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A revisit of farm size and productivity: Empirical evidence from a wide range of farm sizes in Nigeria

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Abstract

The inverse farm size-productivity relationship (IR) has been documented in the agricultural and development economics literature. However, most of the documented evidence in sub-Saharan Africa (SSA) is based on samples of small-scale farms operating 5 hectares or less, with very little evidence assessing this relationship over a wider range of farm sizes. This topic is especially important considering the rapid expansion of medium-scale farms in much of Africa. This study examines the farm size-productivity relationship over a range of farms between zero and 70 hectares in Nigeria. Using four measures of productivity, empirical estimates reveal a U-shaped relationship where IR holds firmly between zero and 20 hectares, is relatively flat between 20-30 hectares, and then turns positive at about 30 hectares. Further evidence suggests heterogeneity in productivity within medium-scale farms depending on whether the owner-operators were formerly active small-scale farmers who expanded their operations or whether they were primarily in non-farm employment and later acquired land for farming. These findings may have important implications for agricultural policy development in SSA, which are highlighted. We recommend a hybrid approach to agricultural policies supporting both small-scale farmers as well as commercial farmers based on the U-shaped findings.

Keywords: Inverse relationship, agricultural productivity, large & medium-scale farms, farm size, Nigeria, sub-Saharan Africa (SSA)

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1. INTRODUCTION

The inverse relationship (IR) between farm size and productivity, defined as output per unit of land, is a longstanding empirical regularity in agricultural and development economics literature. Starting with Chayanov (1966) in Russia and later established by Sen (1966) in India, this relationship has also been widely observed in sub-Saharan Africa (SSA) but mostly among farmers cultivating farms 5 hectares and below (e.g., Barrett, 1996; Carletto et al., 2013, 2015; Julien et al., 2019; Kimhi, 2006). Following this stylized fact and the preponderance of small-scale farms in SSA, many development economists and institutions in agriculture believe that prioritizing smallholder-led development is essential for agricultural development in the region (Hazell et al., 2010; Mellor, 1995). However, with recent drive to promote commercial agriculture in Africa (African Development Bank, 2017) and rapid growth of medium-scale farms in many parts of Africa (Jayne et al., 2016), the farm-size productivity debate may likely intensify on the continent. The fundamental question remains whether African agricultural development and food security can be achieved mainly thorough smallholder-led strategies, or if alternative modes or scales of production are required (Collier & Dercon, 2014). Hence, there is a need for empirical evaluation of farm size-productivity relationship across a wider range of farms beyond the 5-hectare farm size mostly studied in SSA.

Given the paucity of empirical evidence on farm size-productivity relationship involving farms over 10 hectares in developing countries in general and SSA in particular (Julien et al., 2019; Muyanga & Jayne, 2019; Rada & Fuglie, 2019), our goal is to examine this relationship over a relatively wide range of farm sizes in Nigeria and consider its implications for land and agricultural policies. To our knowledge, Muyanga & Jayne (2019) is the only study to have examined this relationship over a wide range of farms in SSA.[1] Examining this relationship in Kenya, Eastern Africa, the authors not only confirmed what has been mostly observed in the literature that IR exists on farm sizes 3 hectares and below, but find a positive relationship between productivity and farm size in the medium to large-scale farms. The present study builds upon Muyanga & Jayne (2019) by examining farm size-productivity relationship across a wide range of farm sizes in Nigeria, providing missing empirical evidence in Western Africa. Specifically, we test whether the IR hypothesis exist beyond the small-scale farms (< 5 hectares) and whether heterogeneity exists in productivity among medium-scale farmers with or without prior engagement in small-scale farming, using Nigeria as a case study. Nigeria is the largest economy and most populous country in Africa (Naidoo, 2020). It is projected to be the third largest country in the world by 2050 (by the UN) This makes understanding of any activity or knowledge to increase productivity and address food security critical on both continental and global level.

[1] Rada et al. (2019) examined this relationship over a wide range of farms in Brazil.

This paper makes three key contributions to the IR literature. First, using new primary data, we examine the farm size-productivity relationship within farm sizes wider than previous studies in our context (Carletto et al., 2013; Julien et al., 2019; Kimhi, 2006). Understanding this relationship may be important for guiding decision making among policymakers and investment decisions within the private sector. Second, we extend Muyanga and Jayne (2019) who assumed homogeneity among medium-scale farm operators and explore potential heterogeneity in productivity among medium scale farms. More specifically, we distinguish between the pathways through which medium-scale farms emerge as follows: i) *stepped-up* medium-scale farm operators who were engaged in small-scale farming prior to stepping up vs. ii) *stepped-in* medium-scale farmers, who are likely commercial investors in agriculture, with no prior involvement in farming prior to stepping in.[2] Third, we use multiple measures of productivity. Rather than restrict productivity to nominal measures of a single crop production or output per hectare (yield) as in many studies on IR (e.g., Assunção and Braido, 2007; Bevis and Barrett, 2017; Carletto et al., 2015; etc.), we use values of crop and farm outputs that allows for multiple crops and livestock, and further extend productivity measures to net output or profit of both crop production and total farm operations. Specifically, we used four measures of productivity: i) gross value of crop output per hectare; ii) gross value of total farm output per hectare operated; iii) net value of crop output per hectare cultivated; and iv), net value of total farm output per hectare operated.

The study utilizes primary data collected from a cross-section of about 2,000 smallholders and medium-scale farm operators in Nigeria as part of the Agricultural Policy Research in Africa (APRA) program, funded by the United Kingdom's Department for International Development (UK-DFID). This new data is different from the kind of household survey data used by most previous studies on IR estimations because of the range of farm sizes covered. Farm sizes in previous nationally representative household survey data are mostly under 5 hectares making such data insufficient to perform our kind of analysis due to underrepresentation of medium and large-scale farms. In addition to the contributions mentioned above, because the new data was collected in part to test the IR hypothesis, the present study is able to account for the usual suspects (imperfect factor markets and omitted variable bias, e.g., lack of soil quality data) culpable for IR findings in the previous literature.

We find evidence of a non-linear U-shaped relationship between farm size and productivity over the range of farm sizes studied (0-70 hectares). However, when restricted to only smallholders, like in many previous studies, we observed an exclusive IR with very smallholder farmers exhibiting highest productivity. In general, regardless of which productivity measure was examined, IR holds firmly between

[2] Productivity may differ among these farm operators resulting from some factors such as farming or farm management experience, knowledge about the local agro-ecology and microclimate, social capital leading to ability to get good quality or easily accessible land, or understanding of input/output market dynamics.

zero and 20 hectares, is relatively flat between 20-30 hectares, and then turns positive afterwards. We equally observed that contrary to homogeneity assumptions among medium-scale farmer operators in previous literature, productivity may be heterogenous in SSA depending on the pathway through which such operators might have emerged. Considering our data is restricted to two states in Nigeria (one in the north and another in the south) that have created an enabling environment for medium-scale agriculture to thrive, our findings should be interpreted in this context and may not be seen as nationally representative. Nevertheless, we present the first evidence testing the IR relationship in the context of wide range of farms in Nigeria and West Africa. These findings, if upheld by future studies, may hold important implications for agricultural development policy in the region.

2. OVERVIEW ON FARM SIZE-PRODUCTIVITY RELATIONSHIP

The literature on IR is robust but limited mainly to smallholder farms. The literature has attributed the IR "puzzle" to a variety of factors. First, the more common explanation has been factor market imperfections in labor where family labor surplus is expended on farm work with low shadow price (Binswanger et al. 1995; Eswaran & Kotwa, 1986; Sen, 1966), increasing labor input per hectare on small farms (Carter, 1984; Reardon et al., 1996). Similarly, Feder (1985) and Eswaran & Kotwa (1986) espoused the principal-agent problem explanation where the cost of hired labor supervision is higher relative to family labor—a moral hazard problem. That is, hired labor used more intensely on larger farms is only more efficient than family labor under increased supervision, hence, larger farms tend to be underproductive than smallholder plots. In this study, we estimate shadow wage for family labor and control for hired labor to account for labor market imperfections.

