}]\frac{y}{\delta}$$

Substituting (3), we obtain:

$$(7) \qquad ALP_i = \frac{\beta_1}{\beta_1 - 1}\frac{ry}{y^*} + f_m(q_i;m_i)\frac{m_i}{q_i}\frac{y}{\delta}$$

From this equation we can directly derive the following results:

$$(8) \frac{\partial ALP}{\partial y^*} = -\frac{\beta_1}{\beta_1 - 1}\frac{ry}{y^{*2}} \qquad (8) \quad \frac{\partial ALP}{\partial q_i} = \frac{y}{\delta}[f_m \frac{1}{q_i}(\frac{\partial m_i}{\partial q_i} - \frac{m_i}{q_i}) - |f_{mm}|\frac{\partial m_i}{\partial q_i}]$$

ALP will thus be lower the higher the threshold value, but it will increase or decrease with operating size depending on the balance of the diffent effects of management quality. As operating size increases, in fact, if management and farm size are positively related (that is, larger farms tend to have better managers or $\frac{\partial m_i}{\partial q_i} > 0$) management will be spread over a larger farm, thereby reducing its impact, but the overall effect may still be positive because of the positive marginal effect that increasing operating size will be in attracting better managers. In general, the fact that the threshold and the management effects may display opposite tendencies to increase or decrease as farm size rises suggests two conclusions:

(1) ALP will display respectively a negative (the IR) or a positive correlation with farm operating size, depending on whether the threshold effect (the higher incentive for larger farms to hold undeveloped land as an option) prevails or is overwhelmed by the management effect (the tendency of ALP to increase with farm size since larger farms attract better managers).

(2) Depending on the functional form of their relationship, the two tendencies may equal each other , once a threshold of farm size is reached, after which the net effect on ALP will be reversed.

(3) Both tendencies and the level of the threshold will depend on the management quality and thus can be expected to vary across farmers, depending on the distribution of management quality and the extent to which a market for managers succeed in allocating them to larger farms.

These conclusions support the idea that the IR relationship may indeed be present in many farming systems, but we should expect it to be neither ubiquitous nor monotonic. In particular, if farmers face dynamic uncertainty by holding a waiting option for land development and unobservable management quality is positively correlated with farm size, both a reverse and a direct effect of operating size on average productivity may be present at any one time. This in turn implies that the net impact of increasing operating size on land productivity will depend on whether a threshold is crossed where the two effects exactly balance each other.

4. The Estimation Problem

Consider the relationship between land productivity and farm size in the stylized form:

$$\frac{y_i}{x_i} = \beta_0 + \beta_1 x_i + \gamma Z_i + \epsilon_i \tag{9}$$

where y_i is some measure of production for the ith farm, x_1 is a correspondent measure of farm size (e.g. operated area), z_i a set of exogenous variables, and e_i a random disturbance. It is important to underline the fact that equation (9) is not a production function, but the result of farmers' choices, on the basis, inter alia, of an underlying technology. If we assume that farmers have adjusted production (either through optimization or through any other common behavioral rule) to the circumstances outside their control, including exogenous variables, states of nature etc., the coefficient β_1 in (1) should be zero. In other words, all systematic differences in production per acre between farms should be accounted for by differences in the z_i variables or in the random term εi. A β_1 different of zero, on the other hand, would imply the existence of systematic differences across farmers that are not accounted for in the equation: these differences could be due to different behavioral rules, different abilities in following the same rules or different levels of information or other omitted variables that are correlated with farm size.

It is also important to notice that a non zero β_1 may be caused by discontinuities in the behavioral function that underlies farmers' adjustment to the exogenous variables. These discontinuities are implied by most of the explanations of the inverse productivity relationship based on anthropological differences between "family" and " non family" or systematic divergence in behavior between "small" and "large" farms (e.g. Feder, 1989; Cornia, 1985). However, if IR is the result of these discontinuities, it should only concern the differences across the two extreme groups of farmers, and not the differences within the groups themselves.

In order to test for the existence of either an inverse or a direct relationship (IR) between land productivity and farm size , we use both OLS regression models and quantile regressions (Koenker and Bassett , 1978). While OLS focuses on modeling the conditional mean of the response variable without accounting for its distribution, the quantile regression model accounts for the full conditional distributional properties of the response variable (or is residual after accounting for the exogenous variables) thereby differing on the assumptions about the error terms of the regression model.

In the case of equation (1), the OLS model is based on the assumption that the error term is normally distributed with zero mean and constant variance: $\epsilon_i \sim \text{i.i.d.}\, N(0, \sigma^2)$

The consequence of the mean zero assumption of the error term implies that the model fits the conditional mean, namely $E[y - \gamma Z|x] = \beta_0 + \beta_1 x_i$ which can be interpreted as the average value of productivity, after accounting for the effect of the exogenous variables Z, corresponding to a fixed value of the covariate x (i.e. farm size). The linear regression model describes how the conditional distribution behaves by utilizing the mean of a distribution to represent its central tendency, a choice that appears appropriate under the assumption o homoscedasticity , namely of constant variance for all values of the covariate x.

The quantile-regression model (QRM) estimates the potential differential effect of a covariate (farm size) on various quantiles in the conditional distribution. A conditional quantile is a statistic corresponding to the probability level of a given distribution, according to a function (the quantile function) defined as $q(p) = \{y: \Pr(Y \leq y) = p\}$. By considering the different quantiles, the QRM estimates how the effect of a covariate varies with the distribution of the response variable and accommodates heteroscedasticity. The QRM corresponding to the LRM in Equation (9) can be expressed as:

$$y_i = \beta_0^{(q)} + \beta_1^{(q)} x_i + \gamma^{(q)} Z_i + \epsilon_i^{(q)} \qquad (10)$$

The parameter vector, $[\beta_0^{(q)} \beta_1^{(q)} \gamma^{(q)}]$ is obtained by minimizing the sum of absolute deviations from an arbitrarily chosen quantile of a farm yield across farmers. In the case of Equation (2) this sum can be expressed

as:

$$\text{Minimize: } \sum_i \left| y_i^q - [\beta_0^{(q)} + \beta_1^{(q)} x_i + \sum_j \gamma_j^q Z_{ij} \right| \qquad (11)$$

