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Is There a Farm-Size Productivity Relationship in African Agriculture?

Evidence from Rwanda

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Abstract

Whether the negative relationship between farm size and productivity that is confirmed in a large global literature holds in Africa is of considerable policy relevance. This paper revisits this issue and examines potential causes of the inverse productivity relationship in Rwanda, where policy makers consider land fragmentation and small farm sizes to be key bottlenecks for the growth of the agricultural sector. Nationwide plot-level data from Rwanda point toward a constant returns to scale crop production function and a strong negative relationship between farm size and output per hectare as well as intensity of labor use that is robust across specifications. The inverse relationship continues to hold if profits with family labor valued at shadow wages are used, but disappears if family labor is rather valued at village-level market wage rates. These findings imply that, in Rwanda, labor market imperfections, rather than other unobserved factors, seem to be a key reason for the inverse farm-size productivity relationship.

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Is there a farm-size productivity relationship in African agriculture? Evidence from Rwanda

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1. Introduction

A recurring finding in the literature on agricultural production has been the existence of an inverse relationship between the size of a farm's operated area and its productivity. The two most common explanations focus on either a failure to properly measure key factors such as land quality or area or application of more than the optimum amounts of certain inputs by small farmers, possibly as a result of imperfections in key factor markets including those for labor, land, and insurance. Studies find this relationship to weaken with technical progress and mechanization and to be less pronounced in Africa than in other regions.

With the recent re-emergence of interest in agriculture, the extent to which small farms use resources efficiently is particularly relevant for African countries that seek to modernize their agricultural sector and make the transition from a subsistence-based to a market-driven rural economy. If they do, policy should focus on attracting investment higher up in the value chain (e.g., in agro-processing) and link smallholders to relevant market channels, e.g., via out-grower schemes but rely on the high poverty elasticity of smallholder agriculture (Ligon and Sadoulet 2008) to support growth and poverty reduction (Larson *et al*. 2012). If not, a strategy that aims to leapfrog directly to large-scale farming (Collier and Venables 2011) and a regulatory environment that reduces the scope for further subdivision and aggressively promotes land consolidation may be more appropriate.

In Rwanda, Africa's most densely populated country, fragmentation and small farm sizes are considered a key issue by policy makers. The 2008 national agricultural household survey puts average holding size at 0.72 hectares per household (in four parcels with 0.18 hectares each on average) which with traditional technology will not generate enough revenue to allow the average household to meet subsistence needs (Republic of Rwanda 2009). To promote efficient and sustainable use of scarce land resources for agricultural development, the country put in place a three-pronged National Land Policy that (i) promotes land use planning to free up land for agricultural investors and non-agricultural development; (ii) aims to consolidate land to achieve 'economic' plot sizes; and (iii) prohibits any subdivision that would result in parcel sizes below one hectare. As such measures were not uncontroversial and proved to be difficult to implement in other settings, an empirical review of the underlying assumptions seems warranted.

Plot-level data, that allows controlling for household-specific heterogeneity, is used to analyze this issue and contribute to the literature in three respects. First, we explore the existence of an inverse relationship not only for output or gross revenue but also for profit per hectare with family labor valued at market wages or an imputed household-specific shadow wage rate. Second, to reduce the possibility of the relationship being driven by measurement error and unobserved plot characteristics, we control for a wide range of time-variant and -invariant characteristics including soil quality and unfavorable productivity shocks. Finally, as plot characteristics that prevent mechanization emerged as a key factor in overturning the relationship in India (Foster and Rosenzweig 2011), we conduct analysis both at plot and holding levels.

Descriptive statistics by tercile of the farm size distribution reveal three regularities. First, plot (and farm) size is inversely related to land quality, i.e., smaller farms and plots have higher land quality and are less likely to be affected by crop shocks. Second, differences in output per hectare and input use intensity across farm size classes are pronounced: output value for farms in the bottom tercile is, at US$ 860, almost three times that of those in the top tercile (US$ 298) with differences even more pronounced (from US$ 1,296 to 317) at plot level. But for profit/ha using actual input costs and valuing labor at market wages, the inverse relationship between size and productivity essentially disappears.

Econometric estimates allow us to infer the underlying production technology, control for other factors such as land quality, and compute household-specific shadow wages to obtain profits that more accurately reflect the opportunity cost of labor. Results suggest that (i) technology is characterized by constant returns to scale; (ii) even after controlling for land quality, yields, labor intensity and shadow profits per hectare are all much higher on small farms; and (iii) profit per hectare (with labor valued at market rates) is virtually identical across holding and plot sizes. Results thus point to labor market imperfections as a major reason for the inverse relationship between farm size and productivity, but suggest that, with existing market imperfections, small farms are able to absorb large amounts of labor in a gainful way.

As long as farmers' labor use responds to price signals, interventions (e.g., restrictions on sub-division or involuntary consolidation programs) may thus yield few benefits and could even be counter-productive. Efforts to reduce labor market imperfections and nonagricultural growth that leads to higher wages and nonagricultural employment opportunities pulling labor out of agriculture may be more effective tools to improve rural welfare than land market interventions.

The paper is organized as follows. Section 2 discusses the conceptual basis for a systematic relationship between farm size and productivity, the empirical evidence in support of this hypothesis, and the way in which it is likely to evolve in light of greater reliance on credit and mechanization. Section 3 presents data and descriptive evidence at the household and plot levels and draws out implications for the estimation strategy. Results from production functions and regressions to explore how gross output and profits vary with farm size under different assumptions regarding labor market functioning are discussed in section 4. Section 5 concludes by drawing out implications for policy and research.

2. Conceptual background

To frame the analysis, we discuss the conceptual basis, empirical evidence, and likely evolution of the farm-size-productivity relationship over time. While one set of explanations focused on unobserved land quality differentials, an alternative one focuses on labor market imperfections that make small producers either apply more effort than larger ones or more than the optimum amount of family labor. Credit market imperfections and constraints to mechanization imposed by plot sizes below a certain size may counter this, providing advantages to large producers that may weaken the relationship as access to mechanization becomes more important, especially if labor market functioning improves.

2.1 Explanations and evolution of the farm size-productivity relationship

A negative relationship between farm size and output per hectare, first noted in Russia (Chayanov 1926) and in Indian farm management studies (Bardhan 1973, Sen 1975, Srinivasan 1972), has been confirmed empirically so frequently as to almost be perceived as a stylized fact in the literature (Eastwood *et al.* 2010, Lipton 2009). Analytically, many studies find agricultural production to be characterized by constant economies of scale, implying that a wide range of farm sizes can coexist. As residual claimants to profit, owner-operators will be more likely to exert effort than wage workers who require supervision which, in light of the spatial dispersion of agricultural production processes, is costly (Frisvold 1994). Owner operators’ knowledge of local soil and climatic conditions, often accumulated over generations, also gives them an edge over wage workers (Rosenzweig and Wolpin 1985).

Under constant returns to scale and with well-functioning factor markets or imperfections in one market only, output and intensity of input use will be identical across farm sizes. Imperfections in more than one factor market will lead to a systematic relationship between the size of cultivated area, inputs, and yields (Feder 1985). Small farmers’ advantages in labor supervision, knowledge, and organizational advantages can be offset by their difficulty in accessing capital and insurance which arises from the high transaction cost of providing formal credit in rural markets, possibly exacerbated by the difficulty of using small farmers’ assets as collateral. Frictions in labor market participation and land markets, e.g., due to transaction costs, could motivate small farmers who are unable to rent additional land to rationally apply family labor to cultivate their fixed land endowment more intensively than they would with perfect markets. An inverse relationship can also emerge if labor and credit markets imperfections are combined with a fixed cost element for production (Eswaran and Kotwal 1986) or if there is heterogeneity in farmers' skills in the presence of credit market imperfections (Assuncao and Ghatak 2003). Land and insurance market imperfections can prompt small farmers who are net buyers of food to use family labor more intensively in an attempt to reduce potentially adverse effects of price fluctuations (Barrett 1996). The lumpiness of certain inputs (e.g., machinery, draft animals and management skills) plus advantages in getting access to working capital or their capacity to diffuse risk may in practice lead the relationship between farm size and productivity to be U-shaped (Heltberg 1998). Thus, with few exceptions,[1] agricultural production in practice thus relies on owner-operated firms (Allen and Lueck 1998, Deininger and Feder 2001).[2]

Empirically, it has long been noted that part of the reason for cross sectional evidence supporting an inverse farm size-productivity relationship (Berry and Cline 1979, Cornia 1985) is likely to have been the failure to fully capture land quality (Bhalla and Roy 1988, Chen *et al.* 2011). However, this relationship appears to be robust to inclusion of broad soil quality measures in cross-sectional estimates, more sophisticated panel data estimation techniques (Assuncao and Braido 2007, Benjamin 1995), and inclusion of a wide array of soil characteristics such as pH, carbon, clay, and sand content (Barrett *et al.* 2010). Measurement error for land size may also explain part of the relationship (Lamb 2003), and use of GPS, though not without challenges, suggests that indeed farmers' area estimates may be biased (Carletto *et al.* 2011). It has also been argued that a proper measures of efficiency should be based on profits rather than gross output (Binswanger *et al.* 1995). In post-green revolution India, use of profits has either weakened the relationship (Rosenzweig and Binswanger 1993) or made it disappear entirely (Carter 1984, Lamb 2003).

The empirical literature also suggests that rising nonagricultural wages and new technology will affect factor price ratios, supervision requirements, and the presence and extent of market imperfections that might have led to an inverse relationship in the first place. The earliest example of this is in India where the green revolution increased the importance of knowledge and capital, weakening the size-productivity relationship in predictable ways: large farmers emerged as more productive in districts suited to new technology while small farms continued to be most efficient where traditional methods prevailed (Deolalikar 1981). More recently, continued subdivision in the context of generational change and the limits on the scope for mechanization by small plot sizes may have contributed to a reversal of the inverse relationship so that, with land market imperfections preventing consolidation, leading to some farms (or more precisely plots) becoming too small for efficient cultivation (Foster and Rosenzweig 2010). In fact, for rice farms in

[1] A well-known exception to the advantages of owner-operated units of production over those relying on wage labor is in perishable plantation crops, where economies of scale in processing may be transmitted to the production stage (Binswanger and Rosenzweig 1986) and employment is often year-round so that the optimum size of a unit is determined by the factory's processing capacity.

[2] As of end 2009, only seven publicly listed farming companies existed worldwide, 3 in South America and 4 Ukraine and Russia (Deininger *et al.* 2011). This contrasts with processing, input industries, and sometimes output markets, all of which are characterized by large fixed costs (e.g., for R&D or processing) that give rise to economies of scale and often a highly concentrated industry structure (Deininger and Byerlee 2012a).

Japan, where factor markets work relatively well, a strongly positive relationship between farm size and productivity has been found (Kawasaki 2010). Recent innovations in crop breeding, tillage, and information technology also make it easier to supervise labor, thus tending to attenuate or eliminate large operations' disadvantages[3] in a way that may have altered or even reversed the traditional farm size-productivity relation in Eastern Europe and South America (Helfand and Levine 2004, Lissitsa and Odening 2005).

2.2 Implications for Rwanda

Whether small farms make efficient use of the resources at their disposal is particularly relevant for African countries aiming to modernize their agricultural sector and make the transition from subsistence-based to a market-driven rural economy. A belief in large holdings' superior performance led influential observers to urge policy-makers to abandon 'smallholder romanticism' and aim to leapfrog to 'efficient' large scale farming based on industrial methods (Collier and Venables 2011). Others claim that, once conditions are accounted for, small farmers remain the most efficient (Larson *et al.* 2012) so that a strategy based on the traditionally high poverty elasticity of smallholder agriculture (Ligon and Sadoulet 2008), possibly supported by investment further up the value chain, will be appropriate.

Empirical evidence from Africa on this issue remains ambiguous, partly due to vast variation of relative land scarcity, capital access, and mechanization across countries. If investment is important and poor farmers' access to finance and insurance constrained, difficulties in accessing financial markets may lead to a positive relationship between farm size and productivity as in Sudan (Kevane 1996). In Kenya, profits per acre were also found to increase monotonically with farm size while the relationship between output per acre and size was U-shaped with a minimum at about 5 ha, a finding partly attributed to crop composition changing across farm sizes (Carter and Wiebe 1990). Detailed grouped farm survey data for Malawi in the 1980s point towards a significant positive relationship between farm size and output per hectare, apparently driven by constrained capital access (Dorward 1999). A positive relationship between output per hectare and farm size also was found in Zambia, although it becomes U-shaped if endogeneity of plot size is considered (Kimhi 2006).

By contrast, in situations with little mechanization, a strong negative relationship between output and farm size is often found even after adjusting for other factors. For example, in Malagasy rice farms, inclusion of household fixed effects and controls for soil nutrients that are generally not observable does

[3] Pest-resistant and herbicide-tolerant varieties facilitated broad adoption of zero tillage and, by reducing the number of steps in the production process and the labor intensity of cultivation, allowed management of larger areas. The ability to have machinery operations guided by GPS technology rather than driver's skills makes close supervision of labor less relevant while information technology can generate data to help better supervise labor. The scope for substituting crop and pest models and remotely sensed information on field conditions for personal observation also reduces the advantage of local knowledge and experience in tactical farm decisions while climate change and the associated greater variability of climatic conditions reduces the value of traditional knowledge (Deininger and Byerlee 2012b).

not reduce the negative relationship (Barrett *et al.* 2010). Similarly, data from Rwanda in the 1990s point towards higher intensity of labor use by small farmers who farm land more intensively, e.g., by reducing fallowing, but also invest more in soil conservation (Byiringiro and Reardon 1996). Farm household survey data from four counties (Malawi, Tanzania, Kenya, Uganda) also point towards a negative relationship between farm size and output (Larson *et al.* 2012).

Detailed empirical study of productivity by farm size will be of relevance for Rwanda where efforts to promote agricultural development prompted adoption of policies to encourage consolidation and prohibit subdivision of plots almost entirely.[4] Such efforts have been controversial and difficult to implement even in countries with higher levels of per capita income. Consolidation efforts in Eastern Europe have a mixed record, partly because they failed to address key institutional factors (Deininger *et al.* 2012). In Mexico, subdivision restrictions had little impact on the ground and merely drove farmers into informality (World Bank 2002). They could thus easily undermine the sustainability of Rwanda's recent, and in many respects exemplary (Ali *et al.* 2011), effort to demarcate and register all of the country's 10.3 million land plots.

3. Data, descriptive statistics, and econometric approach

Detailed plot-level data from Rwanda allow us to explore determinants of agricultural production and the presence of a farm size-productivity relationship using output as well as measures of profit consistent with types of labor market imperfections at holding and plot level. Descriptive data and graphs point towards large differences in intensity of input use and gross value of output across farm sizes, in line with the notion of small producers using inputs more productively. This relationship disappears if profits that value family labor at market wages are considered.

3.1 Data

We use data from a 2010/11 survey of 3,600 rural households in 300 randomly selected villages of Rwanda to provide evidence on the relationship between farm size, and output and profit per unit of cultivated land. The main purpose of the survey, conducted by the World Bank with support from DFID and IGC, was as a baseline to assess impacts of a program of land tenure regularization (LTR). A three-stage stratified cluster sampling strategy was adopted to select study villages from a complete list of enumeration areas provided by the National Institute of Statistics of Rwanda (NISR). First, 100 sectors nationwide (4 in each of the 25 districts) were randomly selected from all sectors that are above the

[4] Article 20 of the Organic Land Law prohibits subdivision of agricultural plots of less than one hectare and requires administrative approval for subdivision of plots below 5 ha. As per our data, 97.9% of plots are below 1 ha and 99.9% below 5 ha, so that virtually everybody is affected.

lowest administrative units (cells) with a coordinating role in the delivery of public services.[5] Three enumeration areas were selected randomly from each sector and 12 households were then chosen randomly per enumeration area. The distribution of the sample, together with the boundaries of the country's main regions, is illustrated in figure 1. In addition to land characteristics, detailed information was collected on inputs and outputs to compute revenue and profit at plot level and on households' demographics, resource endowments, and participation in land, credit and other markets.

Plot-level data on labor and non-labor inputs and output from crop production are for the March-August 2010 agricultural season. Plot size measures are based on owner's estimates.[6] Appendix figures 1 and 2 illustrate that Rwandan farms are, with a mean of 0.37 ha (or a median of 0.17 ha) and a maximum of about 2 ha, small by global standards with most plots smaller than 0.25 ha. To control for unobserved plot-level heterogeneity, we use subjective information on plot characteristics including soil type and topography as well as self-reported land values. After dropping plots that were either temporarily left fallow or lacked information, we are left with a sample of 7,477 plots in 3,080 households.[7] Furthermore, to prevent them from confounding our analysis, we exclude some 15% of rented plots from the analysis.[8]

Household-level descriptive statistics displayed in table 1 point towards clear differences between successive terciles of cultivated area the significance of which, measured by a simple t-tests, is indicated by stars. With 0.37 ha on average, own cultivated area ranges between 0.05 ha for the bottom and 0.88 ha for the top tercile.[9] Owing to the 1994 genocide, the incidence of female headship is high, at 27%. Female headed households are more prevalent in the South (32%) and more likely to cultivate smaller areas; some 33% of those in the bottom but only 20% in the top tercile are female headed. Smaller farmers have lower secondary education and family labor endowments and are somewhat younger than large ones, possibly due to accumulation over the life-cycle. Variations in crop mix by size are less pronounced though large farms have slightly less land under grain or vegetables and more under tubers or tress.