The second types of explanations for IR are omitted variables such as soil qualities and unobserved heterogeneity across plots and lands (Assunção & Braido, 2007; Bhalla & Roy, 1988; Benjamin, 1995; Kimhi, 2006; Lamb 2003). Assuming soil qualities are correlated with farm size, perhaps due to competition for farmland, omission of variables representing these qualities may bias IR estimates. Assunção and Braido (2007) investigated omitted variable bias using household fixed effects and plot level-seasonality effects and found IR remains unchanged. Controlling for land quality reveals that IR still holds between farm size and productivity albeit with slightly weakened magnitude (Assunção & Braido, 2007; Benjamin, 1995; Carter, 1984). On the contrary, Bhalla & Roy (1988) used Indian data and find that controlling for farm-level soil quality eliminates IR. However, they did not control for labor inputs and imperfections in labor markets in their study. Barrett et al. (2010) virtually ended the debate on soil quality as an accessory to IR by using an objectively measured and laboratory-tested soil quality and find no evidence that soil quality explains IR results at the plot-level.

Third, risk concerns such as price risk where smallholders are risk averse can lead to IR (Barrett, 1996; Srinivasan, 1972). For instance, land market imperfections and lack of insurance markets may actively push smallholders (usually net buyers of staple food) to invest excess labor on their farms as a mitigating factor against buying food at a more expensive price later in the market. The reverse being the case for medium to large-scale farmers who are usually net sellers. Hence, smallholders are likely more productive as a result of these multiple market failures.

Lastly, statistical artifacts such as measurement errors either in self-reported plot size (Carletto et al., 2013; 2015; Lamb, 2003) or yield (Desiere & Jolliffe, 2018; Gourlay et al., 2019) have recently been examined in IR literature. Studies by Carletto et al. (2013; 2015) used self-reported (SR) farm size and compared farm size-productivity estimates with GPS plot measurements. Similarly, Dillon et al. (2019) compared SR farm size with GPS and the FAO recommended compass-and-rope (CR) plot measures (Simaika, 1982). These studies found that small-scale farms were more likely to overstate farm size and larger farms likely to under-report farm size, but IR holds regardless of the farm area measurement approach (SR, GPS, or CR); largely supporting that previous IR findings are not statistical artifacts. In fact, Carletto et al. (2013) finds that GPS measure of farm size strengthened evidence in support of IR. However, more recent studies have suggested systematic measurement errors, particularly self-reported output/yield, are key drivers of IR findings (Desiere & Jolliffe, 2018; Gourlay et al., 2019). Both studies use crop-cut method to determine yield and find that IR is an artifact of measurement error, particularly, self-reported yield. Although these studies are largely limited to small-scale farms and evaluated IR using a single crop, yields from crop-cuts within fields may be subject to attenuation depending on whether crops were cut on the interior or the periphery, the 'edge effect' according to Bevis & Barrett (2017).

Whereas most studies have found or upheld the existence of IR hypothesis in SSA (e.g., Carletto et al., 2013; Dillon et al., 2019; Julien et al., 2019), some find a U-shaped relationship between farm size and productivity (Carter & Weibe, 1990; Kimhi, 2006; Muyanga & Jayne, 2019). For instance, Muyanga & Jayne (2019) found IR between farm size and crop productivity among small-scale farms (less than 5 hectares) in Kenya, but the IR gives way for a U-shaped relationship when medium-scale farms were included in their sample. Similarly, Kimhi (2006) examined a relationship between maize productivity and plot size in Zambia and found a U-shaped relationship with IR dominating up to 3 hectares (about 86% of their sample), but constant and increasing returns to scales beyond the 3-hectare threshold. Like in Muyanga & Jayne (2019), we examine farm size-productivity relationship over a wider range of farms than other typical IR studies in the region. As such, our study should account for economies of scale in input use and specialization while also accounting for labor market imperfection and soil quality issues previously reported.

3. DATA, SAMPLING DESIGN AND VARIABLES USED

(a) Data

This study uses primary data collected from a survey of about 2,000 farms ranging up to 70 hectares in two states in Nigeria. The data was collected using a structured questionnaire designed to capture socio-economic information on households managing or operating these farms, agricultural inputs used, crops cultivated, animals raised, output, and marketing information. A unique feature of this data is that farming households cultivate different (and often fragmented) plots of land. We aggregate such plots to household or farm management level, dropping 1.8% of plots that households have not harvested for the agricultural season covered by the survey interviews. There is no correlation between farm size categories and the share of unharvested plots dropped.

Collecting primary data was necessary for this study because the ideal data is not available. Most available nationally representative farm household survey datasets in SSA, such as the Living Standards Measurement Study (LSMS), tend to have very limited medium-scale farms to make inferential conclusions about them.[3] Moreover, because urban-based households appear to constitute a sizeable proportion of new investment in commercialized medium-scale farms, existing nationally-representative farm surveys may increasingly omit an important and growing segment of the population of medium-scale farms (Jayne et al., 2016). For the above reasons, a comprehensive listing and sampling of small-scale and medium-scale farm households was implemented.

(b) Sampling Design

We employed a multistage stratified sampling strategy that started with a listing of the population of households controlling and/or operating a farm size of 5 hectares and above in the study area. Initial decision to list farms larger than 5 hectares was because small-scale farms were ubiquitous unlike medium-scale farms. Administratively, Nigeria is divided into 36 states and the Federal Capital Territory (FCT). For the purpose of this study, Ogun and Kaduna states in southern and northern Nigeria, respectively, were purposely selected because both states have made significant strides in providing necessary policy environment for medium to large-scale commercial agriculture development. For example, Kaduna state was one of the 5 pilot states (Cross River, Enugu, Kaduna, Kano and Lagos) in which a World Bank assisted

[3] For example, the 2010/11 Tanzania LSMS contains 11 farms cultivating between 20-50 hectares, and only one farm between 50-100 hectares. In the Uganda LSMS, there are 12 farms between 20-50 hectares and none over 50 hectares. The Malawi 2010/11 LSMS contains one farm observation between 10-20 hectares, 1 farm between 20-50 hectares, and zero farms over 50 hectares. These surveys do not contain enough sample size to draw meaningful conclusions about farms over 20 hectares. This conclusion is also acknowledged by the World Bank in its recent 2018 Myths and Facts book relying on the use of LSMS data (Christiaensen and Demery, 2018, p. 10).

Commercial Agriculture Development Program (CADP) was implemented between 2009 and 2017. The CADP was designed to improve access of participating small and medium-scale commercial farmers to technology, infrastructure, finance, and output markets (World Bank, 2008). One of the reasons for choosing Ogun State is its proximity to Lagos, the largest commercial center in Nigeria and one of the 5 pilot states for CADP in Nigeria. Furthermore, in the past decade, the Ogun State government has adopted policies and strategies that highly favor the development of commercial agriculture.[4]

Following the selection of states, a second stage listing exercise included systematic selection of three Local Government Areas (LGAs) in each state.[5] Typically, each state in Nigeria has three (3) senatorial districts to represent them at the National Assembly (The Senate). These senatorial districts are an important feature along which infrastructural investments, among other resources, are allocated. Hence, we purposively sampled one LGA per senatorial district based on land size and farmer concentrations. The selected LGAs are Kachia, Chikun, and Soba in Kaduna South, Central, and North senatorial districts, respectively;[6] and Ijebu East, Imeko–Afon, and Obafemi Owondo LGAs in Ogun East, West, and Central senatorial districts, respectively. Within the sampled LGAs, all wards (administrative units within LGAs) were stratified into top terciles in Kaduna and quartiles in Ogun using medium-scale farm concentrations. The final stage of the listing exercise entailed listing of households controlling (e.g., owned, rented-in, borrowed, etc.) or operating farms five hectares and above within the selected LGAs. The exercise was implemented by a team of trained enumerators.[7]

Subsequently, there were two levels of random selection: ward-level and farm-level. Three wards per LGA were randomly selected and in each ward, we employed a random sampling with probability proportional to size to ensure proper representation of the population of medium-scale farms operational in each LGA (see Appendix Table A.1 for breakdown of samples from both states). Furthermore, our sampling design accounted for the two farming systems (smallholder farms and medium-scale farms) in the LGAs. Overall, about 1,000 farm households—500 small-scale and 500 medium-scale farm households—were surveyed in each state, yielding a total sample of about 2,000 respondents (See Muyanga et al (2019) for more details on sampling design). In the end, we categorized farm sizes into four (4) categories: a small-scale (<5ha) category; and three (3) separate medium-scale categories in ($5 \leq ha < 10$), ($10 \leq ha < 20$), and ($20 \leq ha < 70$), respectively, to better understand characteristics of different medium-scale farm distributions

[4] Refer to https://ogunagric.com/investor-relations/

[5] States in Nigeria are administratively divided into Local Government Areas (LGAs), which themselves are further divided into wards comprising many communities, villages or towns.