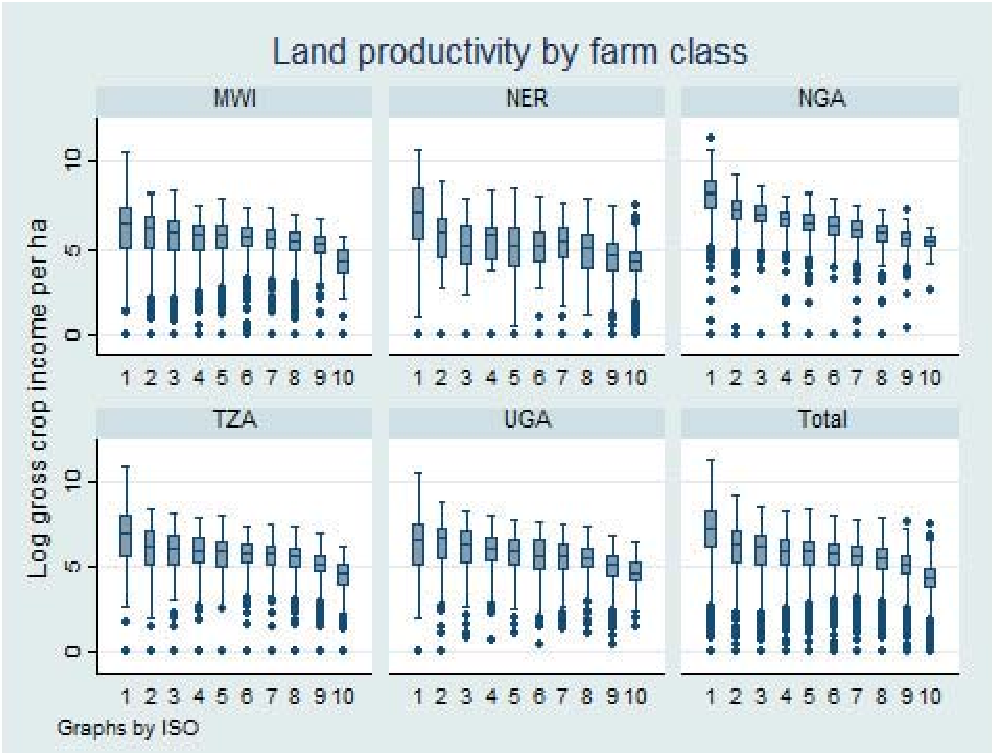
where y_i^q = average productivity for farmer i at quantile q, (i =1, ...n); x_i= farm size Z_{ij}^q = covariate j for farmer i (j = 1,....K).

The solution to Equation (11) is found by rewriting the expression as a linear programming problem over the entire sample (see Chamberlain, 1994) and solving for he values of the parameters. Both the squared-error and absolute-error loss functions are symmetric, as the sign of the prediction error is not relevant. While OLS can be inefficient if the errors are highly non-normal, quantile regression is more robust to non-normal errors and outliers. QR also provides a richer characterization of the data, allowing to consider the impact of a covariate on the entire distribution of y, not merely its conditional mean.

Figure 1 summarizes key aspects of our sample data on land productivity and farm size into a single form. On the horizontal axis farm size classes are reported by increasing size, while the vertical axis measures average land productivity. The top of the rectangular box shaded in the figure marks the 75th percentile of the data range, while the bottom "hinge" marks the lower 25th percentile. The "whiskers" extend another 1.5 times the interquartile range of the nearest quartile. The horizontal line in the middle of the box marks the median of the data for each group. Intuitively, the range of the box delineates observations that are typical. The whiskers contain values that are somewhat atypical relative to most observations, while the dots mark observations that are extreme, with a large number of suspiciously small values with a tendency of dispersion even if we are in the log scale of crop income.

The diagram appears to show a clear tendency for productivity to decline with increase in farm size. This effect is accentuated if we consider the upper and lower tails of the productivity distribution. This crude correlation, however, may be misleading for two reasons: first, it does not consider the effects of the other covariates that are expected to influence farm productivity; second, in the same diagram, dispersion appears to be decreasing with farm size, with a much wider range of values for the smallest size. By characterizing the entire distribution of crop income for each farm class, even for the simple correlation, the plot thus suggests that the relationship between productivity and farm size may not be the same for different levels of productivity, and that group means or medians do not necessarily represent group behavior .

Figure - Log gross crop income (land productivity) by percentiles of land operated



5. Data and Descriptive Statistics

We use data from LSMS-ISA surveys in Malawi, Niger, Nigeria, Tanzania and Uganda, all collected in 2010-2011. These are large multi-purpose household surveys, national representative, with detailed information on agricultural production. Table 1 reports some descriptive statistics from the surveys, showing mean values of broadly comparable magnitude across countries, except for Nigeria, which appears to have a much smaller average operated area and larger yield and labor intensity than the other countries.

Descriptive statistics for the surveys in our sample provide a number of insights pointing in particular to a wide distribution of land ownership, but similar level of crop intensity, difference in rural population density and market access, large productivity gaps across producers, sizable variation in infrastructure, and agro-ecological conditions.

In terms of area operated by farmers (defined by area owned, plus area rented in, and net of area rented out and under fallow), we note that the average across the five countries is 2.1 ha, with the lowest in Malawi (0.73 ha), and the highest in Niger (5.21 ha). With 267 and 218 person per sq. km, Uganda and Nigeria are, respectively, the two countries with the highest rural population density. Somewhat surprisingly, Uganda, with an average rural population density four times the level in Tanzania, has an average operated area quite close to Tanzania's 2.3 ha. While a larger farm size could be expected to compensate for lower population density, labor constraints prevent farmers to make the necessary investment (mechanization, tractor plowing or anima draft), to increase farm endowment. In terms of agriculture intensification, we observe that the majority of the countries have reached a stage of permanent agriculture, as the crop intensity (defined as gross cropped area divided to net cropped area) is larger than one.

The geo-referenced structure of the LSMS-ISA datasets allow us to link geo-variables matched by staff at the World Bank to the external datasets of the *FAO's Harmonized World Soil Database v.1.2* (soil nutrient availability) and use soil quality controls in our regressions. The soil database is the result of a collaboration between the FAO with *IIASA, ISRIC-World Soil* Information, Institute of Soil Science, Chinese *Academy of Sciences* (ISSCAS), and the *Joint Research Centre of the European Commission* (JRC)[1].