Structural similarities notwithstanding, variable input use varies markedly across farm size groups. With about 450 days/ha, labor input is well above that of neighboring countries (Larson *et al.* 2012).[10] Labor intensity varies significantly with farm size: small farmers use almost four times as much own labor per

[5] Areas where the regularization program had already started by the time of data collection were dropped from the frame, implying that Kirehe district in Eastern Province and Rubavu district in Western Province, as well as Kigali city were excluded.
[6] While this may lead to some measurement error (Lamb 2003), measurement by GPS was not an option in light of the small plot sizes which, with standard GPS receivers' limited precision, could have been measured only with large errors (Carletto *et al.* 2011). GPS readings were taken for each plot's centroid and the cultivator's residence to provide information on plots' location relative to each other and the homestead.
[7] Plots were dropped because of unspecified response for crop type (3%), missing quantity of output, lack of prices or conversion factors for nonstandard units (4%), or because they were left temporarily fallow (4%) in the season under consideration.
[8] The fact that they are operated under cash rent reduces the risk of confounding size- and tenancy-related factors and substantive conclusions for the sample including these plots are indeed are almost identical as can be verified from results for the expanded sample in the separate supplementary appendix.
[9] As shown in the supplementary appendix table 1, there is little variation across farm size groups in the extent of land rental market participation: on average nearly 31% of the households rented in land during the season under consideration.
[10] Average amounts of labor used on maize plots are about 310, 157, 116, and 106 d/ha in Malawi, Tanzania, Kenya, and Uganda, respectively.

hectare than large ones (765 vs. 207 days/ha). By comparison, cross-group differences in hired labor shares are marginal with less than 10% of total labor demand covered by hiring labor (although large farmers are three times more likely to use any hired labor than small ones). With 16% and 9% (22% and 12% in the top and 12% and 7% the bottom tercile), respectively, use of fertilizer and pesticide remains low. Regional disaggregation in columns 5-8 points towards inter-regional differences in input use; while some 82% apply manure in the North and West, only 52% do so in the East. Similar differences emerge for fertilizer (25% and 22% in North and West vs. 7% in the East) and pesticide (14% and 10% vs. 5%) use. With US$ 550 on average, the value of output per hectare varies enormously across farm size classes with US$ 860, 492, and 298 for the bottom, middle, and top farm size tercile, respectively.

As finding an inverse relationship between farm size and output per hectare may be due to failure to properly account for inputs, especially own labor, we complement the above with an analysis of profit (or gross revenue) per hectare by subtracting the value of purchased inputs and hired labor.[11] Family labor is treated in three ways, namely (i) not accounted for (equivalent to assuming missing labor markets); (ii) valued at a household-specific shadow wage rate as discussed below in 3.2 (equivalent to labor market access varying by household, e.g., due to transaction costs); and (iii) valued at the mean village wage rate (assuming perfectly competitive labor markets). Table 1 illustrates that the negative farm size relationship is robust to the first two but that the measure of net profit obtained by valuing family labor at village wage rates shows little variation across farm sizes. It also suggests that marginal products of labor, computed as in Jacoby (1993) from regression estimates of a Cobb-Douglas production function, differ significantly across farm size groups with rates for the first and second terciles less than half and about three-fifth of the rate in the top tercile, which is not statistically different from the market rate. Assumptions regarding the nature of labor market imperfections and the resulting valuation of family labor will thus affect the nature of the relationship between farm size and output.

Kernel-weighted nonparametric regressions for the logarithms of crop output value against holding or plot size in figure 2 and labor use in figure 3 illustrate this descriptively. They point to a pronounced decrease in yield from some 1,100 to less than 100 US$/ha and labor use intensity (from close to 2,000 to 45 days/ha) with both holding- and plot-size, similar to estimates found elsewhere (eg Assuncao and Braido 2007). Figures 4 and 5, based on profit computed at plot and holding level using shadow and market wages, respectively, show how different ways of valuing family labor can change this: shadow profit (the dashed lines) still declines monotonically with farm size except for extremely small holding sizes (less

[11] In the absence of farm-gate price information and limited transactions at the village level, median unit sales value of each crop at the national level is used to estimate value of crop output. Note in particular that, as the average household cultivates more than two plots, we can estimate plot level regressions that control for unobserved heterogeneity at household-level.

than 0.007 ha) where the relationship is very imprecisely estimated.[12] By contrast, profit net of family labor valued at market prices (the solid lines) remains virtually constant for all plot/holding sizes above 0.02 ha. If supported by parametric results, this would suggest no benefits from policies to promote consolidation. Gains from measures to prevent subdivision, if existent, would be of small size magnitude and at most affect the very smallest plots (note that 25.8% of plots are below 0.02 ha).

Plot level data in table 2 suggest that small plots are of higher quality (16% in the bottom vs. 8% in the top tercile are wetland and 8% vs. 3% in a valley), a conclusion supported by higher self-assessed land values of US$ 19,070 per hectare for the bottom vs. US$ 8,387 in the top plot size tercile.[13] The relationship between farm size, yield, and gross and shadow profits per hectare remains similar to what was found earlier, i.e., a negative relationship between plot-size and output value that disappears once net profit valuing family labor at market wages is considered.

3.2 Econometric approach

To make inferences on scale of production and technical efficiency across farm size classes and appreciate households' patterns of resource allocation to crop production, we estimate Cobb-Douglas and translog production functions at holding- and plot-levels. The general form of the translog production function with no restrictions on cross elasticities of substitution is (Berndt and Christensen 1973) [14]

$$Y_{ij} = \alpha_i + \sum_k \beta_k X_{ijk} + \frac{1}{2}\sum_k \sum_l \gamma_{kl} X_{ijk} X_{ijl} + \delta' Z_{ij} + \epsilon_{ij} \tag{1}$$

where Y_{ij} is the total value of crop output (in logarithms) on plot j cultivated by household i; α_i is a vector of household fixed effects; X_{ijk} or X_{ijl} are the logarithm of the quantities of variable inputs used (subscripts k and l stand for types of inputs including the number of labor days, quantity of chemical fertilizer, pesticides and manure used); Z_{ij} is a vector of plot characteristics that may affect production, e.g., distance from homestead, years of possession, presence of irrigation or being located in wetland, soil type, topography, and incidence of crop shocks; β, γ, and δ are vectors/matrix of parameters to be estimated; and ϵ_{ij} a random error term. Fixed effects, α_i, at plot or (for household-level regressions) village level include time invariant unobserved factors affecting crop production at the relevant level. Computing the difference between village-level fixed effects and α_i will provide a measure of farmers' ability or technical efficiency (Deininger and Jin 2008).

Value of crop output and all inputs are normalized by dividing them by their sample means. In the empirical estimation, we also include dummies for zero values of non-labor variable inputs (Battese 1997). Given

[12] Note that, in light of the paucity of observations, these are not very precisely estimated.

[13] Note that these values are very high by international standards, reflecting partly the lack of alternative assets.

[14] We present the plot-level specification, noting that it is straightforward to translate this to the holding level where j would index households in village i, and plot-level variables are aggregated at household level using plot size as a weight, and α_i is a village-level fixed effect.

symmetry conditions on all cross elasticities (i.e., $\gamma_{kl} = \gamma_{lk}$), the translog function is homogenous if $\sum_k \gamma_{kl} = 0$ for all l and it will have constant returns to scale if $\sum_k \beta_k = 1$. All these restrictions can be tested empirically. Shadow wage rates, i.e., marginal products of different types of family labor, can be calculated by estimating the Cobb-Douglas version of (1) at holding level with family labor disaggregated by gender (Jacoby 1993).[15]

To examine the relationship between productivity and farm size at plot or holding level, we estimate an aggregate yield equation following the literature (Assuncao and Braido 2007, Barrett *et al.* 2010).[16] The full plot-level specification takes the form:

$$y_{ij} = \alpha_i + \beta A_{ij} + \delta' Z_{ij} + \epsilon_{ij} \tag{2}$$

where y_{ij} is the logarithm of the value of crop output per hectare or different profit measures as discussed above on plot j by household i; α_i is a household fixed effect A_{ij} is the logarithm of plot area; Z_{ij} is a vector of plot characteristics that includes subjective land quality measures (soil type, topography, irrigation) and self-reported land values as well as crop dummies and an indicator variable for having experienced plot-specific crop shocks; β and δ are parameters to be estimated and ϵ_{ij} is a random error term. We first estimate a naïve specification that omits Z_{ij} and α_i and then control for soil quality and possible market imperfections at village- or household-level. The rationale for doing so is simple: if, as much of the literature seems to suggest, soil quality or market imperfections at household- or village-level are the driving forces for the negative relationship between farm size and productivity, β would be significant in the naïve specification but lose significance once additional elements are introduced and δ as well as α_i will be significant.

As more intensive use of labor on small holdings or plots was found to not only be a potential reason for the inverse relationship between output and size but also to result in the opposite relationship for profits (Carter 1984), we run (2) not only for yields and profits but also labor demand. We use the log of family days per hectare as a dependent variable at plot- and holding-levels to do so.

4. Econometric evidence

Various production function specifications support the notion of constant returns to scale at holding level, a negative relationship between cultivated area and total value of crop output, and a strong positive link between farm size and labor used per hectare. Estimated shadow wages are in line with households' level of market integration. While profits computed using shadow wages remain negatively related to farm size, the negative relationship disappears if a measure of profit that values family labor at mean wages is used.

[15] Note that they could, in principle, be estimated using the translog specification as well. However, as violations of positive and diminishing marginal returns are common concerns in more flexible functional forms (Jacoby 1993), we restrict the analysis to the Cobb-Douglas specification only.
[16] At the holding-level, plot characteristics are aggregated using plot size weights and village fixed effects are used.

Small farmers' superior levels of output can thus be attributed to higher intensity of (family) labor, consistent with the notion that they maximize profits in the presence of market imperfections.

4.1 Production function estimates

The top panel of table 3 reports parameter estimates from the Cobb-Douglas and translog specifications at household (columns 1-3) and plot (columns 4 and 5) level, respectively. We note that all conventional factors are significant and positive with elasticities of 0.31for land, 0.41 for labor, 0.9 or 0.14 for fertilizer, 0.05 or 0.10 for pesticides, and 0.12 for manure at holding level. We cannot reject constant returns to scale at holding level though there is some indication of increasing returns to scale (at 5% or 10% level of significance for translog and Cobb-Douglas functional forms, respectively) at plot level. Crop shocks (drought, flooding, damage due to pests or insects), are estimated to reduce output by 21 percentage points, and soil type with loam soils increasing output by some 20 points. Plot level regressions also point towards a negative impact of distance from the homestead; one minute of additional travel time estimated to reduce output by about 0.4 percentage points.

Estimates of technical efficiency from a stochastic frontier production function, plotted against holding size in appendix figure 3 together with a kernel-weighted local polynomial regression fitted through them, fail to support a systematic relationship between efficiency and size.[17] Also, household- and village-fixed effects from plot level regressions can be used to recover a measure of farmers' ability as the difference between household- and village-level fixed effects. Plotting this variable and the regression fitted through it against cultivated area in appendix figure 4 points in the same direction.

Marginal products of male and female family labor together with market wages are displayed in the bottom of table 3. To check the plausibility of the results, appendix figures 5 and 6 plot mean values and 95% confidence intervals of estimated shadow wages for male and female casual and semi-skilled labor against four employment regimes, namely those who are (i) fully autarkic in labor markets; (ii) only work off-farm but do not hire in any labor; (iii) work in off-farm employment and hire in labor; and (iv) only employ others but do not work off-farm.[18] In all cases, and irrespective of gender, shadow wages for households who do not hire in (i.e., remain in autarky or hire out family labor for casual work) are significantly below those for households who hired in agricultural labor. Shadow wage rates for those employing workers are in most cases indistinguishable from the village wage rate. For semi-skilled off-farm work, the situation is similar except that estimated shadow wage rates for households who at the same time hire in and out labor are estimated to be above those for households working only on their own

[17] Results from estimating the stochastic frontier production function with a truncated normal non-negative distribution component are available upon request from the authors.

[18] For casual labor markets, 30% of sample households remained in autarky; 31% only hired out family labor; 8% hired out family labor and employed hired labor on-farm; and 31% only hired labor for farming. For semi-skilled labor, 56% remained in autarky, 5% only hired out family labor, 7% hired out and hired in agricultural labor, and 32% only hired in.

farm (appendix figure 6). This points towards labor market imperfections and considerable seasonality of labor markets in rural Rwanda that would be worth exploring in more detail than is possible with our data.

4.2 Evidence on the farm size-productivity relationship

Tables 4-7 report results from the regressions to explore the relationship between farm size and productivity in terms of yields (table 4), labor use (table 5), shadow profits (table 6), and profits at market prices (table 7) at holding and plot levels. In all cases, we start with a naïve specification that includes only cropped area (columns 1 and 4 at holding and plot-level, respectively) and successively add variables to control for soil quality (type, topography, location in a wetland or presence of irrigation, self-reported land value, length of possession, distance to homestead and incidence of plot-level crop shocks). Village fixed effects are then added from columns 2 and 5, information crop choice and household demography in columns 3 and 6, and plot level fixed effects in column 7.

Results from naive regressions as reported in table 4 point towards a strong negative relationship between the value of output per hectare and own cultivated area with a doubling in cultivated area associated with a 38% or 48% decrease in the value of crop output per unit of cultivated land at the holding- or plot-level, respectively. Other attributes such as per hectare value of land, distance from the homestead, soil type (loam), and having experienced a crop shock all have the expected signs, are highly statistically significant and their inclusion improves the explanatory power of the regression (columns 2 and 5). Still, the magnitude of the estimated farm size productivity relationship is hardly affected. This suggests that, despite descriptive variation in plot attributes with size as suggested by table 2, land quality and village level market imperfections are not at the root of the regularity. Including crop dummies (all negative compared to the base category of vegetables) and observed household characteristics such as head's age and education or female headship provides interesting insights, e.g., by suggesting that females may face difficulties in factor market participation, but yields essentially similar conclusions. Household fixed effects to control for unobserved heterogeneity, including household-specific factor market imperfections that may affect the inverse relationship, do not alter the inverse relationship between plot size and output either and results are not due to the fact that we restrict attention to owned plots.[19]

Table 5 presents results from the equivalent regression for labor demand suggesting that use of labor per area declines steeply, with an estimated elasticity of about -0.45 in a household's cultivated area (columns 1-3) and -0.58 in plot size (columns 4-7). Use of labor is also estimated to increase with land quality as proxied by self-assessed land values and a plot being wetland and to be higher for plots closer to the homestead. The high significance of coefficients on household composition (members 35-60 and less than 14 years old) and demography (female headship) suggest some frictions in labor markets.

[19] The supplementary appendix shows that very similar results are obtained if all plots are included in the analysis.

If, as suggested by the above results, part of the superior output achieved by small farms (or on small plots) can be attributed to more intensive labor use, use of profit measures may result in a weaker, possibly even reversed, relationship. In light of this, table 6 reports estimates of the relationship between farm size and per hectare shadow profit net of purchased inputs and male and female family labor valued at their estimated marginal products. These estimates indicate that smaller farms are significantly more profitable; the magnitude of the (negative) per hectare profit elasticity of land size is broadly equal to that obtained for per hectare value of crop output. An inverse relationship between shadow profit and farm size emerges robustly at holding and plot level, and is unaffected by inclusion of plot characteristics or village and household specific fixed effects.

However, results change if family labor is valued at village market wage rates rather than the estimated marginal products of labor. With the exception of a marginally significant (negative) coefficient in the naïve specification, all coefficients at holding level are insignificant and profit at market prices increases with self-assessed land values and soil quality (loam) while decreasing with incidence of crop shocks. At the plot level, cropped area becomes positive and highly significant when controlling for plot characteristics although this significance disappears if household fixed effects are included (column 7). To explore if our specification may suppress heterogeneity in the data (e.g., an initial portion where profits increase with size), we re-estimate the appropriate regressions allowing for differences in the size of the coefficients across terciles (table 8). While results suggest differences between size groups in terms of yield (with the relationship being less negative for the first tercile in terms of cropped area and the second tercile in terms of plot size) and shadow profit, the hypothesis of any differences for net profits at market prices is rejected.

Taken together, these findings imply that, although yield and shadow profits decrease significantly with farm or plot size, there is no need to resort to unobserved differences in land quality or measurement error to explain these. To the contrary, the fact that profits where family labor is valued at village level wages are virtually unaffected by plot or farm size points towards imperfections in the operation of Rwanda's rural labor markets as the main reason for the inverse relationship between farm size and gross output. As a result, Rwanda's small farms use labor beyond the point where its marginal product equals the market wage. This would suggest that, as wages increase, farm sizes will adjust along the patterns observed in other countries, land market interventions are unlikely to have the desired effect.

5. Conclusion and policy implications

Heightened interest in African agriculture led to a debate on the extent to which the negative relationship between farm size and productivity documented in a large body of literature is relevant for Africa, with implications for countries' strategy in trying to increase sectoral productivity. We find a robust negative relationship between farm size and per hectare gross output and shadow profit that does not disappear if plot characteristics or household attributes are controlled for. More intensive labor use by smaller farms is a key underlying reason. In fact, the relationship disappears (but does not reverse) if profit at market prices rather than output or shadow profit is considered.

Rwandan farmers' behavior seems in line with a scenario of labor market imperfection together with failures in other factor markets. Although non-agricultural development and investment higher up in the value chain may, in due course, lead to higher wages that would trigger farm-size growth through market-driven consolidation, the data fail to support administrative measures to prevent subdivision of holdings. The fact that results at plot level are essentially identical and allow us to reject the notion of a positive relationship between plot size and net profits at market prices even for the smallest size group, reinforces this conclusion. In terms of policy, it suggests that enforcing existing subdivision restrictions will at best yield insignificant benefits and, by forcing land transactions into informality and jeopardizing the sustainability of the country's land regularization effort, could have high costs.