[6] While Birnin Gwari LGA was the largest in Kaduna Central, it could not be included in this study owing to insecurity concerns. Consequently, Chikun—the next largest LGA in Kaduna Central—was selected.

[7] The listing protocol used by enumerators is available upon request.

The ex-post proportions of these farm categories are 54, 31, 11 and 4 percent, respectively (see Table 1 for breakdown and characteristics of each category).

(c) Dependent and explanatory variables

For dependent variables, we computed four measures of agricultural productivity namely i) the gross value of crop output per hectare cultivated, ii) the gross value of total farm output per hectare operated, iii) the net value of crop output per hectare cultivated, and iv) the net value of total farm output per hectare operated. The main difference between crop and farm output is that the farm output included outputs from crop cultivation and animal holdings. However, there is strong correlation between these measures because few farms operated a separate land to animal production.[8] The net values of both cultivated crop and operated farm outputs were computed as the gross values less the total cost including input costs, hired labor cost, and shadow wage imputed for family labor. Carter & Wiebe (1990) find that the IR relationship between productivity and farm size is reversed when profit measure (after removing family labor cost) was examined. Hence, using the net values per hectare as computed in this study may help examine previous assertion that not accounting for some inputs in productivity analysis, particularly family labor, may lead to observed IR (Carter & Wiebe, 1990; Lamb, 2003).

The main explanatory variable of interest are the self-reported area of land cultivated or operated by farms and its squared term. The use of self-reported values as against GPS-measured value may be questioned but recent studies have demonstrated that the use of self-reported farm areas rather than GPS-measured areas does not explain away the IR (Carletto et al., 2013; 2015; Dillon et al., 2019). The explanatory variables included are demographic information of the farming household; assets including farm equipment; proxy for agro-ecology, self-reported soil type (sandy, clay, loamy, stony or forest) and quality (good, fair or poor); categories of crops cultivated—grains, legumes, roots and tubers, fruits and vegetables, and cash crops; inputs, including fertilizer use and labor (hired and family). In addition, information such as access to market and/or input dealers, access to and use of extension services. These variables were derived from asking survey respondents whether they have access to the services. Lastly, a binary indicator variable to capture whether a farm operator stepped up into medium-scale farming from prior small-scale operations (=1) and zero (0) if a farmer stepped in into medium-scale farming without prior small-scale farming engagement. Previous studies have shown these two very distinct pathways into medium-scale farming, with distinct socio-demographic conditions for the two groups (Muyanga et al., 2019; Jayne et al., 2019).

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[8] Pairwise correlations between crop and farm output is about 86%.

4. ESTIMATION STRATEGY

From a theoretical standpoint, a simple Cobb-Douglas production function may be estimated where output/ha is a function of factors including land, capital and other factors. In our case, however, following previous studies based on neo-classical production approach (Assunção and Braido, 2007; Barrett et al., 2010; Muyanga and Jayne, 2019), we estimated a reduced form model as specified in equation (1).[9]

$$Y_i = \beta_o + \beta_1 A_i + \beta_2 A_i^2 + \boldsymbol{\beta_3 X_i} + \beta_4 S_i + \beta_5 A_i * S_i + \varepsilon_i \qquad (1)$$

Let Y_i be the outcome variables (i.e., self-reported measures of productivity) for household i. The explanatory variables are self-reported farm size/area cultivated or operated in hectares (A_i) and its square (A_i^2); a vector of controls ($\boldsymbol{X_i}$) including household characteristics, family and hired labor to account for imperfect factor markets, fertilizer input use, and crop category cultivated (these are binary indicator variables for the five different crop categories mentioned earlier). Other elements in the vector $\boldsymbol{X_i}$ are self-assessed soil types and qualities, household assets, access to agricultural extension and output market, and state fixed effect. The quadratic term is to determine shape of any curvature in the estimated function. Also included in equation (1) is a dummy variable S_i to account for the two distinct pathways of emergence among medium-scale farms as described earlier. We suspect households who were engaged in small-scale farming prior to stepping-up to medium-scale farming may be have more farm management experience or knowledge of agro-ecological and micro-climate of farming areas, than those primarily involved in non-farm jobs who later acquired land for diversification into farming or who started farming after having retired from non-farm work. This dummy variable is also interacted with the farm size variable to examine potential differences in productivity between stepped-up farm operators and other as farm size increases. The β_s (Greek beta) are parameters to be estimated where β_1 and β_2 are the parameters of interest, $\boldsymbol{\beta_3}$ is a vector of parameters including household and farm characteristics, β_4 estimates productivity for stepped-up farm operators relative to other farmers, β_5 captures impact of any incremental productivity attributed to stepping up as farm size increases, and ε_i is the error term. If $\beta_1$is negative, it confirms the existence of IR but if positive, there is a direct relationship between farm size and productivity. The quadratic term parameter (β_2) identifies shape of the curve and helps determine turning points.

For each productivity measure examined, we first estimated a parsimonious model with farm size and exogenous household variables, including market and agricultural extension access in vector ($\boldsymbol{X_i}$). Subsequently, we included other potentially endogenous control variables such as labor and fertilizer use,

[9] Other studies (e.g., Carletto et al., 2013; Desiere and Jolliffe, 2018; Dillon et al., 2019) have used log-log variant of estimating equation (1) in the form of elasticities. Although we estimated a direct level-level relationship between productivity and farm size, as a robustness check, we equally estimated elasticities (log-log). Our findings and conclusions are the same regardless of the functional form (direct or elasticities) estimated.

crop types cultivated, soil qualities, and decision to step up farming from small-scale to medium-scale farming. Including labor ensures that we control for market imperfection in labor use as alluded to in previous IR studies. Given that on-farm household labor valuation may be different than hired labor depending on if the household is subsistent or commercially oriented, we estimated a shadow wage to value household labor. The family labor wage was derived as a shadow price, computed from the marginal revenue product of family labor by estimating a Cobb-Douglas production function, following Skoufias (1994) and Abdulai & Regmi (2000). Lastly, we controlled for household assets to account for wealth, farm equipment, access to both output and input markets, and crop type to account for the fact that some smallholders focus on mainly producing staple crops for food security purpose (Doward, 1999; Fafchamps, 1992; Omamo, 1998).

Overall, we estimated different variants of equation (1) as Models I-IV. In Model I, the sample size is restricted to small-scale farms (<5ha) only. We estimated a separate model for small-scale farms because most of the previous studies on IR in SSA have been within this range of farms. Thus, we can examine if the usual findings of IR among smallholders is sustained in the Nigerian context. Models II and III include samples from both small and medium-scale farms but restricting the medium-scale samples to only *stepped-in* or *stepped-up* farmers, respectively. The *stepped-in* farmers lack prior farming engagement before 'stepping-in' into farming, and are likely commercial farmers, whereas, the *stepped-up* farmers were engaged in small-scale farming before 'stepping-up' into medium-scale farming. A difference between estimated Models II and III would suggest presence of heterogeneity in productivity of medium-scale farm operators, depending on the pathways through which such medium-scale farms have emerged. Finally, Model IV includes the entire sample unrestricted (small and medium-scale) with a dummy variable for stepped-up farmers and interacted with farm size.