[1] The Harmonized World Soil Database is a 30 arc-second roster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981). The resulting database consists of 21600 rows and 43200 columns, which are linked to harmonized soil property data and display the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). http://www.fao.org/fileadmin/user_upload/soils/docs/HWSD/Soil_Quality_data/Rooting_conditions.jpg

Among all the variables tested, two variables are mostly significant in the regressions to indicate lack of soil quality. They are: (i) a dummy constraint oxygen availability equal to 1 if the categorical variable "Oxygen availability to roots" is equal to severe and very severe constraints and zero otherwise; (ii) a dummy "Constraint excess salt", equal to 1 if the categorical variable Excess salts is equal to severe and very severe constraints and zero otherwise.

We use urban gravity and distance to the nearest market or the major road as proxy for urbanization and access to infrastructure respectively. To compute urban gravity we use light intensity data produced by the defense Meteorological Satellite Program (DMSP) of the National Geophysical Data Center, and we convert them into urban gravity using the same approach of Binswanger and Savastano (2015). The proxies for market access are taken from the geospatial dataset of the LSMS-ISA surveys, which include average households' distance to the nearest market and major road[2]. We note large disparities in terms of market access, with an average household distance to reach the nearest market of 35 km for the five countries, with a minimum of 8 km in Malawi to a maximum of 86 km in Tanzania. Also, as a proxy for urbanization, we note that urban gravity is the largest in Malawi and Nigeria and the lowest in Niger and Tanzania.

Table 1 - Descriptive Statistics (Averages)

ISO	MWI	NER	NGA	TZA	UGA	Total
Gross crop income per ha (US$/ha)	507.57	265.2	2229.82	478.52	468.2	733.58
Land operated (owned+ rented in-rented out-fallow) (ha)	0.73	5.21	0.8	2.33	1.45	2.10
Rural population density (pers./sq. km) (2005)	182.5	60.4	218.3	59.9	266.9	157.6
Gross cropped area (ha)	0.74	5.8	1.6	2.03	2.4	2.514
Net crop area (ha)	0.67	4.9	1.3	1.95	1.0	1.964
Crop intensity	1.02	1.19	1.23	1.07	1.89	1.28
Annual Precipitation (mm)	1085.54	375.94	1369.17	1089.87	1225.23	1064.8
Annual Mean Temperature (°C * 10)	218.28	282.03	263.59	227	218.82	233.61
UG: travel time negative exponential, with borders restriction to cities with 500K	142.49	41.36	113.23	49.96	53.59	105.23
HH Distance in (KMs) to Nearest Market	7.96	62.72	71.33	82.67	31.21	35.85
HH Distance in (KMs) to Nearest Major Road	9.69	12.92	17.21	21.73	7.31	12.41
Dummy constraints to oxygen availability to roots[1]	0.1	0.15	0.17	0.12	0.28	0.14
Dummy Excess salts[1]	0.04	0.09	0.03	0.06	0.04	0.05
Pastoral farming system[2]	0	0.49	0.03	0	0.01	0.06

Source: Authors' computation from LSMS-ISA household surveys. [1] Dummy for oxygen availability and excess salt have been computed from the continuous geospatial variable of the LSMS-ISA. A dummy is equal to 1 for higher constraint to soil fertility. Both raw data are derived from the FAO's Harmonized World Soil Database v.1.2 (soil nutrient availability): The dummy for pastoral farming system is drawn from the Harvestchoice dataset, and follow the classification of the farming Systems in sub-Saharan Africa according to FAO's methodology and based on Dixon, J. and A. Gulliver with David Gibbon, Principal [3]Editor Malcolm Hall. Improving Farmers' Livelihoods in a Changing World. FAO/World Bank. 2001

Using both OLS and Quantile regression we estimate the following function at the household level:

$$\ln \frac{Y_i}{v_i} = b_0 + b_1 \ln x_i + b_2 \ln Z_i + u_i$$

where $\frac{Y_i}{v_i}$ represents an indicator of farm productivity (gross crop income per ha , in which case $x_i = v_i$, or total labor productivity) for each household i, x_i is the total area operated, Z_i denotes a vector of exogenous geo referenced households characteristics such as variance of precipitation and temperature, urban gravity, distance to the major road or market, soil quality controls and u_i is an error term.

Table 2 presents the main results from the estimation for the pooled sample. The OLS estimates show a significant negative elasticity for the relationship between gross income per ha and land operated, with a value not significantly different of one and no significant quadratic response. The first (10%) quantile regression estimates, however, "deconstruct" this result as corresponding to the combination of a positive, more than proportional, linear response and a negative, smaller than unity quadratic response. For the other three quantiles considered (the 25th, the 50th, and the 80th), a similar, but reversed sequence, of a negative linear and positive quadratic response is estimated. Moreover, both the quadratic and the linear coefficients increase across the quantiles.

[2] The source for the variable distance to the main road is OpenStreetMap-Tranroad, while the source for the distance to the nearest market is USAID – FEWSNET.

[3] The quantiles represent intervals of the probability distribution of land productivity

The IR hypothesis, therefore, appears to be rejected for all but the very first quantile, where, however, it is reversed after a threshold of operating size is reached. Vice versa, for the other three quantiles, productivity tends to decrease with the cultivated area, according to the IR hypothesis, but also this relationship is reversed, and the threshold of reversal is larger and larger as we move from the 25^{th} to the 80^{th} quantile.

In this regression, the elasticity of productivity with respect to the urban gravity index is low and essentially the same (between 0.01 and 0.03) for all quantiles, except the 20th for which it is not significant. The estimates of the weather impact are somewhat surprising with a large negative effect of the variance of temperature and a smaller positive effect of rainfall variability with both effects tending to vanish for the top quantiles. The elasticities with respect to the distance from the market and the main road are variable and larger. They follow a quadratic relation with a positive linear (in the logs) and a negative quadratic coefficient. The presence of pastoral farming systems appear to impact negatively on average land productivity, only for the lower half of the quantiles, while appears to have no effect in the quantiles in the top 50%. In sum, the results show that performance classes differ significantly in their response to key exogenous variables and that this response from productivity to infrastructure (UG, road and market distance), tends to be nonmonotonic.