Given the importance of factor market imperfections emerging from our analysis, in-depth analysis of key factor markets and their interactions will be desirable. However, our failure to find efficiency gains from larger holding or plot sizes even for Rwanda's very small plot sizes cautions against sweeping generalizations in terms of the most appropriate policies for African agriculture to develop. Instead it reinforces the need for policy recommendations to be based on careful analysis. Exploring whether similar results obtain in more land-abundant African countries where mechanization and capital access will be more relevant would be of great interest not only to understand the role of imperfections in other markets, but also the dynamics of farmers' adaptation to nonagricultural economic development.

Table 1: Descriptive Statistics at Household Level

	Total	Small	Medium		Large		East	North	South	West
Area cultivated & output										
Yield per hectare (US$)	550.619	860.385	492.301	***	298.169	***	521.455	568.117	543.218	573.325
Gross profit (US$/ha)	481.321	766.014	431.390	***	245.605	***	455.745	476.319	499.886	488.057
Net shadow profit (US$/ha)	379.297	604.028	344.521	***	188.544	***	374.842	375.905	382.191	383.173
Net profit (US$/ha)	125.392	136.673	135.245		104.117		83.183	152.326	102.305	172.338
Total cultivated area	0.367	0.048	0.180	***	0.878	***	0.416	0.307	0.357	0.385
Input use										
Family labor days/ha	452.448	765.211	383.676	***	207.532	***	444.476	427.706	474.214	455.307
Hired labor (share)	0.391	0.215	0.384	***	0.574	***	0.420	0.429	0.322	0.414
Hired labor days/ha	52.681	65.221	46.498	**	46.319		55.394	60.154	34.854	65.634
Used chem. fertilizer (share)	0.148	0.095	0.142	***	0.206	***	0.043	0.234	0.119	0.210
if yes, amount (kg/ha)	16.951	24.557	15.007	*	11.252		5.062	23.253	7.813	34.683
Used pesticides (share)	0.078	0.045	0.086	***	0.102		0.032	0.128	0.067	0.092
If yes, amount (US$/ha)	1.932	2.741	2.260		0.788	***	1.929	2.753	0.919	2.470
Used manure (share)	0.731	0.639	0.754	***	0.799	**	0.525	0.826	0.773	0.796
Marginal products[a]										
Male family labor (US$)	0.666	0.429	0.568	***	0.947	***				
Female family labor (US$)	0.539	0.360	0.477	***	0.783	***				
Area shares										
Land with grain	0.497	0.522	0.497	*	0.471	*	0.564	0.600	0.449	0.397
Land with tubers	0.243	0.220	0.250	**	0.258		0.163	0.221	0.269	0.310
Land with tree crops	0.251	0.245	0.242		0.266	**	0.264	0.167	0.272	0.285
Share of vegetable land	0.010	0.012	0.011		0.006	**	0.009	0.012	0.010	0.008
Household characteristics										
Age of head	46.557	44.286	46.672	***	48.718	***	45.420	45.234	48.965	45.860
Female head	0.274	0.329	0.291	*	0.202	***	0.254	0.264	0.328	0.236
Primary school completed	0.576	0.570	0.570		0.588		0.601	0.562	0.568	0.574
Secondary education	0.067	0.054	0.057		0.091	***	0.076	0.060	0.064	0.069
Number of members<=14	2.150	1.975	2.113	**	2.362	***	2.236	2.063	2.047	2.270
No of members 15- 35	1.588	1.414	1.585	***	1.767	***	1.537	1.686	1.563	1.584
No of members 35- 60	0.861	0.670	0.855	***	1.059	***	0.881	0.791	0.917	0.833
No members >=60	0.245	0.212	0.231		0.293	**	0.193	0.236	0.288	0.252
Number of observations	3080	1027	1031		1022		741	666	931	742

Source: Own computation from 2010/11 LTR baseline survey.
Note: Stars indicated significance levels for t-tests of the equality of means for each of the variables between terciles (* significant at 10%; ** significant at 5%; *** significant at 1%). Two outliers with inexplicably high levels of fertilizer use are dropped from the largest tercile.
[a] Marginal products of male and female family labor (shadow wages) are calculated using the formula given in the note at the bottom of table 3.

Table 2: Descriptive Statistics at Plot Level

	Total	Small	Medium		Large	
Area cultivated & output						
Yield per hectare (US$)	757.747	1295.723	584.358	***	316.295	***
Gross profit (US$/ha)	647.898	1113.093	498.044	***	266.083	***
Net shadow profit (US$/ha)	469.367	773.625	385.509	***	221.732	***
Net profit (US$/ha)	132.757	107.632	175.483	*	115.207	***
Plot size	0.152	0.016	0.061	***	0.410	***
Land value US$/ha	13361	19070	11784	***	8387	***
Input use						
Labor days/ha	678.171	1301.356	433.852	***	214.708	***
Used chem. fertilizer (share)	0.096	0.086	0.089		0.116	***
if yes, amount (kg/ha)	121.609	56.176	217.851		92.470	
Used pesticides (share)	0.050	0.045	0.046		0.060	**
if yes, amount (US$/ha)	3.239	5.592	2.696	***	1.070	***
Used manure (share)	0.593	0.537	0.603	***	0.650	***
Area shares						
Share with grains	0.486	0.478	0.502	*	0.478	**
Share with tubers	0.285	0.328	0.267	***	0.255	
Share with trees	0.217	0.179	0.220	***	0.260	***
Share with vegetables	0.012	0.016	0.012		0.007	**
Plot characteristics						
No. of years possessed	18.277	15.996	18.439	***	20.780	***
Affected by crop shock	0.298	0.229	0.309		0.367	
Wetland	0.117	0.157	0.112	***	0.076	***
Irrigated land	0.058	0.069	0.056	*	0.046	
Flat land	0.279	0.307	0.271	***	0.253	
Gently slopped land	0.248	0.230	0.256	**	0.261	
Plot located in a valley	0.053	0.079	0.052	***	0.025	***
Sand soil	0.159	0.171	0.146	**	0.160	
Loam soil	0.367	0.359	0.382	*	0.359	
Light clay soil	0.140	0.145	0.137		0.137	
Heavy clay soil	0.032	0.038	0.030		0.026	
Gravelly soil	0.133	0.122	0.129		0.150	**
Number of observations	7477	2682	2514		2281	

Source: Own computation from 2010/11 LTR baseline survey.

Note: Input use is reported only for those who applied positive amounts. Stars indicated significance levels for t-tests of the equality of means for each of the variables between terciles (* significant at 10%; ** significant at 5%; *** significant at 1%).

Table 3: Parameter Estimates and Output Elasticities for Alternative Specifications of the Production Function

	Holding level			Plot level	
	Translog	**Cobb-Douglas**		**Translog**	**Cobb-Douglas**
Log plot area in hectares	0.308***	0.308***	0.339***	0.266***	0.245***
	(14.163)	(18.922)	(21.566)	(13.759)	(17.040)
Log labor days	0.406***	0.410***		0.501***	0.481***
	(15.051)	(19.620)		(19.226)	(22.277)
Log male family labor days			0.107***		
			(5.510)		
Log female family labor days			0.170***		
			(8.346)		
Log hired labor days			0.123***		
			(6.431)		
Log chemical fertilizer use in kg	0.133**	0.094***	0.095***	0.151***	0.134***
	(2.033)	(3.505)	(3.121)	(3.418)	(3.877)
Log pesticide use in US$	0.001	0.101***	0.107***	0.148	0.142***
	(0.024)	(2.696)	(2.823)	(1.477)	(2.893)
Log manure use in kg	0.117***	0.118***	0.113***	0.092***	0.102***
	(5.986)	(7.943)	(7.581)	(4.105)	(5.140)
Dummy male family labor			0.054		
			(0.859)		
Dummy female family labor			0.340***		
			(3.644)		
Dummy hired labor			-0.129**		
			(2.197)		
Dummy chemical fertilizer use	0.263*	0.160	0.085	-0.100	-0.128**
	(1.829)	(1.609)	(1.016)	(1.580)	(2.130)
Dummy pesticide use	-0.020	-0.029	-0.076	0.111	0.107
	(0.220)	(0.327)	(1.101)	(0.836)	(0.833)
Dummy manure use	-0.336***	-0.341***	0.418***	-0.229***	-0.235***
	(8.012)	(8.394)	(4.726)	(6.108)	(6.595)
Log(plot area in hectares)^2	-0.079***			-0.013	
	(3.631)			(0.886)	
Log(male labor days)^2	-0.099***			-0.057*	
	(2.894)			(1.907)	
Log(chemical fertilizer use in kg)^2	-0.008			0.012	
	(0.540)			(0.554)	
Log(pesticide use in kg)^2	0.071**			-0.006	
	(2.257)			(0.118)	
Log(manure use in kg)^2	-0.013			0.015	
	(0.972)			(0.655)	
Log land X Log labor	0.079***			0.055***	
	(3.462)			(3.384)	
Log land X Log chemical fertilizer	-0.024*			0.029	
	(1.650)			(1.185)	
Log land X Log pesticide use	-0.016			-0.018	
	(0.478)			(0.761)	
Log land X Log manure use	0.022			-0.002	
	(1.635)			(0.118)	
Log labor X Log chemical fertilizer	0.020			-0.014	
	(1.160)			(0.415)	
Log labor X Log pesticide use	-0.060			-0.015	
	(1.504)			(0.474)	
Log labor X Log manure use	-0.017			-0.019	
	(1.005)			(0.940)	
Log chem. fertilizer X Log pesticide use	0.003			0.050*	
	(0.196)			(1.713)	
Log chem. fertilizer X Log manure use	-0.002			0.006	
	(0.212)			(0.200)	
Log pesticide use X Log manure use	0.008			0.031	
	(0.325)			(1.155)	

Distance from homestead in minutes	0.000	0.000	0.001*	-0.004***	-0.004***
	(0.944)	(1.095)	(1.799)	(5.243)	(5.224)
Number of years plot possessed	0.001	0.001	0.003**	0.001	0.001
	(1.457)	(1.319)	(2.565)	(0.623)	(0.771)
Plot located in wet land	0.004	0.008	0.024	-0.036	-0.032
	(0.053)	(0.094)	(0.289)	(0.651)	(0.582)
Irrigated land	0.008	-0.011	-0.039	-0.080	-0.080
	(0.097)	(0.147)	(0.494)	(1.070)	(1.071)
Crop shock	-0.213***	-0.209***	-0.203***	-0.217***	-0.218***
	(6.131)	(6.031)	(5.829)	(6.202)	(6.215)
Share of area cultivated with grains	-0.409	-0.488*	-0.542**	-0.307**	-0.287**
	(1.609)	(1.960)	(2.166)	(2.285)	(2.154)
Share of area cultivated with tubers	-0.180	-0.259	-0.265	-0.398***	-0.389***
	(0.699)	(1.028)	(1.042)	(2.954)	(2.912)
Share of area with tree crops	-0.001	-0.100	-0.194	0.143	0.158
	(0.004)	(0.396)	(0.765)	(1.041)	(1.156)
Plot topography dummies/shares	Yes	Yes	Yes	Yes	Yes
Soil type dummies/shares	Yes	Yes	Yes	Yes	Yes
Constant	-0.076	0.065	3.475***	0.127	0.131
	(0.264)	(0.248)	(12.299)	(0.619)	(0.667)
Number of observations	3,062	3,062	3,062	7,307	7,307
R-squared	0.579	0.575	0.572	0.429	0.425
Output elasticities					
Land	0.305***	0.308***	0.339***	0.246***	0.245***
	(18.525)	(18.922)	(21.566)	(16.971)	(17.040)
Labor	0.405***	0.410***	0.399***	0.480***	0.481***
	(19.305)	(19.620)	(13.850)	(22.097)	(22.277)
Chemical fertilizer	0.139**	0.094***	0.095***	0.132***	0.134***
	(2.334)	(3.505)	(3.121)	(3.766)	(3.877)
Pesticides	0.053	0.101***	0.107***	0.162*	0.142***
	(1.122)	(2.696)	(2.823)	(1.771)	(2.893)
Manure	0.115***	0.118***	0.113***	0.103***	0.102***
	(7.555)	(7.943)	(7.581)	(5.060)	(5.140)
Marginal products					
Male family labor in US$			0.666		
			(1.285)		
Female family labor in US$			0.539		
			(0.959)		
Village level market wages					
Male family labor in US$			0.911		
Female family labor in US$			0.871		
Returns to scale	1.017	1.030	1.054	1.122	1.104
Test of const. ret. to scale: F-value	1.43	0.45	0.28	2.25**	3.00*

Note: All holding-level regressions include village fixed effects while plot-level regressions are estimated using household fixed effects. Most of the Allen cross elasticities are not statistically different from zero. Jointly, they are not or only marginally different from zero. Marginal products of male and female family labor (shadow wages) are calculated using the formula $MPL = \hat{\beta}(\hat{Y}/L)$ where $\hat{\beta}$ is the coefficient on log of male (female) family labor, $\hat{Y}$ is predicted value of output, and L is male (female) family labor use in days (Jacoby 1993). Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Table 4: Farm Size Productivity Relationship: Yield Approach

	Holding level			Plot level			
Cropped area (ha)	-0.376***	-0.347***	-0.379***	-0.476***	-0.436***	-0.448***	-0.462***
	(30.061)	(24.225)	(25.246)	(55.459)	(43.209)	(43.732)	(34.106)
Land value/ha (USD)		0.215***	0.205***		0.200***	0.192***	0.187***
		(12.849)	(12.266)		(17.073)	(16.270)	(10.939)
Dist. from home (min)		0.002***	0.002***		-0.004***	-0.003***	-0.003***
		(5.062)	(4.832)		(5.996)	(4.887)	(4.574)
Years possessed		0.000	0.004**		0.001	0.004***	0.004**
		(0.014)	(2.544)		(0.836)	(3.916)	(2.234)
Plot in wetland		0.139	0.096		0.049	0.031	0.019
		(1.569)	(1.088)		(0.997)	(0.647)	(0.321)
Irrigated land		-0.066	-0.032		-0.011	0.000	-0.020
		(0.777)	(0.387)		(0.206)	(0.003)	(0.253)
Flat land		-0.086	-0.083		-0.074**	-0.074**	0.045
		(1.639)	(1.599)		(2.225)	(2.255)	(1.032)
Gently sloped land		-0.037	-0.041		-0.061**	-0.068**	-0.027
		(0.804)	(0.909)		(1.990)	(2.260)	(0.642)
Plot in valley		0.091	0.092		-0.001	-0.004	0.051
		(0.596)	(0.611)		(0.009)	(0.062)	(0.607)
Sandy soil		-0.094	-0.085		-0.051	-0.046	-0.060
		(1.483)	(1.355)		(1.191)	(1.080)	(1.025)
Loam soil		0.164***	0.164***		0.143***	0.131***	0.031
		(3.102)	(3.156)		(4.023)	(3.726)	(0.629)
Light clay soil		0.074	0.073		0.048	0.039	-0.033
		(1.087)	(1.088)		(1.101)	(0.915)	(0.564)
Heavy soil		0.010	-0.013		0.016	0.013	0.080
		(0.082)	(0.105)		(0.225)	(0.183)	(0.858)
Gravelly soil		-0.031	-0.024		0.002	0.008	0.027
		(0.470)	(0.376)		(0.050)	(0.185)	(0.445)
Crop shock		-0.234***	-0.218***		-0.261***	-0.233***	-0.205***
		(6.151)	(5.807)		(9.810)	(8.817)	(5.527)
Grains			-0.916***			-0.784***	-0.518***
			(3.582)			(6.355)	(3.817)
Tubers			-0.508*			-0.600***	-0.438***
			(1.950)			(4.821)	(3.203)
Tree crops			-0.586**			-0.421***	-0.198
			(2.254)			(3.320)	(1.415)
Age of head			-0.002			-0.001	
			(0.964)			(0.770)	
Female head			-0.159***			-0.149***	
			(3.847)			(4.569)	
Primary school comp.			0.066*			0.052*	
			(1.790)			(1.832)	
Sec. education			0.115			0.123**	
			(1.638)			(2.376)	
No of members <=14			0.026**			0.024***	
			(2.212)			(2.719)	
No of members 15- 35			0.011			-0.008	
			(0.744)			(0.713)	
No of members 35- 60			0.042			-0.014	
			(1.619)			(0.728)	
No of members >=60			0.004			-0.047	
			(0.072)			(1.248)	
Constant	5.124***	3.289***	3.928***	4.511***	2.961***	3.590***	3.346***
	(183.631)	(22.304)	(12.852)	(162.482)	(29.134)	(21.017)	(16.577)
Village fixed effects	No	Yes	Yes	No	Yes	Yes	No
Hh fixed effects				No	No	No	Yes
No of observations	3,080	3,062	3,060	7,477	7,308	7,305	7,308
R-squared	0.227	0.305	0.332	0.292	0.345	0.363	0.361

Note: Regressions are for owned plots only (see separate appendix for results with all plots).
Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Table 5: Farm Size and Intensity of Labor Use