5. RESULTS AND DISCUSSION

(a) Descriptive statistics

Table 1A shows a comparison of variable means across the four farm size categories. For dependent variables (measures of productivity in panel A), results suggest that on average, the small-scale farms appear more productive per hectare using both crop and farm gross outputs. In addition, the net values (gross values less total cost of production from labor and input use) of crop and total farm output suggest that small-scale farmers are, on average, equally more productive than their medium-scale counterparts. However, these medium-scale farms have a much lower crop production cost per hectare once farm size is larger than 10 hectares (see Panel E).

Panel B reveals differences across farm size categories operated in terms of household head's age, family size, and years of education. On average, operators of medium-scale farms appear older with relatively larger household size. Farming households with over 20 hectares have two members more than small-scale households on average whether adult equivalent or direct household membership is used, but years of education for household head is slightly higher for farmers operating over 20 hectares and otherwise, appear largely similar across farm operators. Some of these medium-scale farm operators may be urban-based professionals, retirees or influential rural dwellers as found in a recent study of medium/large farms in sub-Saharan Africa (Jayne et al., 2016). In addition, smallholder farms are significantly more likely to be headed by a female relative to medium-scale farms.

On household assets (Panel C), on average, about 80% of farm operators have access to radio regardless of farm size operated, and mobile phone ownership is nearly universal across farm size at between 95% to 98% ownership. However, significant differences are observed in ownership of high value assets such as motorcycles, cars, water pumps, and mechanical sprayers. Across the categories, the proportion of farm operators owning these high value assets is low among small-scale farmers and increases as farm size increases with farms larger than 20 hectares having highest ownerships.

Panel D shows soil type and quality characteristics, and proxy for weather. Given the potential correlation between soil quality and fertilizer use, results suggest that self-assessment of soil types and quality are largely the same across farm size categories. For instance, majority (95%) identified their soil type as loamy while similar share assessed their soil quality as good.

In Panel E, the proportion of land cultivated or operated is positively correlated with total landholdings. This contrasts with findings from Kenya, where the proportion of land operated is inversely proportional to total landholdings (Muyanga & Jayne, 2019). On the other hand, the total cost of production per hectare reduces with farm size, similar to findings across small to medium-scale farms in Kenya (Muyanga & Jayne, 2019). The lower cost among large-scale farms is expected because of economies of scale. In addition, like previous IR literature where imperfect labor market has been cited as one reason for observing IR (e.g., Carter, 1984; Reardon et al., 1996; Sen 1966, etc.), we find evidence that family labor surplus is intensively expended on farm work among small-scale farmers and that family labor days per hectare significantly decreases as farm size increases. For perspective, at 14 days/ha, family labor on small-scale farms are about five times those of large medium-scale (>20ha) farms (2.7 days/ha). However, the contrast is the case with hired labor days per hectare increasing with farm size. This finding reveals that that hired labor is such an important component of total labor input into farming in Nigeria. The derived shadow wage for family labor suggests that the valuation of labor for smallholders may be grossly undervalued, supporting further evidence of labor market imperfections suggested in previous literature. For example, the imputed family wage per hectare for smallholders (<5ha) is more than five times that of farms larger than 20 hectares.

On input use, perhaps contrary to conventional expectation from SSA, we find fertilizer use per hectare to be high at 164kg/ha, on average. This is consistent with literature that the use of fertilizer among Nigerian farmers is between 128kg/ha and 310kg/ha (Liverpool-Tasie et al., 2017; Sheahan & Barrett, 2017). A further scrutiny reveals that more fertilizer is used in Kaduna state in northern Nigeria than Ogun state in the south. This finding of more fertilizer use in northern part of Nigeria has been documented in the literature (e.g., Liverpool-Tasie et al., 2014). Nevertheless, in theory, larger farms are supposed to be more productive because of economies of scale, efficiency, and access to more modern input use (Binswanger et al., 1995); and our findings demonstrate that larger medium-scale farmers use less fertilizer per hectare (91kg/ha), on average, compared with small and medium-scale farm that use 169kg/ha and 183kg/ha, respectively.

Considering one of our study's objectives is to examine the IR hypothesis for heterogeneity based on pathways through which medium-scale farms have emerged, Table 1B shows the same descriptive characteristics, but only for medium-scale farms or operators considering the emergence pathways (*stepped-up* vs. *stepped-in*). Overall, findings suggest that across all productivity measures, *stepped-up* farmers (with prior engagement as smallholders are more productive than their *stepped-in* counterparts. Furthermore, the stepped-up farmers appear older and less educated with more females as head, but largely similar in assets. On farm characteristics and inputs, average farm size and total landholdings are smaller for stepped-up farmers, but with higher hired labor days, cost, and total cost per hectare. Moreover, fertilizer cost per hectare is the same for both groups of farmers albeit stepped-up farmers used less fertilizer per hectare, suggesting more efficiency over stepped-in farmers with no prior farming experience. Lastly, the stepped-up farmers attended about two agricultural extension programs in the past year while the stepped-in farmers reportedly attended none. These may suggest stepped-up farm operators may be more productive than their stepped-in counterparts.

[Place Table 1A & 1B around here]

(b) Non-parametric regression results

Figure 1 shows a non-parametric estimation of productivity and farm size for small-scale farms using Nadaraya-Watson estimator for two of the productivity measures examined in this study.[10] The estimates

[10] Others follow similar trends, hence, not reported.

show inverse relationship (negative slope) between both gross and net values of crop per hectare and farm size. This is typical of previous IR findings within similar range of farm sizes in SSA (Carletto et al., 2013; Julien et al., 2019). Figure 2 shows the same non-parametric regression estimates but extended the sample over the entire range up to 70 hectares. The figure largely reveals a U-shaped curve with turning points around 25-30 hectares, suggesting IR may only exist up to certain points and then productivity becomes increasing returns to scale. Nevertheless, considering potential endogeneity of the farm size variable, we account for potential confounders in a multivariate regression following previous literature and present results from these regressions below.

[Place Figures 1 & 2 around here]

(c) Multivariate regression results

First, we present estimation results for the relationship between farm size and the value of gross output per hectare cultivated, which is one of the conventional measures of inverse relationship (Table3). Subsequently, we extended productivity measures to gross farm output per hectare operated (Table 4) and ultimately, to net values of crop output per hectare cultivated and farm output per hectare operated (Tables 5 and 6), respectively. For all result tables, we first show estimated results for the small-scale farms (<5ha), Model I, in the first two columns. In the subsequent columns, we present Models II-IV showing estimates from stepped-in, stepped-up, and full-sample, respectively. In addition, for all regression models, we initially regressed output per hectare on farm size, its quadratic term and all household characteristics in a parsimonious regression. Thereafter, we added full set of control variables to account for potential confounders such as farm and soil characteristics and input use. Lastly, the quadratic terms included in each model is used to determine if there is a switch in direction (change in signs) of the slope of regression estimates and at what point the switch occurred, a turning point. These turning points are presented in the last row of each table.

Column (1) in Table 3 shows that small-scale farms have an inverse relationship between gross output of crop cultivated and farm size. Adding further controls for soil characteristics, crop types and input use in column (2) reduced IR magnitude. Although the estimates are imprecisely estimated, the results suggest that for farmers operating 5 hectares and below, productivity declines as farm size increases.[11] This finding is generally consistent with previous literature in SSA (Carletto et al., 2013; 2015; Julien et al.,

[11] Given the imprecise estimate of IR, we do not report turning points (farm size in hectares) at which the inverse relationship between farm size and productivity becomes positive.

2019). Considering the literature in SSA has mostly focused on smallholders cultivating 5 hectares or less, this finding suggests that farm sizes in this range may be influencing the findings in many previous studies that have found IR in SSA.