Estimates on individual countries confirm the results (see Tables 3-7), which are summarized in Table 8 . They suggest distribution dependency of both the form and the intensity of the productivity response to the increases in operating area. We find that productivity effects of acreage increases are different at different levels of productivity and are highest, but with opposite signs, at the extreme ends of the distribution of yield residuals, with very similar patterns of decline, for the linear terms, and increase for the quadratic ones over the distribution (see Figure 1, 2 and 3). This may be due to various causes, such as, for example, that unobserved farmer ability acts as a complement for land increases at low level of yield residuals and as a substitute at higher yield residuals. More generally, it could be because the endowments of critical, unaccounted, components of human and non-human capital are correlated with productivity increases.

Tables 9 and 10 and Figures 2-6 show that the disparities in the coefficients estimated for the individual countries correspond to much smaller differences in the ranges over which the IR relationship holds for low performers and to huge differences for medium and high performers. These differences, on the other hand, appear to depend also on the other control variables. In the case of soil quality, for example, they are especially effective in the case of the lower performers of Malawi and throughout the quantiles in Uganda[4]. In general, however, for the lower performant farms of the first two quantiles, IR appears to take over at about the same level of operating area for values not significantly different of each other and from the pooled sample estimates. This means that land productivity for low performers tends to increase with operating area up to about a level of 2-5 has and then to decline according with the IR traditional evidence. For the highest performers (farms in the top three deciles of the productivity distribution), the results are the opposite, with productivity declining up to an operating size level of 5 to 80 has and above, after which increasing returns to scale appears to settle. The much wider range of the switching levels of operating area appears to depend on the range of the operating size variable that is much larger than the average for Niger and Tanzania.

The U shaped pattern at the lower tail of the productivity distribution suggests that a larger operating size may be a positive factor for low performers, but only up to a point after which the other causes of the IR relation become prevalent (i.e. only if farm size does not become "too large"). For the upper deciles, on the other hand, the IR relationship appears to hold over a much wider range, although in many cases appears to reverse itself for moderately large operating areas. As Tables 9 and 10 and Figures 4-6 show, the size of the operating area at which the IR relationship prevails for the first two deciles is small, although often above the average, depending on the country. For the upper tail of the distribution, on the other hand, the land size at which the IR relationship reverses itself is only moderately larger except for a few outlayers, so that most large farms essentially do not display any IR.

[4] Note that the soil quality variables represent negative qualities and their coefficients have generally the expected negative sign. However, because of the possible correlation with farm size, their signs could also be positive or zero, as the following shows. Consider in fact the model:

(1) $y = b_0 + b_1 x + b_2 z + u$

Where y is average land productivity (LP), x is operating size (OS) and z a soil quality (SQ) variable. The OLS estimates of the coefficients are:

(2) $b_1 = (s_{zz}s_{xy} - s_{xz}s_{zy})/(s_{xx}s_{zz} - s_{xz}^2)$

(3) $b_2 = (s_{xx}s_{zy} - s_{xz}s_{xy})/(s_{xx}s_{zz} - s_{xz}^2)$

(4) $b_0 = \bar{y}$

If both OS and SQ are positively correlated with LP, while OS and SQ are negatively correlated with each other (i.e. larger farms have poorer soils), b_1 and b_2 will be both positive. On the other hand, if SQ is positively correlated with LP and OS ($s_{zy} > 0$, $s_{xz} > 0$), then the signs of the two coefficients become ambiguous.

Table 2 - Dependent Variable: Log Gross Crop Income/ha

VARIABLES	(1) OLS Pooled	(2) Q10	(3) Q25	(4) Q50	(5) Q90
Log land operated	-0.92***	1.25***	-0.86***	-1.72***	-2.70***
Sq. Log land operated		-0.61***	0.04	0.26***	0.56***
Variance of precipitation	0.14***	0.56***	0.22***	0.17***	-0.02
Variance of temperature	-3.72***	-15.96***	-4.85***	-1.27***	1.45***
Log UG	-0.02***	-0.03	-0.04***	-0.03***	-0.03***
Log distance to market	0.34***	1.16***	0.30***	0.19***	0.25***
Lo distance to market sq	-0.05***	-0.16***	-0.04***	-0.03***	-0.04***
Log distance to road	0.33***	0.58***	0.46***	0.27***	0.10***
Lo distance to road sq	-0.07***	-0.10**	-0.10***	-0.07***	-0.03***
Dummy Constraint Oxygen availability to roots	-0.31***	-0.84***	-0.29***	-0.13***	-0.08***
Dummy Constraint Excess salts	-0.33***	-0.96***	-0.58***	-0.13**	0.21***
Pastoral farming system	-0.24***	-0.27	-0.30***	-0.13**	-0.06
Country dummies					
MWI	-0.14*	0.39	0.17	-0.12**	-0.28***
NGA	1.02***	1.44***	1.11***	0.73***	0.72***
TZA	0.04	-0.08	0.08	0.01	0.17***
UGA	-0.20**	-0.46	-0.24*	-0.18***	0.14**
Constant	4.95***	-1.15*	3.89***	5.72***	8.05***
Observations	18,410	18,410	18,410	18,410	18,410
R-squared	0.18				

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. *NER is the comparison group*