	Holding level			Plot level			
Cropped area (ha)	-0.446***	-0.445***	-0.479***	-0.582***	-0.583***	-0.577***	-0.565***
	(41.693)	(36.422)	(37.617)	(87.492)	(74.598)	(73.896)	(60.841)
Land value/ha (USD)		0.159***	0.153***		0.105***	0.123***	0.102***
		(11.149)	(10.787)		(11.576)	(13.739)	(8.736)
Dist. from home (min)		0.003***	0.003***		0.002***	0.000	0.001
		(10.034)	(9.514)		(3.115)	(0.517)	(1.144)
Years possessed		0.001	0.001		0.002***	0.003***	0.006***
		(0.626)	(0.401)		(2.837)	(2.942)	(5.374)
Plot in wetland		0.211***	0.172**		0.115***	0.081**	0.056
		(2.787)	(2.311)		(3.031)	(2.199)	(1.411)
Irrigated land		-0.109	-0.086		-0.010	-0.018	0.097*
		(1.502)	(1.217)		(0.228)	(0.432)	(1.775)
Flat land		-0.004	-0.003		-0.014	-0.019	-0.054*
		(0.081)	(0.067)		(0.537)	(0.742)	(1.775)
Gently sloped land		0.058	0.049		0.038	0.033	-0.041
		(1.494)	(1.297)		(1.621)	(1.428)	(1.422)
Plot in valley		0.078	0.040		0.078	0.016	-0.031
		(0.594)	(0.317)		(1.412)	(0.305)	(0.538)
Sandy soil		-0.101*	-0.089*		-0.068**	-0.071**	-0.023
		(1.856)	(1.668)		(2.068)	(2.214)	(0.572)
Loam soil		-0.040	-0.015		-0.017	-0.011	0.042
		(0.890)	(0.329)		(0.609)	(0.408)	(1.222)
Light clay soil		-0.047	-0.032		-0.034	-0.032	0.060
		(0.805)	(0.558)		(1.008)	(0.969)	(1.480)
Heavy soil		0.085	0.049		0.088	0.051	0.157**
		(0.809)	(0.477)		(1.585)	(0.929)	(2.463)
Gravelly soil		-0.119**	-0.110**		-0.068**	-0.061*	0.094**
		(2.135)	(2.016)		(1.974)	(1.825)	(2.302)
Crop shock		-0.007	0.003		0.033	0.051**	0.023
		(0.220)	(0.085)		(1.600)	(2.526)	(0.902)
Grains			-0.441**			-0.291***	-0.174*
			(2.033)			(3.092)	(1.867)
Tubers			-0.013			0.082	0.164*
			(0.060)			(0.859)	(1.754)
Tree crops			-0.572***			-0.422***	-0.340***
			(2.597)			(4.368)	(3.535)
Age of head			0.000			0.000	
			(0.067)			(0.014)	
Female head			-0.103***			-0.109***	
			(2.942)			(4.384)	
Primary school comp.			-0.004			-0.016	
			(0.114)			(0.742)	
Sec. education			-0.017			-0.007	
			(0.291)			(0.187)	
No of members <=14			0.028***			0.017**	
			(2.825)			(2.549)	
No of members 15- 35			0.021			0.010	
			(1.612)			(1.211)	
No of members 35- 60			0.099***			0.064***	
			(4.548)			(4.381)	
No of members >=60			0.111***			0.022	
			(2.659)			(0.781)	
Constant	4.836***	3.362***	3.540***	4.149***	3.169***	3.155***	3.259***
	(202.426)	(26.734)	(13.674)	(192.890)	(40.250)	(24.214)	(23.538)
Village fixed effects	No	Yes	Yes	No	Yes	Yes	No
Hh fixed effects				No	No	No	Yes
No of observations	3,080	3,062	3,060	7,477	7,308	7,305	7,308
R-squared	0.361	0.431	0.460	0.506	0.544	0.570	0.616

Note: Regressions are for owned plots only (see separate appendix for results with all plots).
Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Table 6: Farm Size Productivity Relationship: Net Profit Approach Using Shadow Wages

	Holding level			Plot level			
Cropped area (ha)	-0.155***	-0.140***	-0.149***	-0.197***	-0.174***	-0.180***	-0.161***
	(20.133)	(15.091)	(15.122)	(22.974)	(16.618)	(16.905)	(10.457)
Land value/ha (USD)		0.097***	0.093***		0.102***	0.093***	0.082***
		(8.963)	(8.535)		(8.443)	(7.558)	(4.200)
Dist. from home (min)		0.000	0.000		-0.002***	-0.002**	-0.000
		(0.946)	(0.904)		(3.510)	(2.328)	(0.463)
Years possessed		0.000	0.002		0.001	0.002**	0.001
		(0.568)	(1.617)		(0.833)	(2.095)	(0.529)
Plot in wetland		0.004	-0.013		-0.006	-0.021	-0.016
		(0.070)	(0.225)		(0.110)	(0.417)	(0.241)
Irrigated land		-0.053	-0.036		-0.028	-0.011	0.008
		(0.972)	(0.665)		(0.488)	(0.197)	(0.088)
Flat land		-0.046	-0.046		-0.053	-0.050	0.029
		(1.360)	(1.354)		(1.539)	(1.470)	(0.587)
Gently sloped land		-0.032	-0.032		-0.023	-0.027	0.022
		(1.088)	(1.104)		(0.714)	(0.856)	(0.454)
Plot in valley		0.108	0.118		0.004	0.007	-0.002
		(1.083)	(1.191)		(0.052)	(0.095)	(0.026)
Sandy soil		-0.027	-0.019		-0.009	-0.002	0.014
		(0.656)	(0.462)		(0.203)	(0.043)	(0.215)
Loam soil		0.040	0.041		0.097***	0.091**	0.085
		(1.180)	(1.219)		(2.632)	(2.483)	(1.492)
Light clay soil		0.068	0.070		0.067	0.064	0.029
		(1.547)	(1.597)		(1.485)	(1.431)	(0.428)
Heavy soil		-0.047	-0.042		-0.047	-0.029	0.001
		(0.590)	(0.533)		(0.627)	(0.397)	(0.011)
Gravelly soil		-0.013	-0.008		0.006	0.013	0.019
		(0.298)	(0.198)		(0.128)	(0.295)	(0.283)
Crop shock		-0.090***	-0.085***		-0.126***	-0.108***	-0.135***
		(3.682)	(3.467)		(4.567)	(3.913)	(3.194)
Grains			-0.397**			-0.785***	-0.838***
			(2.375)			(6.111)	(5.415)
Tubers			-0.242			-0.637***	-0.776***
			(1.423)			(4.917)	(4.984)
Tree crops			-0.196			-0.423***	-0.439***
			(1.150)			(3.203)	(2.752)
Age of head			-0.001			-0.001	
			(1.160)			(0.805)	
Female head			-0.019			-0.026	
			(0.713)			(0.776)	
Primary school comp.			0.021			0.016	
			(0.855)			(0.528)	
Sec. education			0.015			0.017	
			(0.328)			(0.314)	
No of members <=14			0.007			0.015	
			(0.898)			(1.575)	
No of members 15- 35			-0.007			-0.014	
			(0.719)			(1.251)	
No of members 35- 60			0.026			-0.009	
			(1.542)			(0.473)	
Constant	0.099***	-0.702***	-0.384*	-0.105***	-0.905***	-0.177	-0.025
	(5.758)	(7.371)	(1.918)	(3.774)	(8.597)	(0.992)	(0.109)
Village fixed effects	No	Yes	Yes	No	Yes	Yes	No
Hh fixed effects				No	No	No	Yes
Profit elasticity of land	-0.409***	-0.368***	-0.391***	-0.420***	-0.371***	-0.385***	-0.345***
	(17.768)	(14.063)	(14.098)	(19.821)	(15.339)	(15.581)	(10.142)
No of observations	3,065	3,060	3,058	7,428	7,275	7,272	7,275
R-squared	0.117	0.153	0.166	0.066	0.082	0.098	0.076

Note: Regressions are for owned plots only (see separate appendix for results with all plots). Profit elasticity of land is calculated at mean values. Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Table 7: Farm Size Productivity Relationship: Net Profit Approach Using Village Market Wages

	Holding level			Plot level			
Cropped area (ha)	-0.017*	-0.009	-0.010	0.015	0.035***	0.023*	0.007
	(1.936)	(0.882)	(0.875)	(1.522)	(2.969)	(1.897)	(0.426)
Land value/ha (USD)		0.053***	0.051***		0.070***	0.052***	0.030
		(4.197)	(3.987)		(5.145)	(3.822)	(1.417)
Dist. from home (min)		-0.000	-0.000		-0.003***	-0.002**	-0.002**
		(1.503)	(1.280)		(4.105)	(2.396)	(2.197)
Years possessed		0.000	0.003**		-0.001	0.001	-0.002
		(0.419)	(2.392)		(1.023)	(0.786)	(0.806)
Plot in wetland		-0.057	-0.060		-0.024	-0.019	-0.000
		(0.857)	(0.898)		(0.432)	(0.329)	(0.002)
Irrigated land		-0.056	-0.051		-0.052	-0.041	-0.093
		(0.877)	(0.795)		(0.817)	(0.643)	(0.942)
Flat land		-0.058	-0.059		-0.040	-0.039	0.105*
		(1.471)	(1.488)		(1.044)	(1.021)	(1.914)
Gently sloped land		-0.067*	-0.065*		-0.049	-0.052	0.077
		(1.945)	(1.898)		(1.393)	(1.479)	(1.467)
Plot in valley		0.176	0.194*		-0.097	-0.062	0.003
		(1.534)	(1.696)		(1.177)	(0.759)	(0.029)
Sandy soil		0.032	0.031		0.029	0.036	0.024
		(0.664)	(0.640)		(0.594)	(0.725)	(0.333)
Loam soil		0.100**	0.088**		0.152***	0.140***	0.056
		(2.529)	(2.230)		(3.698)	(3.423)	(0.900)
Light clay soil		0.136***	0.128**		0.111**	0.105**	0.019
		(2.657)	(2.514)		(2.204)	(2.103)	(0.254)
Heavy soil		-0.119	-0.111		-0.110	-0.087	-0.014
		(1.293)	(1.212)		(1.314)	(1.052)	(0.124)
Gravelly soil		0.038	0.035		0.076	0.076	0.014
		(0.772)	(0.708)		(1.483)	(1.497)	(0.184)
Crop shock		-0.098***	-0.095***		-0.187***	-0.179***	-0.134***
		(3.420)	(3.337)		(6.090)	(5.812)	(2.899)
Grains			-0.253			-0.476***	-0.511***
			(1.302)			(3.317)	(3.013)
Tubers			-0.274			-0.569***	-0.688***
			(1.387)			(3.928)	(4.037)
Tree crops			-0.045			-0.138	-0.166
			(0.229)			(0.934)	(0.948)
Age of head			-0.002			-0.001	
			(1.287)			(0.641)	
Female head			-0.031			-0.021	
			(0.990)			(0.544)	
Primary school comp.			0.046*			0.055*	
			(1.656)			(1.655)	
Sec. education			0.066			0.106*	
			(1.248)			(1.757)	
No of members <=14			-0.007			0.007	
			(0.745)			(0.686)	
No of members 15- 35			-0.007			-0.013	
			(0.591)			(1.044)	
No of members 35- 60			-0.011			-0.031	
			(0.586)			(1.405)	
No of members >=60			-0.055			-0.032	
			(1.470)			(0.730)	
Constant	0.094***	-0.338***	-0.060	0.176***	-0.320***	0.220	0.389
	(4.674)	(3.055)	(0.260)	(5.635)	(2.718)	(1.106)	(1.543)
Village fixed effects	No	Yes	Yes	No	Yes	Yes	No
Hh fixed effects				No	No	No	Yes
No of observations	3,080	3,062	3,060	7,477	7,308	7,305	7,308
R-squared	0.001	0.022	0.034	0.000	0.016	0.031	0.034

Note: Regressions are for owned plots only (see separate appendix for results with all plots).
Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Table 8: Farm Size Productivity Relationship: Variation by Farm Size

	Yield		Net profit (shadow wages)		Net profit (village wages)	
	Holding	**Plot**	**Holding**	**Plot**	**Holding**	**Plot**
Cropped area in ha, (α_1)	-0.501***	-0.485***	-0.097***	-0.152***	-0.008	-0.025
	(11.512)	(15.269)	(3.392)	(4.201)	(0.248)	(0.620)
Cropped area in ha * first tercile, (γ_1)	0.118***	0.019	-0.050*	-0.007	-0.002	0.025
	(2.983)	(0.841)	(1.945)	(0.262)	(0.056)	(0.872)
Cropped area in ha * second tercile, (γ_2)	0.065	0.043**	-0.029	0.023	-0.016	-0.009
	(1.635)	(2.171)	(1.120)	(1.027)	(0.542)	(0.376)
Village fixed effects	Yes		Yes		Yes	
Household fixed effects		Yes		Yes		Yes
Tests:						
$\alpha_1 + \gamma_1 = 0$	648.14***	982.65***	222.11***	87.86***	0.75	0
$\alpha_1 + \gamma_2 = 0$	315.54***	457.28***	60.81***	29.94***	1.72	1.72
No of observations	3,060	7,308	3,058	7,275	3,060	7,308
R-squared	0.335	0.362	0.167	0.077	0.034	0.036

Note: Coefficients are from the specifications in columns (3) and (7) above for holding and plot levels, respectively with only the relevant coefficients reported. Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Map of sampled cells (total 3,600 households), source: World Bank survey 2011