When stepped-in and stepped-up medium-scale farms are included in the sample (Models II and III) in columns (3) to (6), we find that IR still holds but the slope becomes flatter relative to estimates from the small-scale sample only. Moreover, the addition of control variables to account for input and labor use increased point estimates in both models as shown in column (4) and (6), indicating that not accounting for these variables, particularly hired and family labor, may overestimate relationship between farm size and productivity. Comparing IR estimates between both pathways (stepped-in and stepped-up) to medium-scale farming suggests existence of heterogeneity in crop productivity, depending on pathway of emergence. In previous IR literature, productivity of medium-scale farmers in SSA was assumed homogenous (Muyanga & Jayne, 2019). However, evidence from columns (6) and (4) suggest that stepped-up farmers with prior engagement in small-scale farming are slightly more productive than their stepped-in counterparts without prior small-scale farming experience. The stepped-up farmers' turning points from IR to constant or increasing return to scale is at 29 hectares, at least two hectares earlier than their stepped-in counterparts at 31 hectares.

Columns (7) and (8) show the overall results (Model IV) when all samples are combined. A U-shape relationship is observed over a wide range of farm sizes beyond 5 hectares, indicating that IR may exist up to a certain threshold beyond which farmers demonstrate increasing returns to scale. This finding is consistent with Carter & Wiebe (1990) and Muyanga & Jayne (2019) who found a U-shaped relationship between farm output and farm size in Kenya. In our case, the turning point threshold is about 35 hectares using gross crop output. Like in previous full-sample models estimated, controlling for labor and input use and crops cultivated column (8) increased farm size parameter estimates. Carter and Wiebe (1990) found that the smallest farms use family labor until its marginal product is just a fraction of the market wage while the wage per effective labor for large farms is above the market wage, and perhaps, this explains why the IR magnitude increased after controlling for household labor.

On prior farming engagement impacts in mediums-scale farm productivity, the negative parameter estimates on β_4 suggest that relative to all other farmers, stepped-up farmers may be less productive in general. However, the positive estimate of interaction term between stepped-up dummy variable and farm size demonstrates that prior farming engagement is positively correlated with gross crop productivity as farm size increases. This further confirms heterogeneity in productivity within medium-scale farms and crop productivity.

Table 4 shows that IR is more pronounced (steeper slope) when gross farm output per hectare is considered relative to crop productivity. Gross farm output includes output from crop and animal productions. We find a U-shaped curve and findings largely follow a similar pattern like gross crop output per hectare (in Table3). However, the thresholds at which IR turns positive appears earlier. In addition, we estimate the turning point from IR to increasing returns for stepped-up farmers to be two hectares faster than stepped-in farm operators. The similarity in results between gross farm and crop productivity measures may have been driven by the fact that very few farms had used a separate land for livestock production.

[Place Tables 3 & 4 around here]

Considering the advantage of lower production cost that bigger farms possess over small-scale farms (see Table 1), it is imperative to examine the existence of IR on net output (gross output less total production cost including family labor) per hectare. Table 5 shows regression results of net crop output per hectare on farm size. When compared with estimates from gross value of crop output, the relationship between net value and farm size is weakened but the U-shape relationship still holds, largely. This finding is consistent with previous literature that IR relationship between productivity and farm size is either weakened or reversed when profit (net value) is used (Carter & Wiebe, 1990; Lamb, 2003). For instance, Carter & Wiebe (1990) found that profit (defined as gross value of output less total costs including family labor) increases monotonically with farm size unlike gross value of output. In our case however, we find that although net output or profit weakens the observed IR, the inverse productivity relationship largely persists even after controlling for intensive use of labor by smallholders. Despite a weakened IR finding, the turning point threshold at which IR switches are quite similar across both gross and net outputs, indicating consistency. Beyond the net value of cultivated crop, Table 6 reveals that the relationship between farm size and net output from total farm operations follow similar patterns like other productivity measures.

[Place Tables 5 & 6 around here]

In summary, three trends emerged across all measures of productivity. First, there is evidence of IR between farm size and productivity within small-scale farms in Nigeria, albeit mostly imprecisely estimated. Second, within 5 to 70-hectare farms, a U-shaped relationship emerges suggesting that inverse relationship holds for medium-scale farms, but up to a certain threshold point generally between 25 and 30 hectares, depending on the productivity measure examined. Although Muyanga & Jayne (2019) estimated a similar U-shaped curve in a study of similar farm size (0-70ha) in Kenya, the IR in their study is mostly restricted to smallholders and the turning points occurred much earlier (at 3ha) in the farm size distribution. This difference provides an evidence that there could be heterogeneity in the relationship between farm size and productivity across SSA, unlike the commonly observed IR over small-scale farms in the region (Carletto et al., 2013; Julien et al., 2019). Perhaps, size-productivity relationship may differ by country or study area based on the economic growth and development status (Otsuka et al., 2016; Rada & Fuglie, 2019). Rada & Fuglie (2019) reviewed more recent IR literature and found that the erosion of IR in Asian countries undergoing rapid growth may be tied to off-farm economic growth, which facilitated agricultural factor markets. Third, medium-scale farm operators who were small-scale farmers appear more productive than counterparts without prior farming engagements, suggesting heterogeneity within medium-scale farmers.

(d) Robustness checks

First, we acknowledge the potential endogeneity of farm size in estimating the relationship between farm size and productivity. In our case, we attempted to account for this fact using a control function approach (Wooldridge, 2010). The use of a valid instrumental variable should remove such endogeneity. Following Muyanga and Jayne (2019), we used the number of years a household has spent in a community and the amount of land previously owned by the household head's father before subdivision as instrumental variables. Another instrument considered was the number of male siblings the head of household has. This instrument would be relevant for cultural reasons because male children tend to inherit land from fathers, influencing access to land but not directly influencing productivity. However, we do not have this data available. Nevertheless, the other two instruments are equally relevant because they can determine access to land. In addition, these instruments are statistically significant at p-val 0.01 (see column (1) in Appendix Table A.2), and we maintain validity from previous literature and because there is no direct link between these instruments and productivity except through farm size. We reject the endogeneity claim based on lack of significance of the residual variable derived from the reduced form equation and included as a control variable in the structural equation (Wooldridge, 2010). Column (2) in Appendix Table A.2 shows a lack of significance not only in the residual parameter estimates but also on the main parameter of interest, farm size, even though IR still holds.

Second, like previous IR studies, we report parameter estimates at conditional means of productivity and not across the entire distribution of productivity; but productivity may change within the distribution (Savastano and Scandizzo, 2017). Therefore, we estimated a quantile regression across the productivity distribution. Savastano and Scandizzo (2017) find a direct-inverse-direct relationship with differing relationships between farm size and land productivity—inverted U-shaped for less productive farmers and the converse for more productive farmers. That is, the threshold or turning point is a minimum for less productive and maximum for more productive farmers, suggesting the relationship between farm size and productivity may not be univocal or monotonic across the productivity distribution. In our case, we find that although the relationship between farm size and land productivity may not be constant over the entire productivity distribution, the signs however do not change, and the U-shaped relationship is maintained throughout the quantiles. Our quantile regression findings confirm that IR exists up to certain threshold and reverses to positive productivity, with the most productive quantile reaching a turning point faster than the rest (see Appendix Table A.3).

Lastly, we estimated a different functional form using elasticities (log-log variant) and arrive at the same conclusions as the level-level estimates presented. Hence, we did not present the log-log results.

6. CONCLUSION AND POLICY IMPLICATIONS

This study examines the relationship between farm size and productivity over a wider range of farm sizes than is usually studied in SSA. To our knowledge, this paper is one of two to have examined this relationship among the small-scale (<5ha) to medium-scale (5<ha≤70) farms in the region. The study covers farms ranging up to 70 hectares, and our analysis and conclusions are restricted to this range. The recent drive to promote commercial agriculture in Africa (African Development Bank, 2017), and the rapid growth of medium-scale farms in many parts of the continent (Jayne et al., 2016), means farm size-productivity debates may likely intensify on the continent. The inverse farm size-productivity relationship is an important stylized fact in the development literature but most of the evidence is based on studies examining farms of 5 hectares or less. It is therefore imperative to substantiate whether this stylized fact can be generalized beyond smallholder farms. Although our study is representative of only two purposively selected states in Nigeria, it nevertheless provides documented evidence of IR relationship in areas where medium-sized commercialized farms have grown in Nigeria. As one of very limited studies to examine IR hypothesis over a wider range of farms in SSA, findings from this study helps contribute to the IR debate beyond what is currently available.