Table 3: Results for MWI

Y = Log Gross Crop Income/ha	Q10	Q20	Q30	Q40	MALAWI Q50	Q60	Q70	Q80	Q90
Log land operated	11.22***	1.38**	-0.11	-1.44***	-2.02***	-2.52***	-3.00***	-3.49***	-4.30***
log land operated sq	-5.37***	-1.02***	-0.39*	0.15	0.45***	0.68***	0.88***	1.15***	1.52***
Log mean area of land operated by quantile	-7.93***	-0.35	-0.09	1.21*	1.27***	1.60***	1.94***	2.23***	2.90***
Dummy rent in land	-0.11	0.15	0.08	0.08	0.07	0.07	0.06	0.04	0.01
Log UG	-0.33**	-0.28***	-0.28***	-0.20***	-0.15***	-0.11***	-0.10***	-0.08***	-0.07***
Log UG Sq	0.05**	0.04***	0.04***	0.02***	0.02***	0.01***	0.01***	0.01**	0.00
Log distance to road	0.13	0.35**	0.32***	0.30***	0.27***	0.20***	0.21***	0.14***	0.13***
Lo distance to road sq	-0.02	-0.09**	-0.09***	-0.08***	-0.07***	-0.06***	-0.06***	-0.04***	-0.04***
Log distance to market	1.26**	0.44	0.18	0.02	0.07	0.07	0.11	0.10	0.05
Lo distance to market sq	-0.20	-0.06	-0.02	0.01	-0.01	-0.01	-0.02	-0.02	-0.00
Dummy Constraint Oxygen availability to roots	-2.06***	-1.05***	-0.53***	-0.15**	-0.01	-0.04	-0.01	-0.04	-0.02
Dummy Constraint Excess salts	-1.93***	-3.39***	-1.51***	-0.96***	-0.58***	-0.31***	-0.09	-0.04	-0.07
Agro Pastoral farming system									
AEZ_TEXT==Tropic - cool / humid	1.01***	0.56***	0.52***	0.45***	0.39***	0.35***	0.36***	0.30***	0.26***
AEZ_TEXT==Tropic - cool / semiarid	0.59*	0.06	0.04	0.09	0.13**	0.09*	0.10**	0.15***	0.12**
AEZ_TEXT==Tropic - warm / arid	-0.16	-0.13	-0.08	0.01	0.02	0.03	0.02	0.01	-0.01
Constant	12.05***	4.29*	5.36***	3.96***	4.26***	4.13***	3.88***	3.80***	3.17***
Observations	9,157	9,157	9,157	9,157	9,157	9,157	9,157	9,157	9,157

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors' estimate based on MWI 2010-2011, LSMS-ISA project

Table 4: Results for NER

Y = Log Gross Crop Income/ha	Q10	Q20	Q30	Q40	NIGER Q50	Q60	Q70	Q80	Q90
Log land operated	3.07***	0.76**	-0.27	-0.37*	-0.78***	-1.17***	-1.39***	-1.84***	-2.11***
log land operated sq	-0.96***	-0.31***	-0.13*	-0.11*	0.03	0.12**	0.16***	0.26***	0.27***
Log mean area of land operated by quantile	-0.85	-0.48	0.18	0.06	-0.18	-0.06	-0.04	0.18	0.60*
Dummy rent in land	0.50*	0.28	0.14	0.21*	0.18	0.24**	0.20**	0.27**	0.19
Log UG	0.36*	0.18	0.12	-0.03	-0.06	-0.07	-0.07	-0.03	0.03
Log UG Sq	-0.07**	-0.03	-0.02	0.01	0.02	0.02*	0.02*	0.01	0.00
Log distance to road	0.97***	0.77***	0.67***	0.49***	0.45***	0.26***	0.24***	0.22**	0.15
Lo distance to road sq	-0.19***	-0.14**	-0.12***	-0.10***	-0.09***	-0.05**	-0.05**	-0.04	-0.03
Log distance to market	1.51***	1.01***	0.75***	0.72***	0.61***	0.45***	0.46***	0.42***	0.48***
Lo distance to market sq	-0.26***	-0.18***	-0.13***	-0.11***	-0.10***	-0.07***	-0.07***	-0.07***	-0.08***
Dummy Constraint Oxygen availability to roots	0.21	0.16	0.15	0.21*	0.18	0.13	0.15*	0.23*	0.11
Dummy Constraint Excess salts	-0.69*	-0.28	-0.24	-0.28*	-0.16	-0.05	-0.01	0.01	0.19
Pastoral farming system	0.58*	0.18	-0.03	-0.12	-0.17	-0.20*	-0.21**	-0.31**	-0.49***
Agro Pastoral farming system	0.99***	0.51*	0.14	-0.05	-0.18	-0.20*	-0.25**	-0.39***	-0.53***
AEZ_TEXT==Tropic - cool / humid	-0.45*	-0.52**	-0.56***	-0.35***	-0.14	-0.01	0.19**	0.44***	0.78***
Constant	-0.61	2.19*	2.77***	3.72***	5.11***	5.76***	6.16***	6.49***	6.41***
Observations	1,963	1,963	1,963	1,963	1,963	1,963	1,963	1,963	1,963

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors' estimate based on NER 2010-2011, LSMS-ISA project

Table 5: Results for NGA

Y = Log Gross Crop Income/ha	Q10	Q20	Q30	Q40	NIGERIA Q50	Q60	Q70	Q80	Q90
Log land operated	-3.03***	-4.45***	-4.54***	-4.65***	-5.10***	-5.46***	-5.57***	-5.67***	-5.95***
log land operated sq	1.01*	1.48***	1.59***	1.63***	1.84***	1.97***	2.01***	2.08***	2.15***
Log mean area of land operated by quantile	0.43	1.93*	1.33*	1.28**	1.67***	1.99***	1.87***	1.61***	1.98***
Dummy rent in land	-0.06	-0.11	-0.17**	-0.06	-0.04	-0.04	-0.02	-0.02	-0.09
Log UG	-0.26*	-0.16**	-0.13***	-0.08**	-0.06*	-0.06*	-0.06**	-0.07**	-0.04
Log UG Sq	0.01	0.01	0.00	0.00	-0.00	-0.00	0.00	0.00	0.00
Log distance to road	0.25	0.14	-0.01	0.01	0.02	0.03	0.02	0.06	-0.02
Lo distance to road sq	-0.04	-0.02	0.01	0.01	-0.00	-0.01	-0.01	-0.01	0.01
Log distance to market	0.54	0.41	0.31	0.29*	0.21	0.14	0.17	0.07	-0.00
Lo distance to market sq	-0.08	-0.06	-0.05	-0.04*	-0.03	-0.02	-0.02	-0.01	-0.00
Dummy Constraint Oxygen availability to roots	-0.12	-0.21*	-0.09	-0.02	-0.00	-0.01	-0.03	-0.01	-0.07
Dummy Constraint Excess salts	0.03	0.02	0.07	0.02	0.01	-0.08	-0.11	-0.03	-0.02
Pastoral farming system	-1.12*	-0.77***	-0.58***	-0.62***	-0.57***	-0.36**	-0.42***	-0.46***	-0.69***
Agro Pastoral farming system	-0.23	-0.21	-0.20**	-0.21***	-0.14*	-0.18**	-0.20***	-0.20***	-0.29***
AEZ_TEXT==Tropic - cool / humid	0.56	0.60	0.33	0.09	0.07	0.10	0.04	-0.14	-0.27
AEZ_TEXT==Tropic - cool / semiarid	-2.29***	-0.51***	-0.45***	-0.28***	-0.25***	-0.21**	-0.21***	-0.23***	-0.24***
AEZ_TEXT==Tropic - cool / subhumid	-0.11	-0.15	-0.25***	-0.25***	-0.29***	-0.23***	-0.20***	-0.23***	-0.13**
Constant	5.24	3.54*	5.42***	5.69***	5.47***	5.28***	5.66***	6.53***	6.34***
Observations	2,813	2,813	2,813	2,813	2,813	2,813	2,813	2,813	2,813