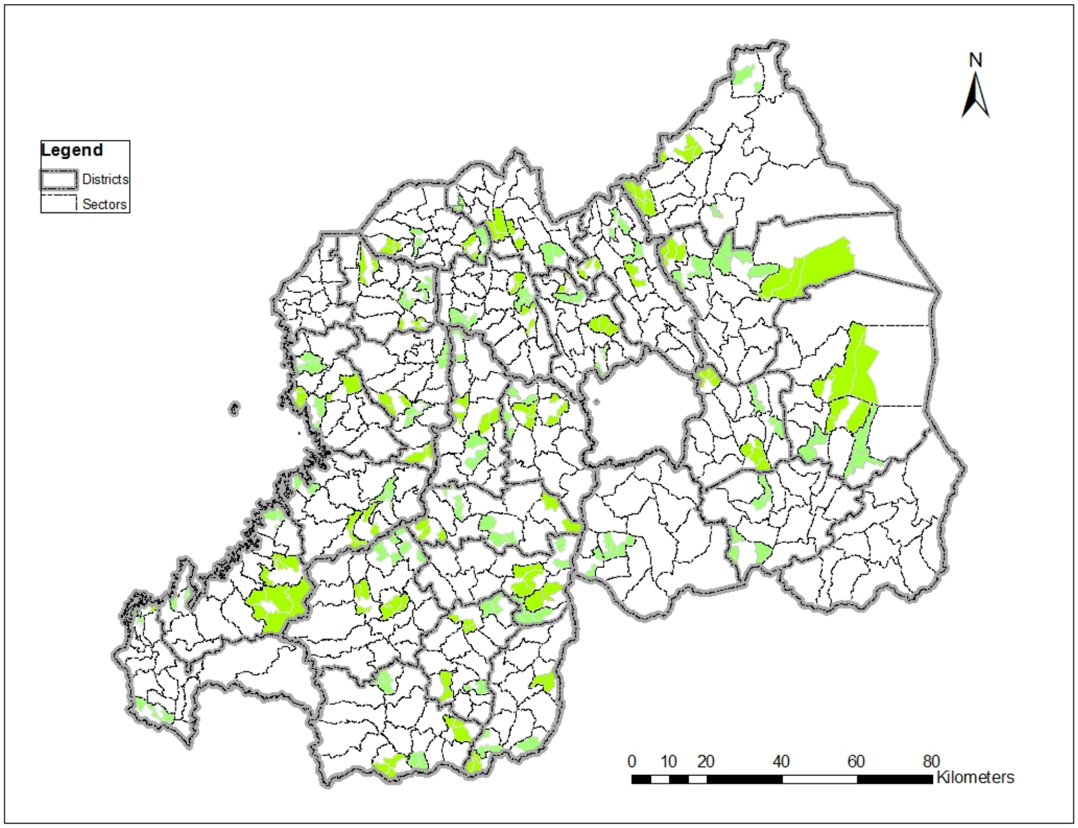


Figure 1

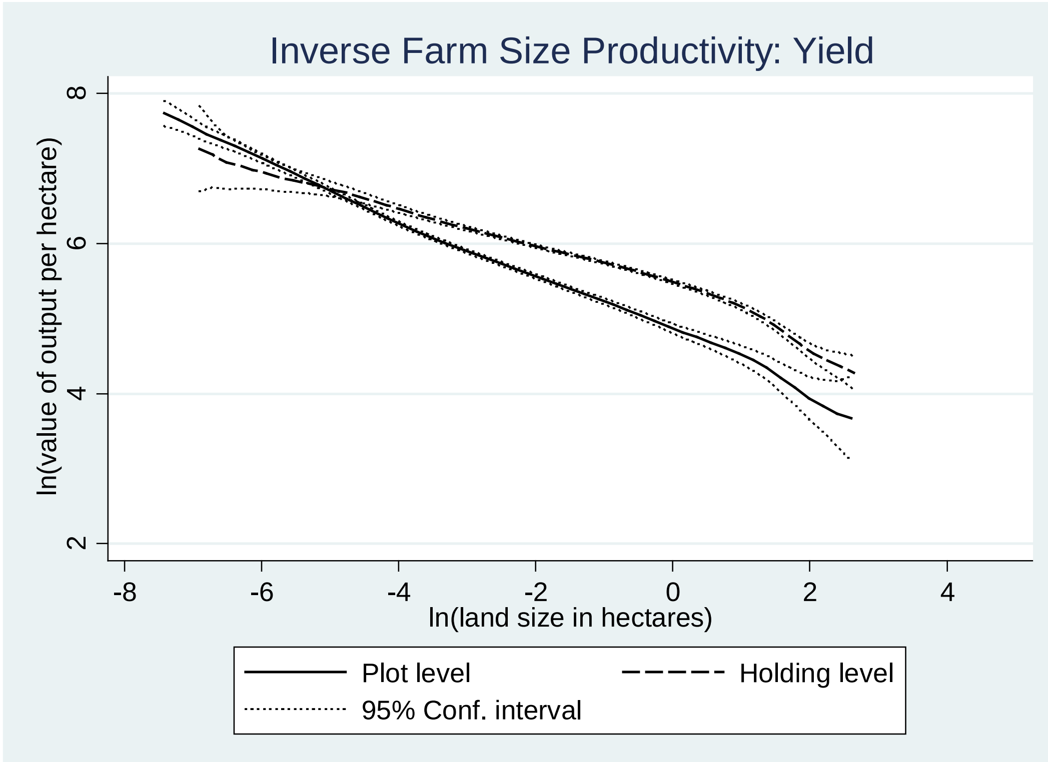


Figure 2

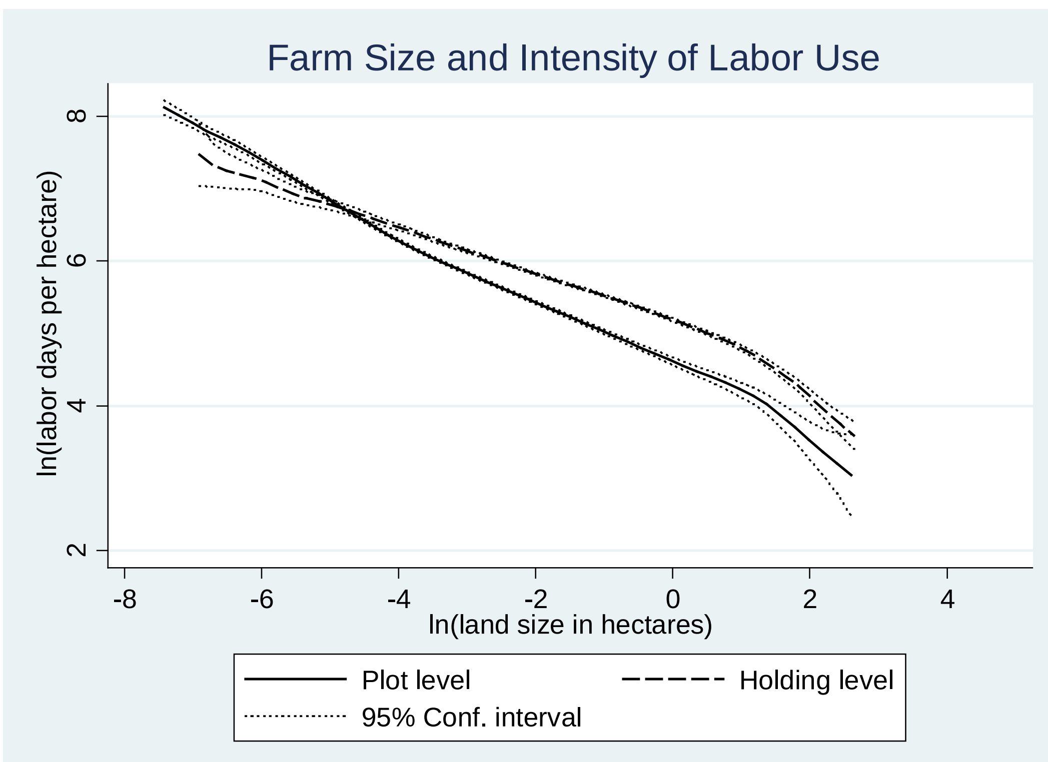


Figure 3

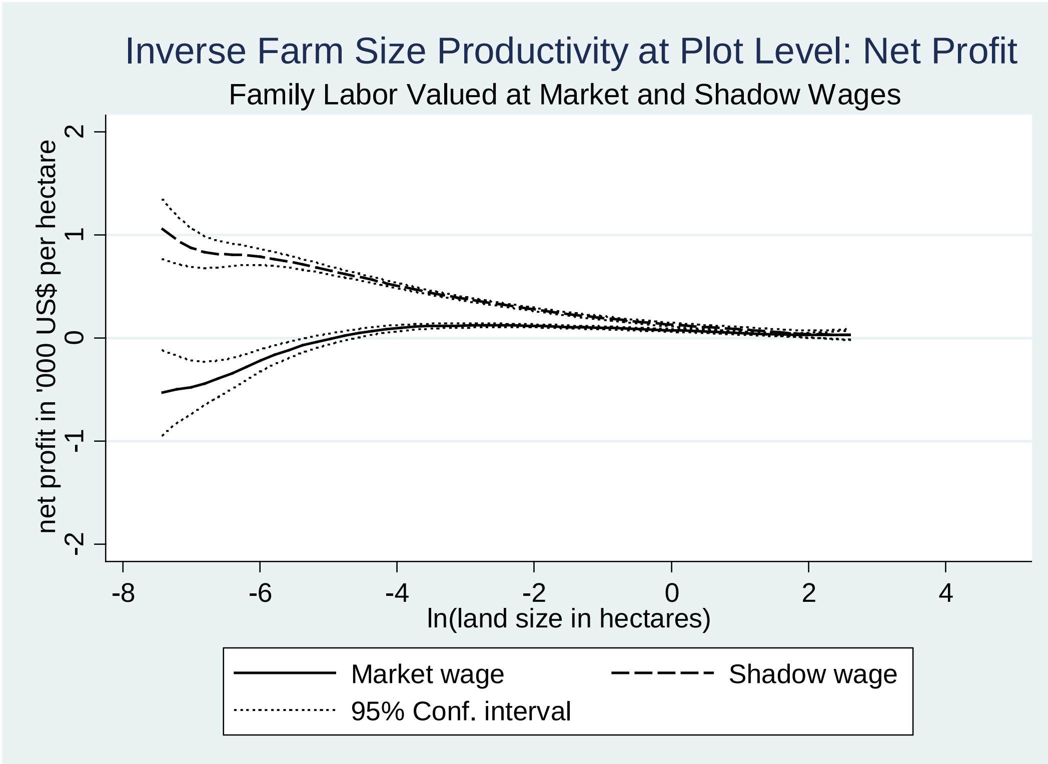


Figure 4

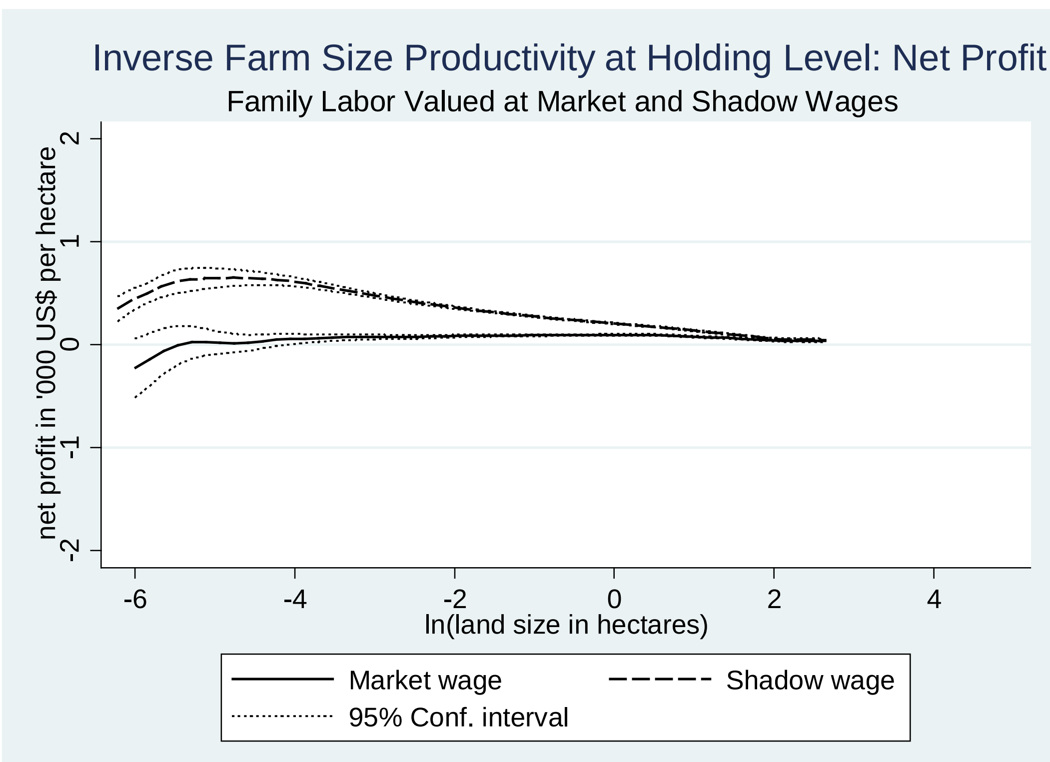
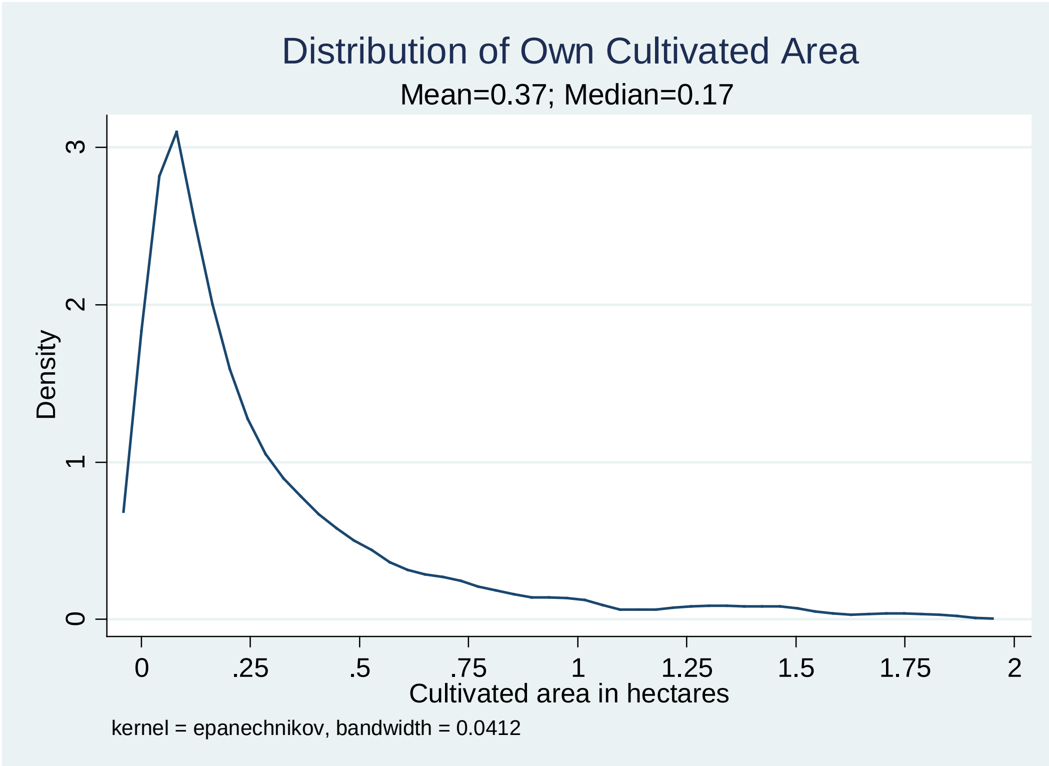
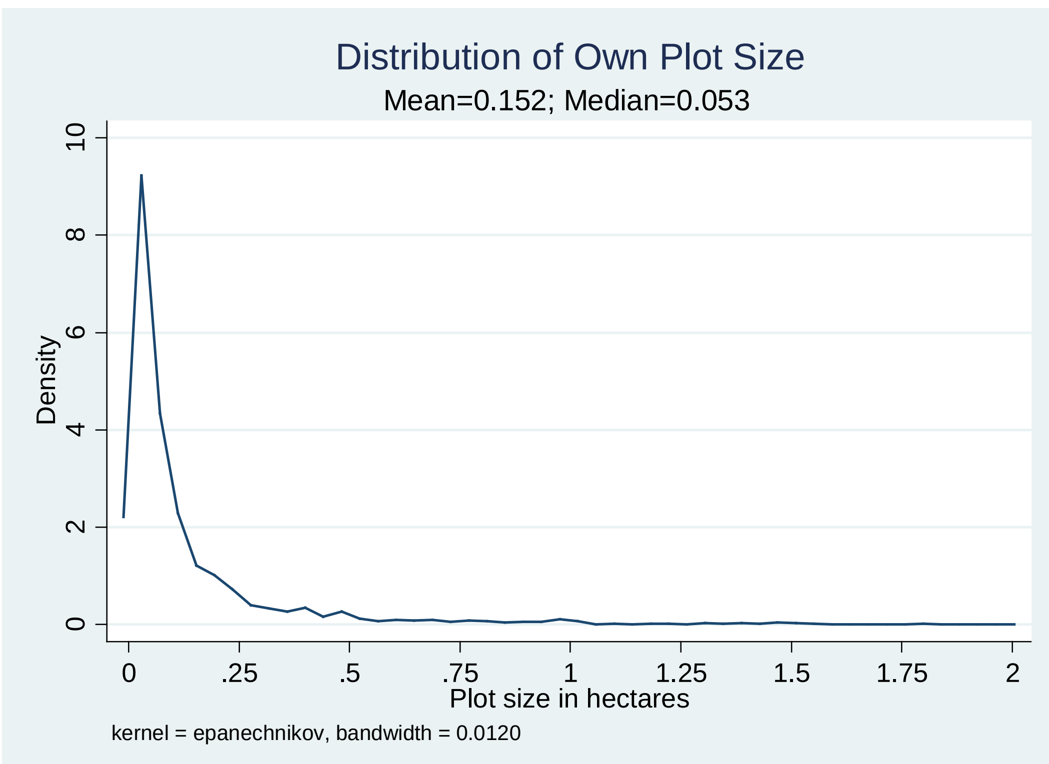