There are three key findings from our study. First, consistent with previous literature in SSA region, IR exists within small-scale (<5ha) farms in Nigeria. Second, regardless of productivity measure examined, a U-shaped relationship exists between farm size and productivity among medium-scale farms in Nigeria, consistent with previous findings over a similar range of farm sizes in Kenya (Muyanga & Jayne, 2019). That is, productivity is high within small-scale (<5ha) and large medium-scale farms (approximately>30ha). In our case, it means the IR hypothesis holds consistently over a very large domain in our sample where most of the observed farms exhibit inverse relationship between farm size and productivity. Third, contrary to assumption of homogeneity in productivity among medium-scale farms, we find evidence of heterogeneity depending on emergence pathways for the farm operators.

Considering the paucity of empirical evidence showing IR hypothesis beyond smallholder farms, the above findings may hold important policy implications for agricultural policy development in SSA if upheld by future studies in SSA. First, our findings of U-shaped farm size-productivity relationship in this study suggests the pursuit of policies that emphasize a hybrid approach that includes support for both smallholders as well as larger commercial farming operations. While we make no explicit call for transitioning to bigger medium-scale farms, farms larger than 30 hectares in Nigeria have productivity advantages that derive from economies of scale. The Latin American and Asian experiences seem to make the case for larger farms and the corresponding benefits from economy of scale and potentially lowered input costs. Second, considering that medium-scale farmers with prior small-scale farming engagements appear more productive and attain IR turning point thresholds faster than counterparts without prior small-scale farming activities, policies encouraging smallholder access to larger agricultural land may not only enhance agricultural productivity, but also improve their living standards.

However, considering our sample is limited to two states in Nigeria (one in the north and another in the south) that have created an enabling environment for medium-scale agriculture to thrive, our findings should be interpreted in this context and may not be seen as nationally representative. We recommend more studies considering diverse regions, multiple agro-ecologies, and different levels of economic growth or development to generate more evidence for generalization.

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TABLE 1A—DESCRIPTIVE STATISTICS FOR VARIABLES BY FARM SIZES AND CATEGORIES

	Small-scale		Medium-scale						Full Sample
	(ha<5)		(5≤ha<10)		(10≤ha<20)		(20≤ha<70)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
	(1)	(2)	(3)	(4)	(5)	(6)	(5)	(6)	(7)
A. Dependent variables									
Gross value of crop output/ha cultivated*	349	318	303	286	276	284	266	286	323
Gross value of farm operated output/ha*	381	367	315	297	279	284	267	287	344
Net value of crop output/ha cultivated*	270	310	218	280	209	276	218	280	245
Net value of farm operated output/ha*	298	355	226	288	210	276	219	280	262
B. Farm household characteristics									
Age of household head (years)	45.3	13.7	46.6	12.4	50.6	13.0	49.9	13.7	46.5
Household size	5.77	2.85	6.70	3.21	7.14	3.17	8.29	3.74	6.31
=1 if female-headed household	0.06	0.24	0.04	0.20	0.01	0.11	0.01	0.11	0.05
Years of education of HH head	7.00	5.04	7.28	5.33	7.35	5.30	7.55	5.14	7.15
Adult equivalent	4.85	2.45	5.61	2.71	6.06	2.77	6.87	3.09	5.30
C. Assets									
=1 if HH has a radio	0.79	0.41	0.83	0.37	0.84	0.37	0.80	0.41	0.81
=1 if HH has a TV	0.36	0.48	0.41	0.49	0.51	0.50	0.49	0.50	0.40
=1 if HH has a mobile phone	0.95	0.21	0.95	0.21	0.97	0.17	0.96	0.19	0.96
=1 if HH has a motorcycle	0.63	0.48	0.66	0.47	0.76	0.43	0.80	0.41	0.66
=1 if HH has a car	0.06	0.24	0.10	0.29	0.17	0.38	0.33	0.47	0.10
=1 if HH has a water pump	0.03	0.17	0.07	0.25	0.10	0.30	0.11	0.31	0.05
=1 if HH has plow	0.10	0.30	0.11	0.32	0.09	0.28	0.12	0.33	0.10
==1 if HH has a sprayer	0.40	0.49	0.56	0.50	0.68	0.47	0.82	0.39	0.50
D. AEZ & self-assessment of soil qualities									
=1 if Ogun	0.52	0.50	0.43	0.50	0.58	0.49	0.60	0.49	0.50
=1 if Kaduna	0.48	0.50	0.57	0.50	0.42	0.49	0.40	0.49	0.50
=1 if sandy soil	0.04	0.19	0.14	0.35	0.13	0.34	0.12	0.33	0.08
=1 if clay soil	0.04	0.20	0.07	0.25	0.07	0.26	0.06	0.24	0.05
=1 if loamy soil	0.96	0.19	0.92	0.27	0.95	0.23	0.94	0.24	0.95
=1 if stony soil	0.02	0.12	0.03	0.18	0.03	0.18	0.05	0.22	0.02
=1 if forest soil	0.00	0.05	0.00	0.06	0.00	0.06	0.01	0.11	0.00
= 1 if good	0.94	0.24	0.96	0.20	0.97	0.18	0.98	0.15	0.95
=1 if fair	0.09	0.29	0.12	0.32	0.10	0.30	0.05	0.22	0.10
=1 if poor+	0.00	0.07	0.01	0.10	0.03	0.16	0.01	0.11	0.01
E. Production and input use practices									
Farm size (ha)	2.38	1.12	6.37	1.27	12.82	2.71	28.70	11.33	5.84
Total landholding (ha)	5.40	59.93	11.15	46.25	17.89	16.67	35.53	20.00	9.80
Ratio operated farm size/total landholdings	83.5	26.6	86.5	23.1	86.9	22.5	87.8	21.0	85.0
Total cost of crop production/ha planted*	79	68	85	89	68	64	48	47	78
Family labor days/ha	14.1	22.0	8.3	29.0	6.7	25.0	2.69	4.44	11.02
Hired labor days/ha	8.43	15.91	9.50	31.30	10.24	42.65	7.3	20.0	8.92
Estimated family labor cost/ha*	3.7	5.8	2.2	7.6	1.8	6.6	0.7	1.2	2.9
Hired labor cost/ha*	57.8	62.2	52.2	84.9	41.9	53.8	29.0	2.2	49.7
Fertilizer quantity (kg/ha)	168.7	226.3	182.9	220.8	119.0	177.0	91.4	176.7	164.4
Fertilizer cost (NGN/ha)	34	62	14	15	7	7	3	3	23.2
No. of extensions attended by HH members	5.26	4.85	1.33	2.10	0	0	0	0	5.08
=1 if HH has access to market	0.46	0.50	0.33	0.47	0.30	0.46	0.23	0.42	0.39
=1 if HH has access to extension agents	0.11	0.31	0.12	0.33	0.21	0.41	0.08	0.28	0.12
=1 if HH has access to agro-input dealer	0.30	0.46	0.25	0.44	0.21	0.41	0.18	0.39	0.27
=1 if stepped-up to medium-scale farming (%)	0.02	0.13	0.50	0.50	0.41	0.49	0.32	0.47	0.22
Sample size (N)	1,123		652		237		83		2095

Notes: Farm operated includes crop cultivation and animal holding operations.

* Values reported in '000 naira ('000 NGN)

+Some households have more than one plot and may report different quality on different plots. Thus, summing the share of households reporting of soil qualities (poor, fair or good) may exceed 100%.