*** p<0.01, ** p<0.05, * p<0.1

Source: Authors' estimate based on NGA 2010-2011, LSMS-ISA project

Table 6: Results for TZA

Y = Log Gross Crop Income/ha	Q10	Q20	Q30	Q40	Q50 (TANZANIA)	Q60	Q70	Q80	Q90
Log land operated	7.49***	7.86***	6.35***	2.62***	0.91***	-0.14	-0.78***	-1.27***	-2.11***
log land operated sq	-2.17***	-2.25***	-1.80***	-0.79***	-0.38***	-0.14***	-0.01	0.09*	0.31***
Log mean area of land operated by quantile	-4.35***	-4.51***	-4.32***	-2.65***	-1.61***	-0.82***	-0.31	0.07	0.37
Dummy rent in land	0.44**	0.68***	0.53*	0.39	0.37**	0.30**	0.20*	0.23*	0.18
Log UG	0.03	-0.19	-0.57**	-0.44*	-0.36***	-0.21**	-0.21**	-0.06	0.13
Log UG Sq	-0.02	0.02	0.05	0.04	0.04*	0.02	0.02	-0.00	-0.03**
Log distance to road	0.20	0.34**	0.09	0.16	0.16	0.08	0.04	-0.05	0.04
Lo distance to road sq	-0.04	-0.07*	-0.03	-0.04	-0.04	-0.02	-0.01	0.01	-0.01
Log distance to market	0.04	0.34	1.23**	0.93*	0.73**	0.76***	0.79***	0.54**	0.18
Lo distance to market sq	-0.00	-0.05	-0.16**	-0.12	-0.10**	-0.10***	-0.11***	-0.08***	-0.03
Dummy Constraint Oxygen availability to roots	-0.05	-0.40**	-0.44	-0.37	-0.37**	-0.15	-0.18*	-0.05	0.16
Dummy Constraint Excess salts	0.01	0.15	0.25	0.37	0.25	0.18	0.26**	0.21	0.08
Pastoral farming system	0.93	0.19	-0.32	-0.63	-0.85	-1.03	-1.41	-1.68	-1.80
Agro Pastoral farming system	0.75	0.97	0.73	0.55	0.41	0.22	0.37	0.19	0.21
AEZ_TEXT==Tropic - cool / humid	1.65***	2.75***	2.72***	1.36**	0.74**	0.57**	0.75***	0.49**	0.21
AEZ_TEXT==Tropic - cool / semiarid	-0.00	-0.26	-0.31	-0.33	-0.32	-0.20	-0.14	-0.03	-0.01
AEZ_TEXT==Tropic - cool / subhumid	0.01	0.06	0.20	0.14	0.13	0.13*	0.13**	0.15**	0.20***
AEZ_TEXT==Tropic - warm / arid	0.55	1.58***	1.44**	0.92	1.12***	0.86***	0.71***	0.42	0.02
AEZ_TEXT==Tropic - warm / humid	-0.97***	-0.82***	-0.97***	-0.70**	-0.61***	-0.64***	-0.40***	-0.32***	-0.29**
Constant	7.97***	8.10***	7.85***	7.60***	7.19***	6.47***	6.04***	6.37***	7.02***
Observations	1,853	1,853	1,853	1,853	1,853	1,853	1,853	1,853	1,853

*** p<0.01, ** p<0.05, * p<0.1
Source: Authors' estimate based on TZA 2010-2011, LSMS-ISA project

Table 7: Results for UGA

Y = Log Gross Crop Income/ha	Q10	Q20	Q30	Q40	Q50 (UGANDA)	Q60	Q70	Q80	Q90
Log land operated	8.31***	3.79***	1.09**	-0.39	-0.79***	-1.37***	-1.70***	-2.18***	-2.37***
log land operated sq	-2.67***	-1.39***	-0.51***	-0.14	-0.04	0.11	0.18**	0.36***	0.42***
Log mean area of land operated by quantile	-8.64***	-4.01***	-2.45***	-0.97	-0.56	-0.03	0.42	0.56	0.51
Dummy rent in land	0.80***	0.65***	0.40***	0.22*	0.15*	0.14*	0.15**	0.13**	0.12*
Log UG	0.08	0.07	0.09	0.08	0.11	0.14**	0.07	0.05	0.06
Log UG Sq	-0.03	-0.02	-0.02	-0.02	-0.02*	-0.02**	-0.02*	-0.01	-0.00
Log distance to road	0.18	0.18	0.40*	0.23	0.16	0.16	0.16	0.27***	0.26**
Lo distance to road sq	-0.02	-0.04	-0.11*	-0.06	-0.04	-0.05	-0.05	-0.08***	-0.07**
Log distance to market	0.79	1.42**	1.25***	1.51***	1.42***	1.35***	1.00***	0.88***	0.50**
Lo distance to market sq	-0.14	-0.23**	-0.20***	-0.25***	-0.24***	-0.22***	-0.17***	-0.15***	-0.09**
Dummy Constraint Oxygen availability to roots	-0.49***	-0.39**	-0.27**	-0.23**	-0.22***	-0.19**	-0.21***	-0.23***	-0.16***
Dummy Constraint Excess salts	0.76	0.20	0.03	0.01	0.13	0.06	0.21	0.16	-0.02
Pastoral farming system	-0.02	-1.55**	-1.38***	-1.76***	-2.03***	-2.08***	-1.94***	-1.46***	-1.45***
AEZ_TEXT==Tropic - cool / humid	0.51***	0.48**	0.43***	0.42***	0.42***	0.39***	0.37***	0.31***	0.35***
AEZ_TEXT==Tropic - cool / semiarid	-0.48**	0.20	0.49***	0.72***	0.81***	0.78***	0.69***	0.66***	0.65***
AEZ_TEXT==Tropic - warm / arid	0.54	0.90	0.82**	0.75**	0.71***	0.59***	0.48**	0.30*	0.34*
Constant	15.43***	8.44***	7.23***	5.35***	5.25***	4.78***	4.82***	5.17***	6.15***
Observations	1,976	1,976	1,976	1,976	1,976	1,976	1,976	1,976	1,976