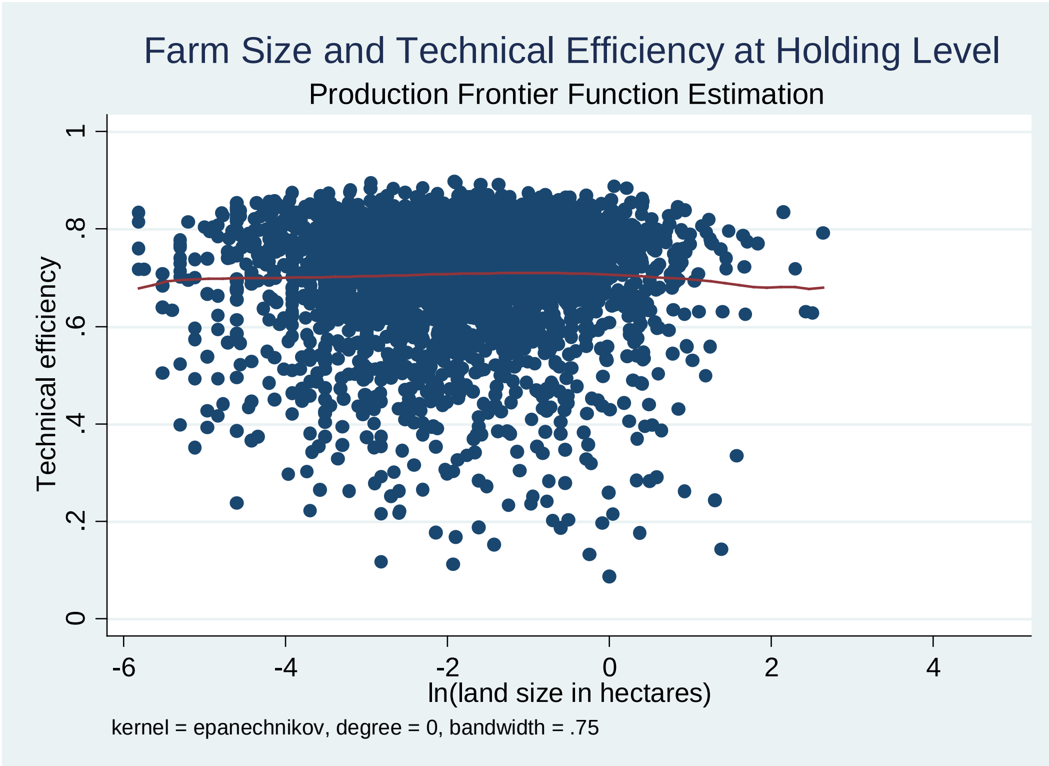
Figure 5



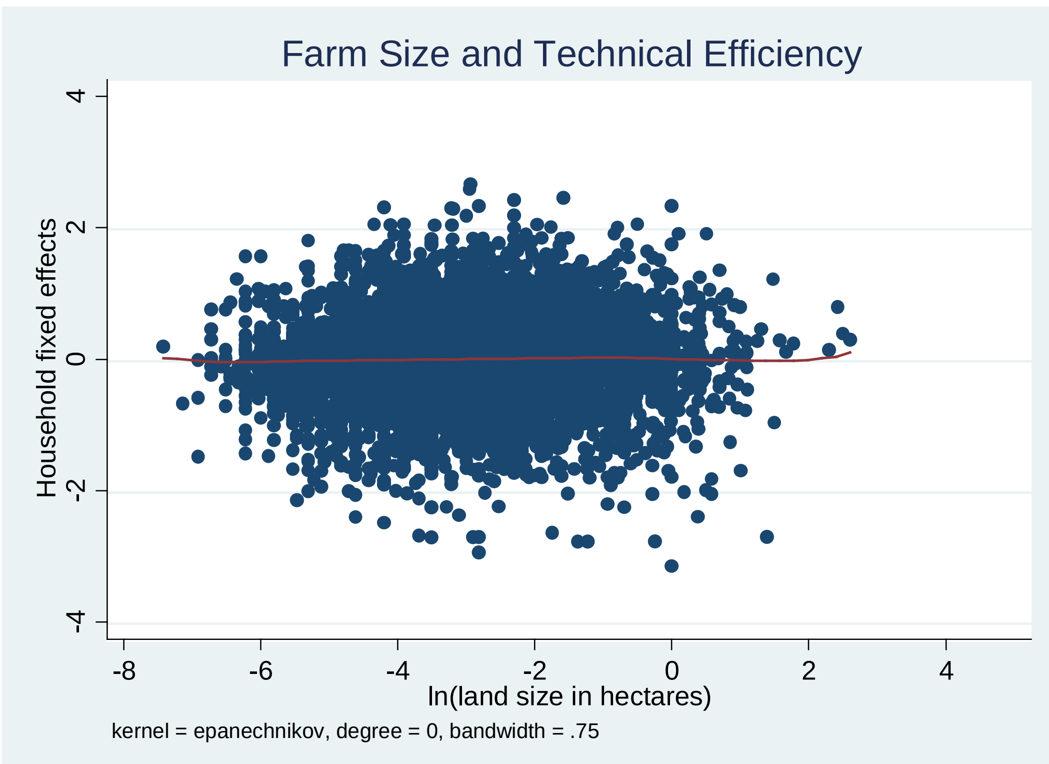
Appendix figure 1



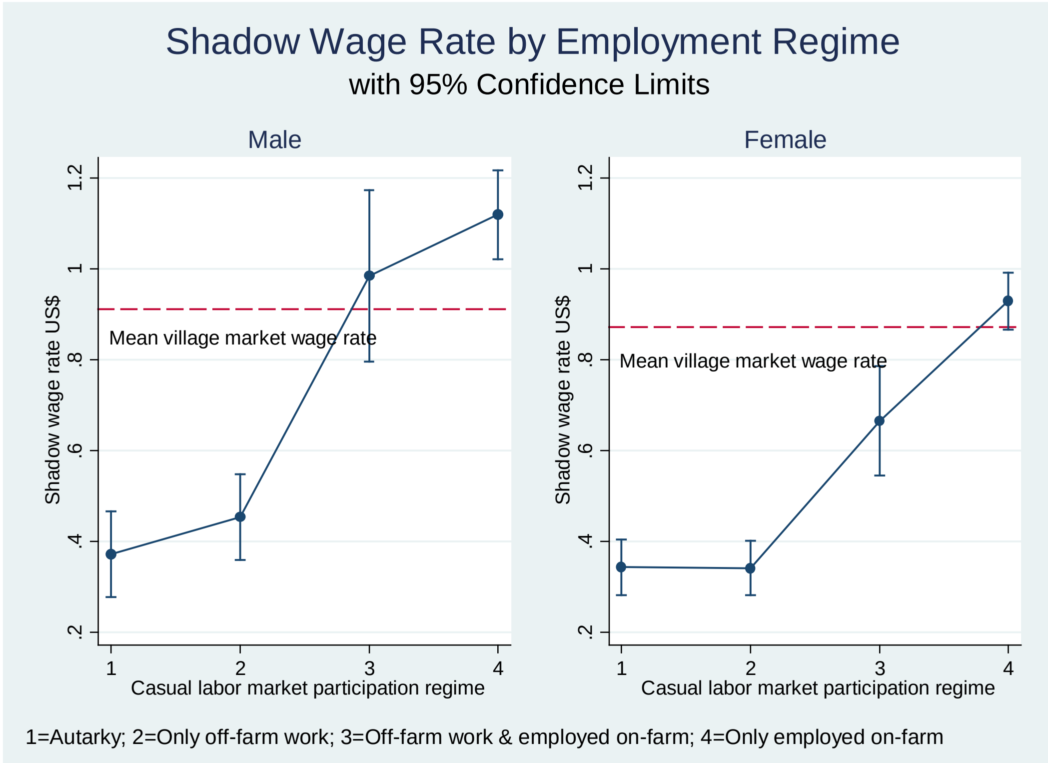
Appendix figure 2



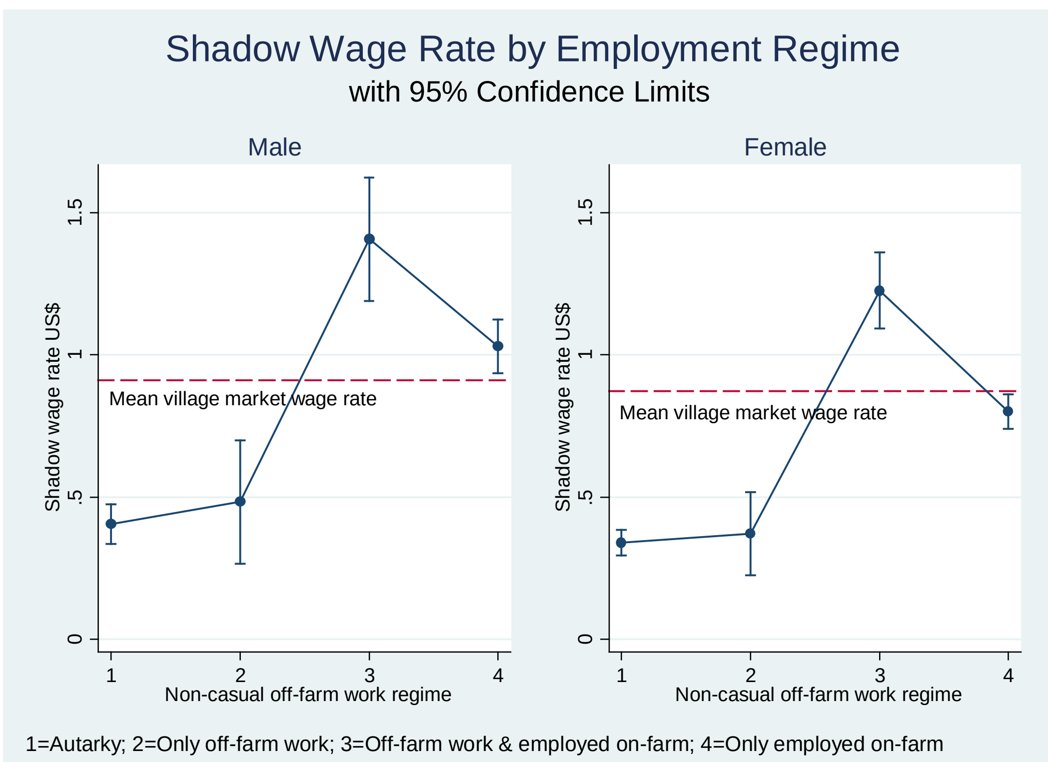
Appendix figure 3



Appendix figure 4



Appendix figure 5



Appendix figure 6

References

Ali, D. A., K. Deininger, and M. Goldstein. 2011. "Environmental and Gender Impacts of Land Tenure Regularization in Africa: Pilot evidence from Rwanda." World Bank Policy Research Paper 5765. Washington, DC: World Bank.

Allen, D. and D. Lueck. 1998. "The Nature of the Farm." *Journal of Law and Economics 41* (2): 343-86.

Assuncao, J. J. and L. H. B. Braido. 2007. "Testing Household-Specific Explanations for the Inverse Productivity Relationship." *American Journal of Agricultural Economics 89* (4): 980-90.

Assuncao, J. J. and M. Ghatak. 2003. "Can Unobserved Heterogeneity in Farmer Ability Explain the Inverse Relationship between Farm Size and Productivity." *Economics Letters 80* (2): 189-94.

Bardhan, P. 1973. "Size, productivity and returns to scale: an analysis of farm-level data in Indian agriculture." *Journal of Political Economy 81* (6): 1370-86.

Barrett, C. B. 1996. "On Price Risk and the Inverse Farm Size-Productivity Relationship." *Journal of Development Economics 51* (2): 193-215.

Barrett, C. B., M. F. Bellemare and J. Y. Hou. 2010. "Reconsidering Conventional Explanations of the Inverse Productivity-Size Relationship." *World Development 38* (1): 88-97.

Battese, G. E. 1997. "A Note on the Estimation of Cobb-Douglas Production Functions When Some Explanatory Variables Have Zero Values." *Journal of Agricultural Economics 48* (2): 250-2.

Benjamin, D. 1995. "Can Unobserved Land Quality Explain the Inverse Productivity Relationship?" *Journal of Development Economics 46* (1): 51-84.

Berndt, E. and L. Christensen. 1973. "The internal structure of functional relationships: Separability, substiution, and aggregation." *Review of Economic Studies 40* (2): 403-11.

Berry, R. A. and W. R. Cline. 1979. *Agrarian Structure and Productivity in Developing Countries.* Baltimore: Johns Hopkins University Press.

Bhalla, S. S. and P. Roy. 1988. "Misspecification in Farm Productivity Analysis: The Role of Land Quality." *Oxford Economic Papers 40* 55-73.

Binswanger, H. P., K. Deininger and G. Feder. 1995. "Power, Distortions, Revolt and Reform in Agricultural Land Relations." *Handbook of development economics 3B* 2659-772.

Binswanger, H. P. and M. R. Rosenzweig. 1986. "Behavioural and Material Determinants of Production Relations in Agriculture." *Journal of Development Studies 22* (3): 503-39.

Byiringiro, F. and T. Reardon. 1996. "Farm Productivity in Rwanda: Effects of Farm Size, Erosion, and Soil Conservation Investments." *Agricultural Economics 15* (1): 127-36.

Carletto, C., S. Savastano, and A. Zezza. 2011. "Fact or artfact: The impact of measurement errors on the farm size productivity relationship." Policy Research Working Paper 5908. Washington DC: World Bank.

Carter, M. R. 1984. "Identification of the inverse relationship between farm size and productivity: an empirical analysis of peasant agricultural production." *Oxford Economic Papers 36* 131-45.

Carter, M. R. and K. Wiebe. 1990. "Access to Capital and its Impact on Agrarian Structure and Productivity in Kenya." *American Journal of Agricultural Economics 72* 1146-50.

Chayanov, A. V. 1926. *The theory of peasant cooperatives*. Columbus, OH: Ohio State University Press.

Chen, Z., W. E. Huffman and S. Rozelle. 2011. "Inverse Relationship between Productivity and Farm Size: The Case of China." *Contemporary Economic Policy 29* (4): 580-92.

Collier, P. and A. J. Venables. 2011. "Land Deals in Africa: Pioneers and Speculators." Discussion Paper 8644. London: Centre for Economic Policy Research.

Cornia, G. A. 1985. "Farm Size, Land Yields and the Agricultural Production Function: An Analysis for Fifteen Developing Countries." *World Development 13* (4): 513-34.

Deininger, K. and D. Byerlee. 2012a. "The rise of large farms in land abundant countries: Do they have a future?" *World Development 40* (4): 701-14.

Deininger, K. and D. Byerlee. 2012b. "The rise of large farms in land abundant countries: Do they have a future?" *World Development 40* (4): 701-14.

Deininger, K., D. Byerlee, J. Lindsay, A. Norton, H. Selod and M. Stickler. 2011. *Rising global interest in farmland: Can it yield sustainable and equitable benefits?* Washington, D.C.: World Bank.

Deininger, K., G. Carletto and S. Savastano. 2012. "Land fragmentation, corpland abandonment, and land market operation in Albania." *World Development 40* (10): 2108-22.

Deininger, K. and G. Feder. 2001. "Land Institutions and Land Markets." *Handbook of Agricultural Economics (B.Gardner and G.Raussser, Eds)* 288-331.

Deininger, K. and S. Jin. 2008. "Land Sales and Rental Markets in Transition: Evidence from Rural Vietnam." *Oxford Bulletin of Economics and Statistics 70* (1): 67-101.

Deolalikar, A. B. 1981. "The inverse relationship between productivity and farm size: A test using regional data from India." *American Journal of Agricultural Economics 63* (2): 275-9.

Dorward, A. 1999. "Farm Size and Productivity in Malawian Smallholder Agriculture." *Journal of Development Studies 35* (5): 141-61.

Eastwood, R., M. Lipton and A. Newell. 2010. "Farm size." In Pingali, P. L. and R. E. Evenson, eds., *Handbook of agricultural economics*. North Holland: Elsevier.

Eswaran, M. and A. Kotwal. 1986. "Access to Capital and Agrarian Production Organization." *Economic Journal 96* 482-98.

Feder, G. 1985. "The Relation between Farm Size and Farm Productivity: The Role of Family Labor, Supervision and Credit Constraints." *Journal of Development Economics 18* (2-3): 297-313.

Foster, A. and M. R. Rosenzweig. 2010. "Is there surplus labor in rural India?" Econojmic Growth Center, Yale University New Haven CT.

Foster, A. and M. R. Rosenzweig. 2011. "Are Indian farms too small? Mechanization, agency cost, and farm efficiency." Econojmic Growth Center, Yale University New Haven CT.

Frisvold, G. B. 1994. "Does Supervision Matter? Some Hypothesis Tests using Indian Farm-Level Data." *Journal of Development Economics 43* (2): 217-38.

Helfand, S. M. and E. S. Levine. 2004. "Farm size and the determinants of productive efficiency in the Brazilian Center-West." *Agricultural Economics 31* (2-3): 241-9.

Heltberg, R. 1998. "Rural Market Imperfections and the Farm Size-Productivity Relationship: Evidence from Pakistan." *World Development 26* (10): 1807-26.

Jacoby, H. 1993. "Shadow wages and peasant family labour supply: An econometric application to the Peruvian Sierra." *Reviw of Economic Studies 60*, 903-21.

Kathiresan, A. 2012. "Farm land use consolidation in Rwanda." Kigali: Republic of Rwanda, Ministry of Agriculture and Animal Resources.

Kawasaki, K. 2010. "The Costs and Benefits of Land Fragmentation of Rice Farms in Japan." *Australian Journal of Agricultural and Resource Economics 54*, 509-526.

Kevane, M. 1996. "Agrarian Structure and Agricultural Practice: Typology and Application to Western Sudan." *American Journal of Agricultural Economics 78* (1): 236-45.

Kimhi, A. 2006. "Plot size and maize productivity in Zambia: is there an inverse relationship?" *Agricultural Economics 35* (1): 1-9.

Lamb, R. L. 2003. "Inverse Productivity: Land Quality, Labor Markets, and Measurement Error." *Journal of Development Economics 71* (1): 71-95.

Larson, D., K. Otsuka, T. Matsumoto, and T. Kilic. 2012. "Should African rural development strategies depend on smallholder farms? An exploration of the inverse productivity hypothesis." Policy Research Working Paper 6190. Washington, DC: World Bank.

Ligon, E. and E. Sadoulet. 2008. "Estimating the effects of aggregate agricultural growth on the distribution of expenditures." . Washington DC: World Bank.

Lipton, M. 2009. *Land Reform in Developing Countries: Property Rights and property Wrongs*. New York: Routledge (or Taylor and Francis).

Lissitsa, A. and M. Odening. 2005. "Efficiency and Total Factor Productivity in Ukrainian Agriculture in Transition." *Agricultural Economics 32* (311): 325.

Republic of Rwanda. 2009. "Strategic Plan for the Transformation of Agriculture in Rwanda Phase II (PSTA II). Final Report." . Kigali: Ministry of Agriculture and Animal Resources .

Rosenzweig, M. R. and H. P. Binswanger. 1993. "Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments." *Economic Journal 103* (416): 56-78.

Rosenzweig, M. R. and K. I. Wolpin. 1985. "Specific Experience, Household Structure, and Intergenerational Transfers: Farm Family Land and Labor Arraangements in Developing Countries." *Quarterly Journal of Economics 100* (5): 961-87.

Sen, A. 1975. *Employment, technology, and development*. London: Oxford University Press.

Srinivasan, T. N. 1972. "Fram size and productivity: Implications of choice under uncertainty." *Sankhya - The Indian Journal of Statistics 34* (2): 409-20.

World Bank. 2002. "Mexico- Land Policy: A Decade after the Ejido Reforms." . Washington, DC: The World Bank, Rural Development and Natural Resources Sector Unit.

Supplementary Appendix

Preamble:

The material contained herein is supplementary to the article name in the title. The empirical analysis is done using all the plots, i.e., owned and rented-in plots.

Appendix Table 1: Descriptive Statistics at Household Level

	Total	Small	Medium		Large		East	North	South	West
Area cultivated & output										
Yield per ha (US$)	538.60	868.02	462.64	***	284.91	***	493.13	565.41	520.82	584.58
Gross profit (US$/ha)	458.77	748.51	392.73	***	234.89	***	412.91	467.94	461.95	492.64
Net profit (US$/ha)	105.57	114.31	98.33		104.06		57.70	140.94	79.85	157.08
Total cultivated area	0.459	0.063	0.228	***	1.087	***	0.549	0.391	0.441	0.452
Own cultivated are (ha)	0.541	0.067	0.243	***	1.278	***	0.756	0.398	0.507	0.497
Rented-in land (%)	0.309	0.330	0.309		0.287		0.297	0.229	0.400	0.269
Size of rented land (ha)	0.215	0.040	0.110	***	0.528	***	0.313	0.120	0.221	0.163
Input use										
Labor days/ha	456.167	787.205	388.862	***	192.199	***	436.438	433.915	466.595	481.350
Used chemical fertilizer	0.164	0.115	0.156	***	0.221	***	0.071	0.252	0.130	0.226
Fertilizer use (kg/ha)	87.260	28.040	13.511	***	220.348		6.072	24.984	7.955	327.521
Used pesticides	0.093	0.068	0.092	**	0.119	**	0.050	0.139	0.086	0.106
Pesticides (US$/ha)	2.716	4.930	2.027	**	1.188	**	1.607	4.340	1.869	3.546
Used manure	0.735	0.668	0.762	***	0.774		0.520	0.829	0.775	0.815
Share of land with grain	0.508	0.530	0.510		0.484	**	0.614	0.597	0.456	0.394
Share of land with tubers	0.262	0.250	0.260		0.275		0.165	0.233	0.297	0.336
Share of land with tree crops	0.221	0.210	0.219		0.233		0.211	0.158	0.235	0.265
Share of vegetable land	0.010	0.010	0.011		0.008	*	0.009	0.012	0.012	0.006
Household characteristics										
Age of head	46.33	44.32	46.39	***	48.28	***	45.38	45.26	48.17	45.76
Female head	0.277	0.354	0.265	***	0.214	***	0.260	0.265	0.323	0.246
Primary school completed	0.576	0.538	0.585	**	0.604		0.602	0.557	0.570	0.574
Secondary education	0.070	0.061	0.063		0.087	**	0.075	0.064	0.073	0.068
Number of members<=14	2.13	1.93	2.12	***	2.35	***	2.21	2.04	2.03	2.26
No of members 15- 35	1.59	1.45	1.56	***	1.76	***	1.56	1.69	1.56	1.59
No of members 35- 60	0.85	0.66	0.85	***	1.04	***	0.87	0.79	0.91	0.82
No members >=60	0.24	0.21	0.23		0.28	**	0.20	0.23	0.27	0.25
Number of observations	3353	1118	1118		1117		802	691	1060	800

Source: Own computation from 2010/11 LTR baseline survey.
Note: Stars indicated significance levels for t-tests of the equality of means for each of the variables between terciles (* sig. at 10%; ** sig. at 5%; *** sig. at 1%).Two outliers with inexplicably high levels of fertilizer use are dropped from the largest tercile.