TABLE 1B— DESCRIPTIVE STATISTICS FOR VARIABLES BY MEDIUM-SCALE FARMER TYPES (5-70 HA)

	Stepped-up		Stepped-in	
Variables	Mean	SD	Mean	SD
A. Dependent variables				
Gross value of crop output/ha cultivated (‘000 NGN)	317.77	302.99	271.07	266.53
Gross value of farm operated output/ha (‘000 NGN)	324.67	311.55	281.05	273.07
Net value of crop output/ha cultivated (‘000 NGN)	235.30	295.03	197.77	261.17
Net value of farm operated output/ha (‘000 NGN)	239.82	301.59	204.01	266.01
B. Farm household characteristics				
Age of household head (years)	49.24	12.47	46.48	12.79
Household size	7.19	3.36	6.73	3.18
=1 if female-headed household	0.04	0.21	0.02	0.15
Years of education of HH head	7.08	5.32	7.60	5.27
Adult equivalent	6.03	2.85	5.65	2.70
C. Assets				
=1 if HH has a radio	0.84	0.36	0.81	0.39
=1 if HH has a TV	0.46	0.50	0.42	0.49
=1 if HH has a mobile phone	0.96	0.19	0.96	0.20
=1 if HH has a motorcycle	0.68	0.47	0.72	0.45
=1 if HH has a car	0.14	0.35	0.12	0.33
=1 if HH has a water pump	0.08	0.27	0.08	0.27
=1 if HH has plow	0.15	0.36	0.07	0.25
==1 if HH has a sprayer	0.64	0.48	0.59	0.49
Household off-farm income (‘000 NGN)	386.50	754.64	253.83	761.49
D. AEZ & self-assessment of soil qualities				
=1 if Ogun	0.56	0.50	0.42	0.49
=1 if Kaduna	0.44	0.50	0.58	0.49
=1 if sandy soil	0.15	0.35	0.12	0.33
=1 if clay soil	0.10	0.29	0.05	0.21
=1 if loamy soil	0.94	0.24	0.92	0.28
=1 if stony soil	0.04	0.19	0.03	0.18
=1 if forest soil	0.00	0.07	0.00	0.06
= 1 if good	0.97	0.18	0.96	0.20
=1 if fair	0.10	0.30	0.12	0.32
=1 if poor	0.02	0.13	0.01	0.10
E. Production and input use practices				
Farm size (ha)	8.75	6.04	10.49	8.24
Total landholding (ha)	13.09	29.49	16.13	46.20
Ratio operated farm size/total landholdings (%)	84.31	24.04	87.26	22.70
Total cost of crop production/ha planted (‘000 NGN)	82.47	86.71	73.30	75.91
Family labor days/ha	7.01	15.69	7.93	33.30
Hired labor days/ha	10.39	33.44	8.72	33.04
Estimated family labor cost/ha (‘000 NGN)	1.85	4.14	2.09	8.79
Hired labor cost/ha (‘000 NGN)	52.38	79.85	43.90	70.43
Fertilizer quantity (kg/ha)	136.79	183.48	177.30	227.47
Fertilizer cost (kg/ha)	11.58	16.32	11.25	11.23
Number of extensions attended by HH members	1.80	2.15	0.00	0.00
=1 if HH has access to market	0.43	0.50	0.21	0.41
=1 if HH has access to extension agents	0.17	0.38	0.11	0.32
=1 if HH has access to agro-input dealer	0.28	0.45	0.20	0.40
Sample size (N)	470		530	

Table 3: MULTIVARIATE REGRESSION OF GROSS CROP OUTPUT/HA CULTIVATED ('000 NGN)

	SMALL-SCALE SAMPLE (0-5 ha)		FULL SAMPLE					
			Stepped-in (0-70 ha)		Stepped-up (0-70 ha)		All Combined (0-70 ha)	
VARIABLES	Model I (1)	Model I (2)	Model II* (3)	Model II* (4)	Model III+ (5)	Model III+ (6)	Model IV◊ (7)	Model IV◊ (8)
Farm Size (ha)	-62.13	-32.50	-17.69***	-20.21***	-15.88**	-18.83***	-16.36***	-18.01***
Squared Farm Size (ha)	8.97	3.07	0.29**	0.32**	0.27	0.33*	0.27***	0.25**
Age HH head (years)	0.90	1.06	1.09	1.06	1.03	1.07	1.14	1.09
Household size	-0.47	-2.63	-0.51	-2.27	-0.68	-3.02	-0.56	-2.29
=1 if female headed HH	-12.69	-60.71	-12.28	-56.38	-8.67	-51.95	-8.89	-48.13
Years of education of HH head	2.64	0.19	2.96	0.66	2.79	0.74	2.89	0.99
=1 if Ogun state	58.98***	-90.92**	55.25***	-83.90**	62.60***	-68.90	57.66***	-69.17*
=1 if market access	-28.63	-41.44*	-27.82	-39.41*	-25.80	-38.77*	-24.20	-36.09*
=1 if extension access	-77.60***	-43.18	-77.26***	-46.66*	-73.15***	-37.49	-72.29***	-42.32*
=1 if agro-dealer access	-3.73	-0.66	-0.67	1.60	-2.79	4.35	-0.59	4.33
Family labor days/ha		0.73		0.73*		0.56		0.60*
Hired labor days/ha		4.49***		3.06***		1.75*		1.58**
Fertilizer (kg/ha)		0.07		0.09*		0.08		0.10*
=1 if grains		-12.77		-20.40		-14.84		-22.53
=1 if legumes		62.21**		55.82**		56.04**		50.52**
=1 if roots & tubers		167.42***		163.96***		163.84***		160.13***
=1 if fruits & vegetables		61.75*		68.06**		70.80**		70.14**
=1 if cash crop		109.90**		102.71**		101.63**		97.97**
HH assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality & types		Yes		Yes		Yes		Yes
=1 if HH 'stepped up' from small-scale								-98.67***
'Stepped up'*farm size								8.33***
Constant	267.19***	189.58	214.60***	187.26**	208.03***	146.51*	209.35***	163.75**
Observations	1,123	1,123	1,645	1,645	1,572	1,572	2,095	2,095
R-squared	0.07	0.18	0.07	0.18	0.07	0.17	0.06	0.16
Turning point for cultivated farm size	3.5	5.3	30.4	31.1	29.7	28.8	30.8	35.9

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Notes: *Model II comprises small and medium-scale farmers that stepped into medium-scale farming with no prior experience as small-scale farmers (stepped-in)

+Model III comprises small-scale and medium-scale farmers that stepped into medium-scale farming with prior experience as small-scale farmers (stepped-up)

◊Model IV is the full sample including small and medium-scale farmers with stepped-in and stepped-up farmers inclusive.

Table 4: MULTIVARIATE REGRESSION OF GROSS FARM OUTPUT/HA OPERATED ('000 NGN)

	SMALL-SCALE SAMPLE (0-5 ha)		FULL SAMPLE					
			Stepped-in (0-70 ha)		Stepped-up (0-70 ha)		All Combined (0-70 ha)	
VARIABLES	Model I (1)	Model I (2)	Model II* (3)	Model II* (4)	Model III+ (5)	Model III+ (6)	Model IV◊ (7)	Model IV◊ (8)
Farm Size (ha)	-92.77*	-59.02	-34.51***	-35.23***	-37.42***	-38.47***	-31.24***	-30.90***
Squared Farm Size (ha)	8.99	2.41	0.63***	0.62***	0.72***	0.75***	0.55***	0.48***
Age HH head (years)	0.64	0.85	0.83	0.79	0.76	0.82	0.90	0.82
Household size	6.75	3.80	5.60	3.20	5.69	2.57	5.11	2.83
=1 if female headed HH	-41.33	-91.26*	-41.36	-85.09*	-35.47	-78.91	-36.84	-75.16
Years of education of HH head	-0.87	-4.04	-0.25	-3.19	-0.60	-3.23	-0.20	-2.64
=1 if Ogun state	54.12**	-119.77**	50.82**	-109.87**	60.47**	-90.71	54.73**	-91.59*
=1 if market access	-39.15	-47.22	-38.75	-46.08*	-34.86	-43.96	-33.95	-42.43
=1 if extension access	-105.37***	-64.63*	-104.53***	-68.45**	-98.73***	-57.43*	-96.49***	-62.04**
=1 if agro-dealer access	-4.05	-2.21	1.20	1.79	-1.41	4.66	1.88	5.83
Family labor days/ha		1.07		1.24**		1.04*		1.09**
Hired labor days/ha		4.96**		3.55***		2.13*		1.88*
Fertilizer (kg/ha)		0.05		0.08		0.07		0.09
=1 if grains		-9.12		-25.41		-17.41		-28.48
=1 if legumes		58.88		51.60		51.86		45.38
=1 if roots & tubers		181.14***		173.68***		173.25***		169.46***
=1 if fruits & vegetables		77.19		74.43		78.55*		75.21*
=1 if cash crop		113.91*		106.68*		105.62*		102.30*
HH assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality & types		Yes		Yes		Yes		Yes
=1 if HH 'stepped up' from small-scale								-146.71***
'Stepped up'*farm size								12.99***
Constant	372.26***	360.16**	298.60***	337.96***	296.90***	291.91**	289.16***	300.01***
Observations	1,123	1,123	1,645	1,645	1,572	1,572	2,095	2,095
R-squared	0.10	0.18	0.09	0.18	0.09	0.17	0.09	0.17
Turning point for cultivated farm size	5.2	12.2	27.6	28.3	26.1	25.8	28.2	32.1