*** p<0.01, ** p<0.05, * p<0.1
Source: Authors' estimate based on UGA 2010-2011, LSMS-ISA project

Table 8 - Summary table for land coefficient: Testing IR by individual countries

Y = Log Value of Gross Crop Income/ha

		Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
MWI	Log land operated	11.22***	1.38**	-0.11	-1.44***	-2.02***	-2.52***	-3.00***	-3.49***	-4.30***
	log land operated sq	-5.37***	-1.02***	-0.39*	0.15	0.45***	0.68***	0.88***	1.15***	1.52***
NER	Log land operated	3.07***	0.76**	-0.27	-0.37*	-0.78***	-1.17***	-1.39***	-1.84***	-2.11***
	log land operated sq	-0.96***	-0.31***	-0.13*	-0.11*	0.03	0.12**	0.16***	0.26***	0.27***
NGA	Log land operated	-3.03***	-4.45***	-4.54***	-4.65***	-5.10***	-5.46***	-5.57***	-5.67***	-5.95***
	log land operated sq	1.01*	1.48***	1.59***	1.63***	1.84***	1.97***	2.01***	2.08***	2.15***
TZA	Log land operated	7.49***	7.86***	6.35***	2.62***	0.91***	-0.14	-0.78***	-1.27***	-2.11***
	log land operated sq	-2.17***	-2.25***	-1.80***	-0.79***	-0.38***	-0.14***	-0.01	0.09*	0.31***
UGA	Log land operated	8.31***	3.79***	1.09**	-0.39	-0.79***	-1.37***	-1.70***	-2.18***	-2.37***
	log land operated sq	-2.67***	-1.39***	-0.51***	-0.14	-0.04	0.11	0.18**	0.36***	0.42***
Pooled	Log land operated	1.42***	-0.62***	-1.12***	-1.50***	-1.74***	-1.94***	-2.15***	-2.39***	-2.67***
	log land operated sq	-0.67***	-0.03	0.10***	0.20***	0.26***	0.31***	0.37***	0.45***	0.54***

*** p<0.01, ** p<0.05, * p<0.1

Following controls included but not reported:
- Log mean area by quartile of land operated
- Dummy rent in land
- Log UG, and square
- Log distance to road
- Log distance to market
- Dummy Constraint Oxygen availability to roots
- Dummy Constraint Excess salts
- Pastoral farming system
- AEZ dummies

Table 9 - Summary table for switching land size levels (has)

	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90	Max Operating area	Average size	SD
MWI	2.84	1.97	0.87	121.51	9.44	6.38	5.50	4.56	4.11	13.83	0.73	13.8
NER	4.95	3.41	0.35	0.19	-	130.97	77.00	34.41	49.77	38.25	5.21	38.3
NGA	4.48	4.50	4.17	4.16	4.00	4.00	4.00	3.91	3.99	7.35	0.8	7.35
TZA	5.62	5.74	5.84	5.25	3.31	0.61	0.00	-	30.06	65.47	2.33	65.5
UGA	4.74	3.91	2.91	0.25	0.00	-	-	20.65	16.80	13.72	1.45	13.7
Pooled	2.89	0.00	-	42.52	28.39	22.85	18.27	14.23	11.85			

Note: The sign – indicates that the switching level is outside the sample range.

Table 10 - Differences of country regression switching values from pooled regression

	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
MWI	-0.04	-0.92	-2.02	118.62	6.55	3.49	2.61	1.67	1.23
NER	2.06	0.52	-2.53	-2.70		128.09	74.11	31.53	46.88
NGA	1.60	1.61	1.28	1.28	1.11	1.11	1.11	1.02	1.10
TZA	2.73	2.85	2.95	2.36	0.43	-2.28	-2.89	1156.40	27.18
UGA	1.86	3.91	-267.52	-42.27	-28.39	483.52	94.15	6.42	4.95