Appendix Table 2: Descriptive Statistics at Plot Level

	Total	Small	Medium		Large	
Area cultivated & output						
Yield per ha (US$)	768.49	1327.94	579.74		304.49	
Gross profit (US$/ha)	646.10	1118.01	489.62		251.82	
Net profit (S$/ha)	91.12	26.03	154.12		101.76	
Plot size	0.167	0.016	0.062	***	0.441	***
Land value US$/ha	13361	19070	11784	***	8387	***
Input use						
Labor days/ha	731.33	1421.23	447.25	***	213.32	***
Used chemical fertilizer	0.094	0.082	0.089		0.113	***
Fertilizer use (kg/ha)	101.68	54.69	179.65		75.07	
Used pesticides	0.051	0.045	0.049		0.060	*
Pesticides (US$/ha)	4.518	8.664	3.078	***	1.121	***
Used manure	0.560	0.524	0.566	***	0.596	**
Share with grain	0.496	0.483	0.515	***	0.493	**
Share with tubers	0.298	0.344	0.274	***	0.269	
Share with trees	0.192	0.156	0.198	***	0.230	***
Share with vegetables	0.013	0.017	0.013		0.008	**
Plot characteristics						
No. of years possessed	16.582	14.407	16.640	***	19.100	***
Affected by crop shock	0.301	0.233	0.311		0.371	
Wetland	0.123	0.162	0.114	***	0.084	***
Irrigated land	0.065	0.074	0.063	*	0.056	
Flat land	0.282	0.311	0.276	***	0.255	*
Gently slopped land	0.249	0.224	0.259	***	0.267	
Plot located in a valley	0.057	0.084	0.053	***	0.029	***
Sand soil	0.161	0.173	0.148	***	0.160	
Loam soil	0.368	0.363	0.387	**	0.356	**
Light clay soil	0.137	0.139	0.137		0.135	
Heavy clay soil	0.031	0.038	0.029	**	0.025	
Gravelly soil	0.131	0.123	0.125		0.147	**
Number of observations	9583	3505	3122		2956	

Source: Own computation from 2010/11 LTR baseline survey.
Note: Input use is reported only for those who applied positive amounts. Stars indicated significance levels for t-tests of the equality of means for each of the variables between terciles (* sig. at 10%; ** sig. at 5%; *** sig. at 1%).

Appendix Table 3: Parameter Estimates and Output Elasticities for Alternative Specifications of the Production Function

	Holding level		Plot level	
	Translog	**Cobb-Douglas**	**Translog**	**Cobb-Douglas**
ln plot area in hectares	0.291***	0.277***	0.264***	0.249***
	(14.924)	(19.190)	(17.123)	(21.221)
ln labor days	0.412***	0.421***	0.491***	0.472***
	(16.497)	(21.929)	(23.120)	(26.385)
ln chemical fertilizer use in kg	0.128**	0.087***	0.154***	0.125***
	(2.044)	(3.723)	(4.053)	(4.173)
ln pesticide use in US$	0.040	0.115***	0.125*	0.122***
	(0.923)	(3.884)	(1.755)	(3.045)
ln manure use in kg	0.111***	0.112***	0.102***	0.104***
	(6.099)	(8.464)	(5.309)	(6.278)
Dummy chemical fertilizer use	0.215	0.117	-0.086	-0.111**
	(1.594)	(1.338)	(-1.643)	(-2.247)
Dummy pesticide use	0.018	-0.021	0.052	0.041
	(0.249)	(-0.317)	(0.485)	(0.385)
Dummy manure use	-0.354***	-0.358***	-0.220***	-0.220***
	(-9.123)	(-9.449)	(-7.005)	(-7.346)
ln (plot area in hectares)2	-0.049***		-0.010	
	(-2.585)		(-0.823)	
ln(male labor days)2	-0.095***		-0.014	
	(-3.018)		(-0.571)	
ln(chemical fertilizer use in kg)2	-0.007		0.003	
	(-0.551)		(0.132)	
ln(pesticide use in kg)2	0.054**		-0.007	
	(2.292)		(-0.216)	
ln(manure use in kg)2	0.000		0.006	
	(0.021)		(0.351)	
ln land X ln labor	0.067***		0.035***	
	(3.306)		(2.674)	
ln land X ln chemical fertilizer	-0.023**		0.034	
	(-2.019)		(1.543)	
ln land X ln pesticide use	-0.018		-0.020	
	(-0.771)		(-1.089)	
ln land X ln manure use	0.012		0.012	
	(1.055)		(1.168)	
ln labor X ln chemical fertilizer	0.010		-0.006	
	(0.639)		(-0.195)	
ln labor X ln pesticide use	-0.044		-0.011	
	(-1.311)		(-0.405)	
ln labor X ln manure use	-0.018		-0.033*	
	(-1.190)		(-1.933)	
ln chem. fertilizer X ln pesticide use	0.005		0.024	
	(0.451)		(0.969)	
ln chem.. fertilizer X ln manure use	0.009		0.013	
	(0.956)		(0.495)	
ln pesticide use X ln manure use	-0.016		0.009	
	(-0.696)		(0.409)	
Distance from homestead in minutes	0.000	0.000	-0.003***	-0.003***
	(1.527)	(1.607)	(-6.106)	(-6.174)
Number of years plot possessed	0.002**	0.002**	0.003**	0.003**
	(2.291)	(2.062)	(2.242)	(2.366)
Plot located in wet land	0.035	0.039	-0.028	-0.022
	(0.448)	(0.505)	(-0.617)	(-0.481)
Irrigated land	0.086	0.073	-0.040	-0.045
	(1.238)	(1.054)	(-0.651)	(-0.743)
Flat land	-0.055	-0.062	0.055	0.058*
	(-1.242)	(-1.387)	(1.571)	(1.658)
Gently slopped land	-0.072*	-0.082**	0.005	0.005
	(-1.858)	(-2.122)	(0.161)	(0.143)
Plot located in a valley	0.112	0.105	0.039	0.035

	(0.855)	(0.797)	(0.593)	(0.531)
Sandy soil	0.007	0.015	-0.001	-0.002
	(0.133)	(0.271)	(-0.028)	(-0.045)
Loam soil	0.196***	0.203***	0.051	0.050
	(4.413)	(4.589)	(1.285)	(1.262)
Light clay soil	0.143**	0.149***	-0.022	-0.023
	(2.492)	(2.597)	(-0.483)	(-0.489)
Heavy soil	0.087	0.081	0.078	0.079
	(0.823)	(0.768)	(1.055)	(1.058)
Gravelly soil	0.034	0.034	-0.003	-0.001
	(0.619)	(0.621)	(-0.057)	(-0.017)
Used improved seed	-0.214***			
	(-6.715)			
Use extension knowledge	-0.514**			
	(-2.058)			
Crop shock	-0.214***	-0.218***	-0.241***	-0.240***
	(-6.715)	(-6.833)	(-8.259)	(-8.258)
Share of area cultivated with grains	-0.514**	-0.533**	-0.207*	-0.210*
	(-2.058)	(-2.154)	(-1.868)	(-1.932)
Share of area cultivated with tubers	-0.277	-0.293	-0.293***	-0.300***
	(-1.094)	(-1.167)	(-2.643)	(-2.770)
Share of area with tree crops	-0.130	-0.153	0.236**	0.233**
	(-0.514)	(-0.608)	(2.083)	(2.095)
Constant	0.018	0.142	0.031	0.066
	(0.062)	(0.553)	(0.193)	(0.419)
Number of observations	3,339	3,339	9,315	9,315
R-squared	0.576	0.572	0.424	0.422
Output elasticities				
Land	0.274***	0.277***	0.248***	0.249***
	(18.780)	(19.190)	(21.096)	(21.221)
Labor	0.416***	0.421***	0.470***	0.472***
	(21.560)	(21.929)	(26.158)	(26.385)
Chemical fertilizer	0.132**	0.087***	0.119***	0.125***
	(2.355)	(3.723)	(3.893)	(4.173)
Pesticides	0.096***	0.115***	0.148**	0.122***
	(2.715)	(3.884)	(2.262)	(3.045)
Manure	0.113***	0.112***	0.106***	0.104***
	(8.329)	(8.464)	(6.308)	(6.278)
Returns to scale	1.031	1.011	1.092	1.072
Test of const. ret. to scale: *F*-value	1.66	0.09	1.74	2.08
Test for global separability				
Test for Cobb-Douglas: F-value	1.91**		1.57*	

Note: All the regressions include village fixed effects to control for unobserved differences between villages. Most of the Allen cross elasticities are not statistically different from zero. Jointly, they are not significantly different from (marginally). Thus, the translog specification does not really strongly dominate the Cobb-Douglas specification. Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Appendix Table 4: Farm Size Productivity Relationship: Yield Approach

	Holding level			Plot level			
Cropped area (ha)	-0.419***	-0.458***	-0.492***	-0.495***	-0.524***	-0.534***	-0.535***
	(-35.486)	(-35.902)	(-37.086)	(-66.722)	(-64.907)	(-65.990)	(-53.105)
Dist. from home (min)		0.002***	0.002***		-0.005***	-0.004***	-0.004***
		(6.932)	(6.508)		(-8.520)	(-6.669)	(-7.369)
Years possessed		0.002	0.004***		0.003***	0.005***	0.006***
		(1.498)	(2.607)		(4.163)	(5.264)	(4.645)
Plot in wetland		0.089	0.077		-0.012	-0.019	-0.018
		(1.008)	(0.888)		(-0.277)	(-0.431)	(-0.366)
Irrigated land		0.104	0.114		0.078	0.085*	0.013
		(1.320)	(1.462)		(1.642)	(1.798)	(0.195)
Flat land		-0.027	-0.036		-0.055*	-0.055*	0.039
		(-0.529)	(-0.724)		(-1.823)	(-1.835)	(1.046)
Gently sloped land		-0.058	-0.067		-0.058**	-0.067**	-0.025
		(-1.317)	(-1.541)		(-2.112)	(-2.461)	(-0.703)
Plot in valley		0.125	0.137		0.012	0.008	0.042
		(0.835)	(0.927)		(0.197)	(0.124)	(0.597)
Sandy soil		0.015	0.007		-0.004	0.003	-0.017
		(0.241)	(0.110)		(-0.109)	(0.086)	(-0.339)
Loam soil		0.225***	0.219***		0.174***	0.165***	0.051
		(4.467)	(4.389)		(5.458)	(5.243)	(1.211)
Light clay soil		0.146**	0.140**		0.086**	0.082**	-0.004
		(2.233)	(2.161)		(2.189)	(2.125)	(-0.075)
Heavy soil		0.154	0.093		0.127*	0.120*	0.136*
		(1.286)	(0.779)		(1.917)	(1.838)	(1.701)
Gravelly soil		-0.000	-0.015		0.002	0.010	0.025
		(-0.001)	(-0.244)		(0.048)	(0.261)	(0.508)
Crop shock		-0.223***	-0.214***		-0.249***	-0.225***	-0.210***
		(-6.164)	(-5.964)		(-10.418)	(-9.454)	(-6.721)
Grains		-1.451***	-1.342***			-0.808***	-0.506***
		(-5.449)	(-5.091)			(-7.695)	(-4.598)
Tubers		-1.022***	-0.920***			-0.669***	-0.454***
		(-3.767)	(-3.426)			(-6.324)	(-4.123)
Tree crops		-1.066***	-0.979***			-0.375***	-0.109
		(-3.919)	(-3.632)			(-3.456)	(-0.961)
Age of head			0.002			-0.000	
			(1.114)			(-0.308)	
Female head			-0.176***			-0.134***	
			(-4.586)			(-4.601)	
Primary school comp.			0.107***			0.048*	
			(3.078)			(1.866)	
Sec. education			0.174***			0.112**	
			(2.667)			(2.415)	
No of members <=14			0.034***			0.021***	
			(3.204)			(2.637)	
No of members 15- 35			0.039***			0.017*	
			(2.799)			(1.677)	
No of members 35- 60			0.041*			-0.013	
			(1.714)			(-0.759)	
No of members >=60			-0.007			-0.020	
			(-0.144)			(-0.596)	
Constant	5.118***	6.172***	5.709***	4.436***	4.381***	4.927***	4.711***
	(213.679)	(22.768)	(20.300)	(183.985)	(105.223)	(38.890)	(38.562)
Village fixed effects	No	Yes	Yes	No	Yes	Yes	No
Hh fixed effects				No	No	No	Yes
No of observations	3,353	3,339	3,336	9,583	9,315	9,309	9,315
R-squared	0.273	0.328	0.346	0.317	0.346	0.364	0.359

Note: Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Appendix Table 5: Farm Size and Intensity of Labor Use

	Holding level			Plot level			
Cropped area (ha)	-0.481***	-0.534***	-0.568***	-0.495***	-0.524***	-0.534***	-0.535***
	(-46.783)	(-48.472)	(-49.636)	(-66.722)	(-64.907)	(-65.990)	(-53.105)
Dist. from home (min)		0.003***	0.003***		-0.005***	-0.004***	-0.004***
		(11.487)	(10.959)		(-8.520)	(-6.669)	(-7.369)
Years possessed		0.001	-0.000		0.003***	0.005***	0.006***
		(1.429)	(-0.217)		(4.163)	(5.264)	(4.645)
Plot in wetland		0.123	0.115		-0.012	-0.019	-0.018
		(1.617)	(1.538)		(-0.277)	(-0.431)	(-0.366)
Irrigated land		-0.049	-0.033		0.078	0.085*	0.013
		(-0.726)	(-0.488)		(1.642)	(1.798)	(0.195)
Flat land		0.065	0.051		-0.055*	-0.055*	0.039
		(1.499)	(1.177)		(-1.823)	(-1.835)	(1.046)
Gently sloped land		0.065*	0.052		-0.058**	-0.067**	-0.025
		(1.704)	(1.390)		(-2.112)	(-2.461)	(-0.703)
Plot in valley		0.010	0.004		0.012	0.008	0.042
		(0.080)	(0.028)		(0.197)	(0.124)	(0.597)
Sandy soil		-0.019	-0.016		-0.004	0.003	-0.017
		(-0.348)	(-0.295)		(-0.109)	(0.086)	(-0.339)
Loam soil		0.036	0.041		0.174***	0.165***	0.051
		(0.827)	(0.948)		(5.458)	(5.243)	(1.211)
Light clay soil		0.009	0.012		0.086**	0.082**	-0.004
		(0.154)	(0.210)		(2.189)	(2.125)	(-0.075)
Heavy soil		0.147	0.110		0.127*	0.120*	0.136*
		(1.416)	(1.075)		(1.917)	(1.838)	(1.701)
Gravelly soil		-0.083	-0.087		0.002	0.010	0.025
		(-1.530)	(-1.617)		(0.048)	(0.261)	(0.508)
Crop shock		0.003	0.014		-0.249***	-0.225***	-0.210***
		(0.090)	(0.462)		(-10.418)	(-9.454)	(-6.721)
Grains		-0.817***	-0.791***			-0.808***	-0.506***
		(-3.550)	(-3.479)			(-7.695)	(-4.598)
Tubers		-0.407*	-0.382*			-0.669***	-0.454***
		(-1.735)	(-1.648)			(-6.324)	(-4.123)
Tree crops		-0.921***	-0.911***			-0.375***	-0.109
		(-3.917)	(-3.919)			(-3.456)	(-0.961)
Age of head			0.001			-0.000	
			(0.485)			(-0.308)	
Female head			-0.104***			-0.134***	
			(-3.136)			(-4.601)	
Primary school comp.			0.030			0.048*	
			(0.995)			(1.866)	
Sec. education			0.024			0.112**	
			(0.427)			(2.415)	
No of members <=14			0.029***			0.021***	
			(3.084)			(2.637)	
No of members 15- 35			0.040***			0.017*	
			(3.304)			(1.677)	
No of members 35- 60			0.118***			-0.013	
			(5.668)			(-0.759)	
No of members >=60			0.143***			-0.020	
			(3.579)			(-0.596)	
Constant	4.878***	5.338***	5.020***	4.436***	4.381***	4.927***	4.711***
	(233.811)	(22.781)	(20.689)	(183.985)	(105.223)	(38.890)	(38.562)
Village fixed effects	No	No	Yes	No	Yes	Yes	No
Hh fixed effects	No	Yes	No	No	No	No	Yes
No of observations	3,353	3,339	3,336	9,583	9,315	9,309	9,315
R-squared	0.395	0.457	0.474	0.317	0.346	0.364	0.359