Figure 2

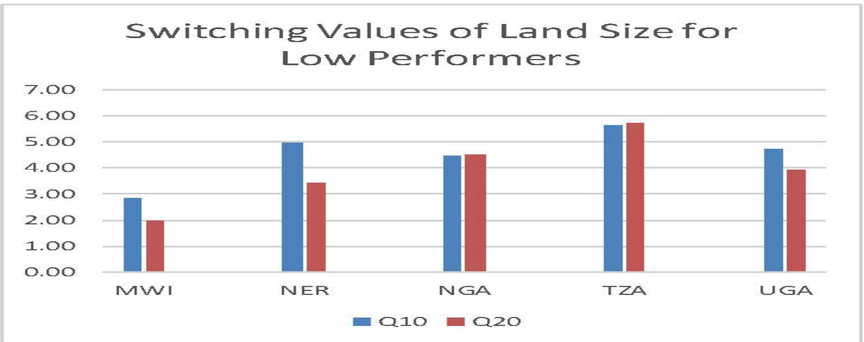


Figure 3

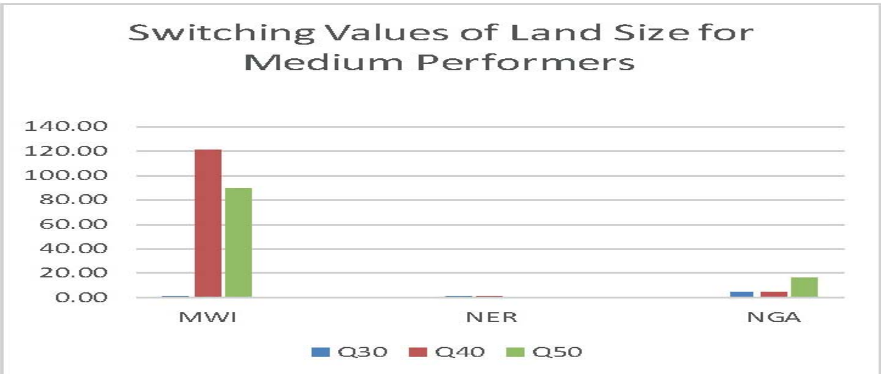


Figure 4

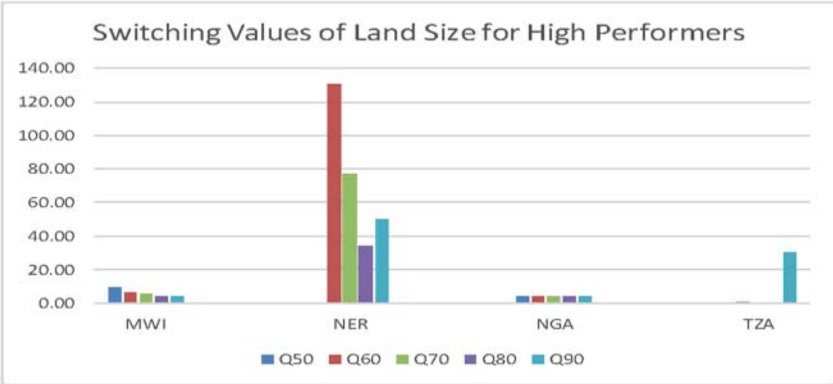


Figure 5

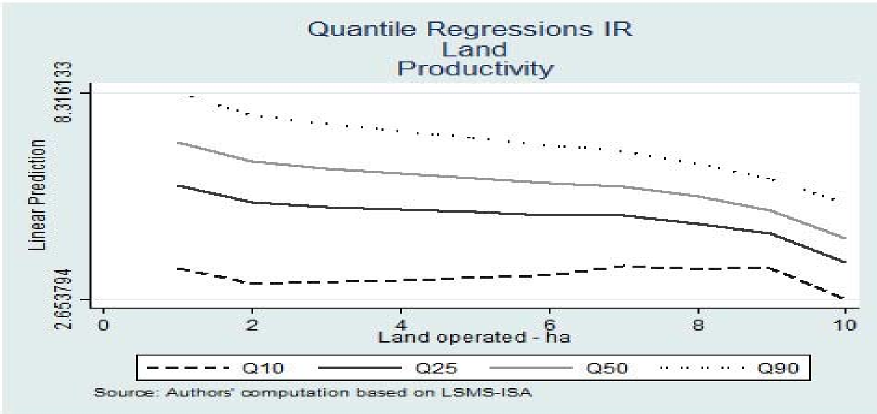
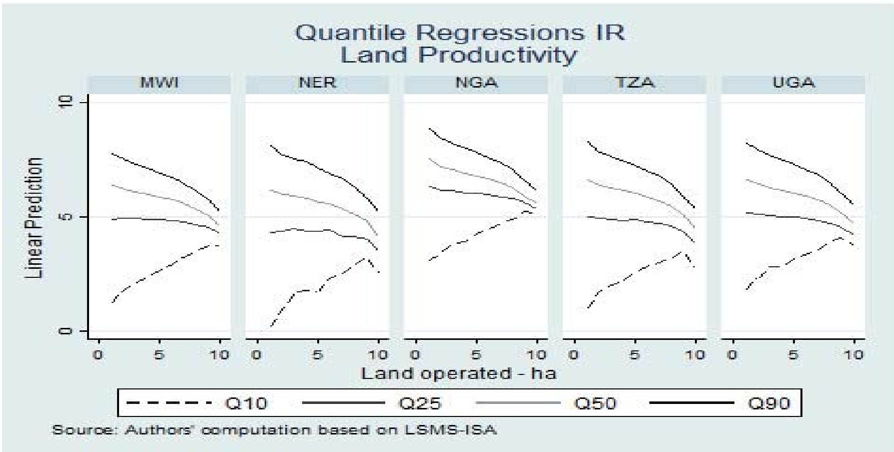


Figure 6



6. Conclusions

The inverse relationship (IR) between land productivity and land size has been the object of a voluminous literature , raising both objections and explanations. In this study, after a brief review of some of the main arguments, we have presented evidence from five recent farm surveys that in part rebut and in part confirm the existence of the relationship. The survey data used are from detailed household interviews and contain a number of accurate georeferenced information on farmers' location, distance from the markets, distance from the main road, and land quality. In order to test the IR hypothesis, we have used a specification entirely relying on exogenous variables and estimation procedures according to the quantile regression model.

The results of our analysis, show that for all countries, except Nigeria, and for the pooled sample, IR holds only for the top 6-7 quantiles of the productivity variable (the yield residual once we consider the effect of the exogenous variables), while for the bottom quantiles a positive relationship tends to hold. These results appear to hold across different specifications and both for the pooled sample and the individual countries. They suggest that at the two ends of the yield residual distribution, farmers' performance is influenced by land size in a markedly different way. As already noted, although in a different context by Evenson and Mwabu (1998), this may be due to the fact that individual management factors do matter and that in the two areas of the distribution, different complementary and substitute relations may exist between land sizes and unobserved human capital variables, such as farmers' abilities, skills and experience. In turn, these results are consistent with a revised version of Savastano and Scandizzo (2009) option model, where management quality is supposed to be positively correlated with farm size.

Our results also suggest the existence of a U shaped relationship between productivity and farm size. This relationship implies a turning point for the lower quantiles of the yield residual distribution at which a positive relationship becomes negative and one for the upper quantiles where IR becomes positive. Both turning points are for small to medium farm sizes, but the ones of the lower quantiles tend to be smaller than those for the upper quantiles. Thus, while there is some significant negative relationship between productivity and operating size for low performers over a relevant range of farm sizes, higher performers tend to display IR only over a range from small to medium farm sizes.

In sum, our results confirm that IR may be an ubiquitous relationship, as found in much of the literature, but indicate that its form, shape and importance may significantly differ across the spectrum of farm productivity performance. At the low end of the yield distribution, IR appears to prevail, once a minimum threshold of farm size is reached, while at the higher hand, IR only appears to be mainly a characteristic of farmers with operating sizes not exceeding medium size thresholds. The literature on transaction costs and the role of the firm suggests that these differences will require a deeper analysis of some of the critical factors determining the performance of the farm as a "productivity agent" and of the role played by management and capabilities in shaping farmers' choices.

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