Note: Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

Appendix Table 6: Farm Size Productivity Relationship: Net Profit Approach

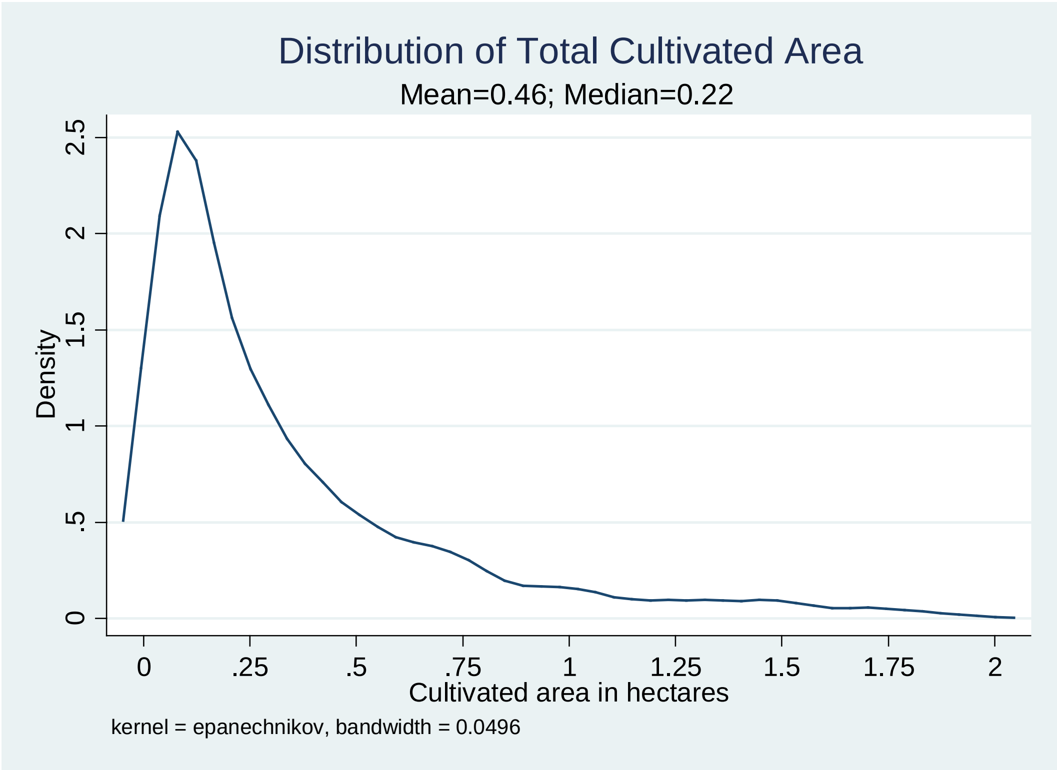
	Holding level			Plot level			
Cropped area (ha)	-0.008	-0.010	-0.013	0.037***	0.030***	0.024**	0.006
	(-0.896)	(-1.011)	(-1.301)	(4.437)	(3.217)	(2.499)	(0.445)
Dist. from home (min)		-0.000*	-0.000*		-0.004***	-0.002***	-0.003***
		(-1.758)	(-1.672)		(-6.056)	(-3.712)	(-4.130)
Years possessed		0.001	0.003***		0.000	0.002	-0.000
		(0.876)	(2.701)		(0.522)	(1.515)	(-0.184)
Plot in wetland		-0.071	-0.073		-0.043	-0.028	0.010
		(-1.081)	(-1.116)		(-0.840)	(-0.545)	(0.167)
Irrigated land		0.039	0.039		-0.006	-0.003	-0.117
		(0.667)	(0.660)		(-0.110)	(-0.060)	(-1.437)
Flat land		-0.046	-0.046		-0.020	-0.019	0.129***
		(-1.225)	(-1.216)		(-0.575)	(-0.551)	(2.754)
Gently sloped land		-0.062*	-0.061*		-0.054*	-0.056*	0.073*
		(-1.905)	(-1.873)		(-1.687)	(-1.754)	(1.674)
Plot in valley		0.084	0.090		-0.096	-0.066	-0.014
		(0.753)	(0.806)		(-1.308)	(-0.910)	(-0.160)
Sandy soil		0.017	0.013		0.022	0.024	0.021
		(0.380)	(0.290)		(0.501)	(0.553)	(0.335)
Loam soil		0.137***	0.133***		0.135***	0.123***	0.044
		(3.658)	(3.535)		(3.665)	(3.345)	(0.823)
Light clay soil		0.103**	0.099**		0.087*	0.082*	-0.004
		(2.107)	(2.033)		(1.921)	(1.817)	(-0.063)
Heavy soil		-0.148*	-0.163*		-0.097	-0.086	0.047
		(-1.662)	(-1.818)		(-1.263)	(-1.123)	(0.465)
Gravelly soil		0.038	0.031		0.061	0.062	0.023
		(0.815)	(0.665)		(1.313)	(1.345)	(0.369)
Crop shock		-0.095***	-0.095***		-0.175***	-0.172***	-0.101***
		(-3.522)	(-3.530)		(-6.308)	(-6.187)	(-2.583)
Grains		-0.484**	-0.442**			-0.478***	-0.501***
		(-2.444)	(-2.227)			(-3.905)	(-3.649)
Tubers		-0.532***	-0.492**			-0.607***	-0.659***
		(-2.636)	(-2.433)			(-4.920)	(-4.788)
Tree crops		-0.255	-0.218			-0.107	-0.109
		(-1.263)	(-1.077)			(-0.842)	(-0.771)
Age of head			-0.000			-0.001	
			(-0.394)			(-0.480)	
Female head			-0.066**			-0.027	
			(-2.296)			(-0.802)	
Primary school comp.			0.030			0.044	
			(1.139)			(1.467)	
Sec. education			0.065			0.127**	
			(1.331)			(2.342)	
No of members <=14			-0.005			0.004	
			(-0.557)			(0.463)	
No of members 15- 35			-0.002			-0.008	
			(-0.207)			(-0.726)	
No of members 35- 60			-0.013			-0.038*	
			(-0.733)			(-1.876)	
No of members >=60			-0.064*			-0.045	
			(-1.833)			(-1.141)	
Constant	0.094***	0.533***	0.506**	0.200***	0.234***	0.663***	0.578***
	(5.367)	(2.646)	(2.390)	(7.292)	(4.840)	(4.486)	(3.783)
Village fixed effects	No	No	Yes	No	Yes	Yes	No
Hh fixed effects	No	Yes	No	No	No	No	Yes
No of observations	3,353	3,339	3,336	9,583	9,315	9,309	9,315
R-squared	0.000	0.026	0.031	0.002	0.013	0.031	0.036

Note: Absolute value of t-statistics in parenthesis: *** significant at 1%; ** significant at 5%; * significant at 1%.

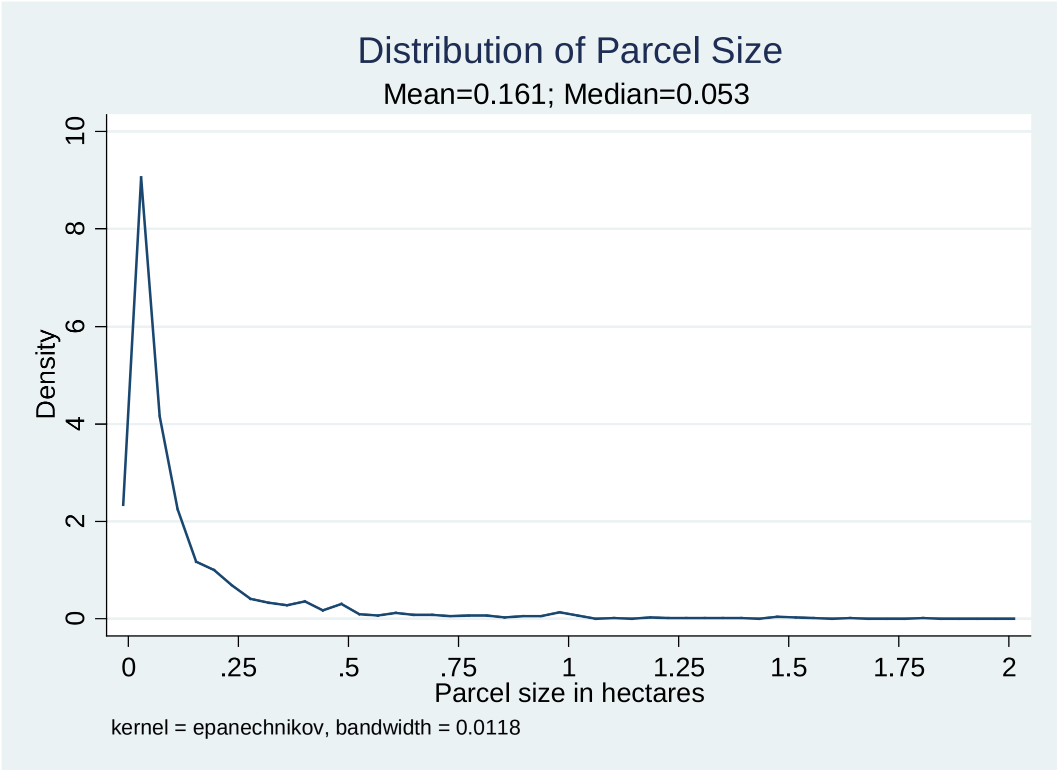
Appendix Table 7: Farm Size Productivity Relationship: Variation by Farm size

	Yield		Net profit	
	Holding	**Plot**	**Holding**	**Plot**
Cropped area (ha)	-0.597***	-0.598***	-0.032	-0.019
(α_1)	(-14.588)	(-22.185)	(-1.031)	(-0.578)
Cropped area (ha) *	0.108***	0.051**	0.019	0.019
first tercile (γ_1)	(2.705)	(2.554)	(0.643)	(0.761)
Cropped area (ha) *	0.076*	0.066***	0.023	-0.015
second tercile (γ_2)	(1.798)	(3.708)	(0.729)	(-0.658)
Village fixed effects	Yes		Yes	
Hh fixed effects		Yes		Yes
Tests:				
$\alpha_1 + \gamma_1 = 0$	1350.03***	2387.03***	1.54	4.17**
$\alpha_1 + \gamma_2 = 0$	473.42***	1046.99***	0.23	0.39
No of observations	3,336	9,315	3,336	9,315
R-squared	0.348	0.361	0.031	0.037

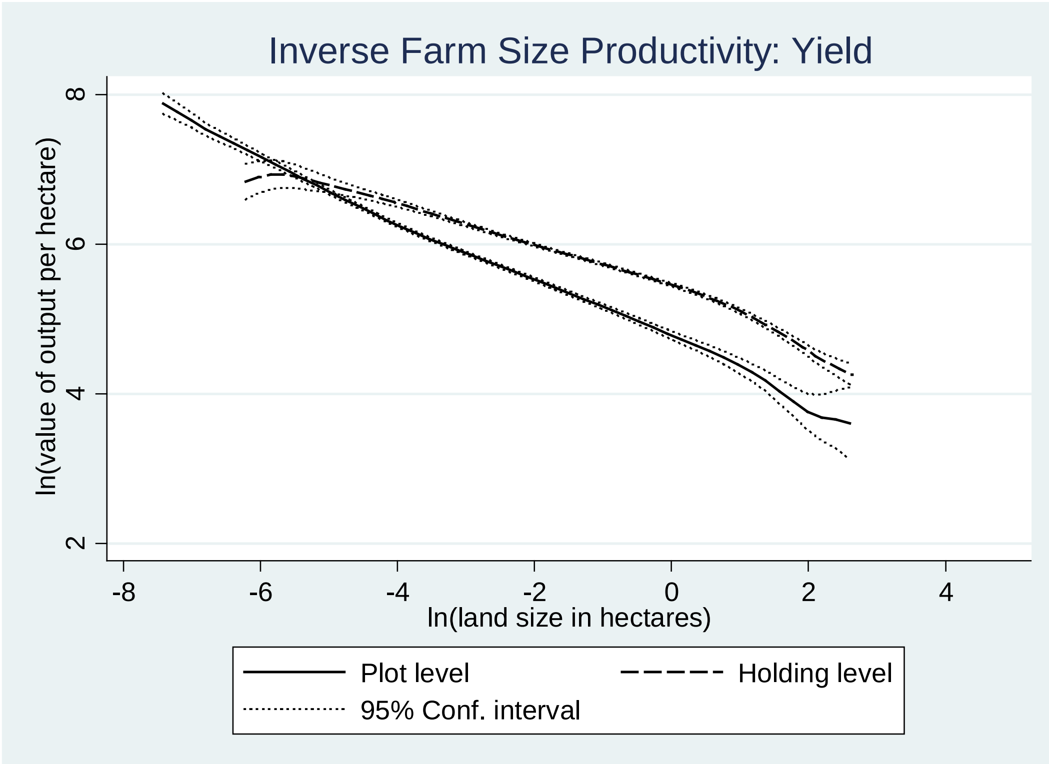
Note: Coefficients are from the specifications in columns (4) and (7) above for holding and plot levels, respectively with only the relevant coefficients reported.



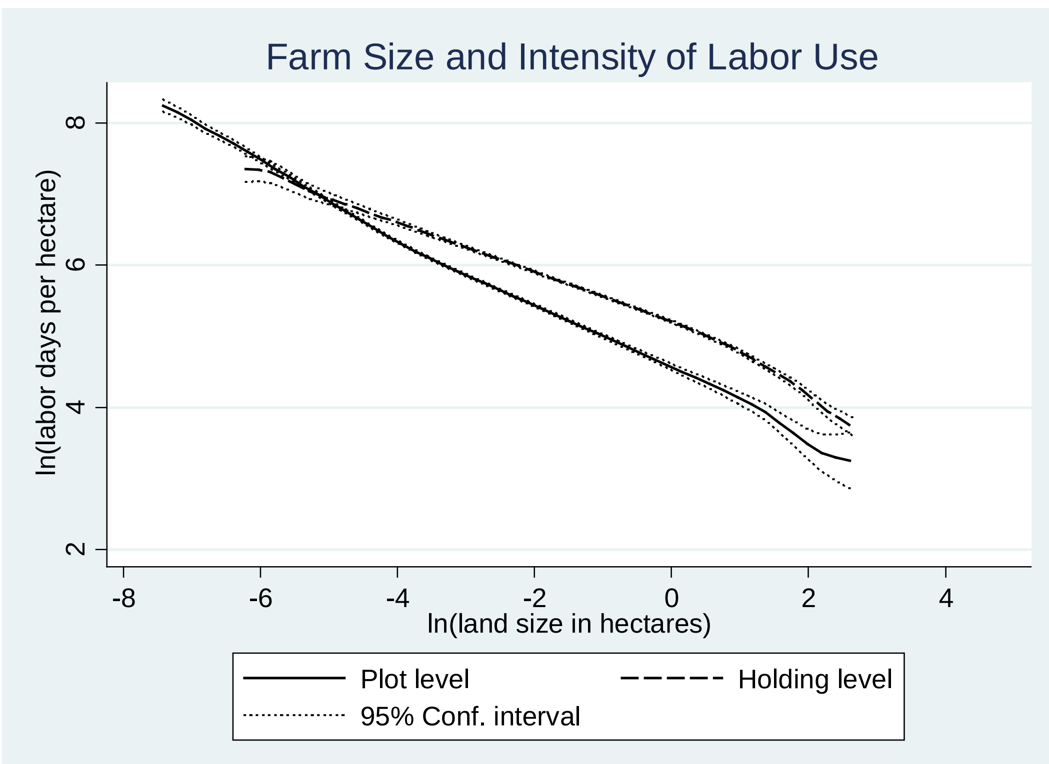
Appendix Figure 1.



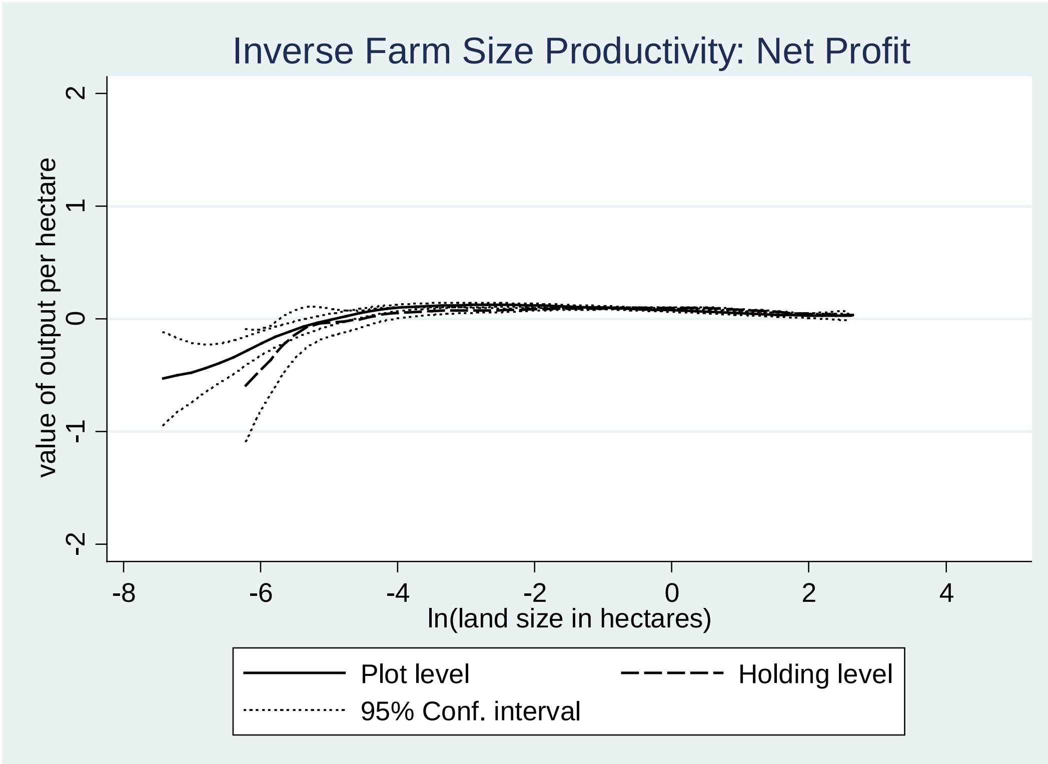
Appendix Figure 2.



Appendix Figure 3.



Appendix Figure 4.



Appendix Figure 5.