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Notes: *Model II comprises small and medium-scale farmers that stepped into medium-scale farming with no prior experience as small-scale farmers (stepped-in)

+Model III comprises small-scale and medium-scale farmers that stepped into medium-scale farming with prior experience as small-scale farmers (stepped-up)

◊Model IV is the full sample including small and medium-scale farmers with stepped-in and stepped-up farmers inclusive.

Table 5: MULTIVARIATE REGRESSION OF NET CROP OUTPUT/HA CULTIVATED (‘000 NGN)

	SMALL-SCALE SAMPLE (0-5 ha)		FULL SAMPLE					
			Stepped-in (0-70 ha)		Stepped-up (0-70 ha)		All Combined (0-70 ha)	
VARIABLES	Model I (1)	Model I (2)	Model II* (3)	Model II* (4)	Model III+ (5)	Model III+ (6)	Model IV◊ (7)	Model IV◊ (8)
Farm Size (ha)	-33.54	-16.37	-13.57***	-17.20***	-11.94*	-14.98**	-13.25***	-14.37***
Squared Farm Size (ha)	4.73	0.49	0.22*	0.28**	0.19	0.26	0.22**	0.19*
Age HH head (years)	1.09	1.06	1.26	1.11	1.17	1.09	1.28	1.13
Household size	-0.94	-3.46	-0.92	-2.99	-1.04	-3.65	-1.00	-2.89
=1 if female headed HH	-4.74	-49.38	-6.30	-47.00	-1.28	-42.42	-2.85	-39.42
Years of education of HH head	2.40	0.05	2.61	0.34	2.37	0.30	2.49	0.53
=1 if Ogun state	70.23***	-76.75*	64.13***	-78.18**	71.70***	-66.46	65.41***	-69.91*
=1 if market access	-38.13*	-45.63**	-36.87*	-42.85**	-35.35	-42.65**	-33.76*	-40.03**
=1 if extension access	-68.45**	-39.54	-67.46***	-42.34*	-64.41***	-35.12	-63.66***	-39.72*
=1 if agro-dealer access	-23.69	-9.84	-20.07	-8.69	-22.32	-7.66	-19.06	-6.90
Family labor days/ha		0.65		0.65*		0.58		0.59
Hired labor days/ha		0.64		0.19		-0.36		-0.35
Fertilizer (kg/ha)		-0.02		-0.00		-0.01		0.00
=1 if grains		-13.68		-21.99		-16.17		-24.66
=1 if legumes		61.75**		54.91**		55.00**		49.06**
=1 if roots & tubers		159.66***		156.61***		156.34***		152.89***
=1 if fruits & vegetables		54.48		56.83*		57.32*		56.93**
=1 if cash crop		102.40**		98.26**		96.46**		94.18**
HH assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality & types		Yes		Yes		Yes		Yes
=1 if HH ‘stepped up’ from small-scale								-115.72***
‘Stepped up’*farm size								9.03***
Constant	168.44**	166.34	146.61***	179.97**	142.10***	142.58	145.00***	158.53**
Observations	1,123	1,123	1,645	1,645	1,572	1,572	2,095	2,095
R-squared	0.06	0.15	0.06	0.15	0.06	0.14	0.05	0.14
Turning point for cultivated farm size	3.5	16.2	30.6	31.4	32.2	29.1	30.3	38.1

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Notes: *Model II comprises small and medium-scale farmers that stepped into medium-scale farming with no prior experience as small-scale farmers (stepped-in)

+Model III comprises small-scale and medium-scale farmers that stepped into medium-scale farming with prior experience as small-scale farmers (stepped-up)

◊Model IV is the full sample including small and medium-scale farmers with stepped-in and stepped-up farmers inclusive.

Table 6: MULTIVARIATE REGRESSION OF NET FARM OUTPUT/HA OPERATED (‘000 NGN)

	SMALL-SCALE SAMPLE (0-5 ha)		FULL SAMPLE					
			Stepped-in (0-70 ha)		Stepped-up (0-70 ha)		All Combined (0-70 ha)	
VARIABLES	Model I (1)	Model I (2)	Model II* (3)	Model II* (4)	Model III+ (5)	Model III+ (6)	Model IV◊ (7)	Model IV◊ (8)
Farm Size (ha)	-57.49	-35.35	-29.16***	-31.23***	-31.97***	-33.14***	-27.07***	-26.35***
Squared Farm Size (ha)	3.85	-1.26	0.53***	0.55***	0.60**	0.64**	0.49***	0.40***
Age HH head (years)	0.90	0.91	1.06	0.90	0.96	0.91	1.11	0.95
Household size	5.62	2.48	4.60	2.06	4.74	1.53	4.12	1.84
=1 if female headed HH	-33.29	-80.02	-35.63	-76.30	-28.16	-69.88	-31.07	-67.16
Years of education of HH head	-1.15	-4.06	-0.65	-3.43	-1.06	-3.59	-0.66	-3.03
=1 if Ogun state	66.88***	-105.15*	60.58**	-104.06*	70.67***	-88.84	63.25***	-92.85*
=1 if market access	-44.58	-48.96*	-44.10	-47.20*	-40.64	-45.37*	-40.13	-44.15*
=1 if extension access	-95.11***	-60.79*	-93.38***	-63.56*	-88.88***	-54.65*	-86.68***	-58.91*
=1 if agro-dealer access	-28.95	-14.95	-22.86	-12.05	-25.84	-11.26	-21.11	-9.06
Family labor days/ha		0.98		1.13*		1.03*		1.06*
Hired labor days/ha		0.89		0.52		-0.11		-0.14
Fertilizer (kg/ha)		-0.04		-0.02		-0.02		-0.01
=1 if grains		-12.52		-28.14		-20.64		-31.70
=1 if legumes		58.74*		51.14		51.33		44.45
=1 if roots & tubers		174.55***		167.64***		167.33***		163.68***
=1 if fruits & vegetables		74.27		67.23		68.49		65.38
=1 if cash crop		104.26*		100.31*		99.14*		96.86*
HH assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality & types		Yes		Yes		Yes		Yes
=1 if HH ‘stepped up’ from small-scale								-160.98***
‘Stepped up’*farm size								13.45***
Constant	263.33***	330.09**	226.83***	330.75***	227.23***	288.28**	221.27***	294.78***
Observations	1,123	1,123	1,645	1,645	1,572	1,572	2,095	2,095
R-squared	0.08	0.15	0.08	0.15	0.08	0.14	0.07	0.14
Turning point for cultivated farm size			27.5	28.2	26.6	25.8	27.9	32.8

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Notes: *Model II comprises small and medium-scale farmers that stepped into medium-scale farming with no prior experience as small-scale farmers (stepped-in)

+Model III comprises small-scale and medium-scale farmers that stepped into medium-scale farming with prior experience as small-scale farmers (stepped-up)

◊Model IV is the full sample including small and medium-scale farmers with stepped-in and stepped-up farmers inclusive.

Table 7: PRODUCTIVITY MEASURES FOR MEDIUM-SCALE FARMS (000 NGN): STEPPED-UP vs STEPPED-IN

VARIABLES	(1) GROSS CROP OUTPUT/HA	(2) GROSS FARM OUTPUT/HA	(3) NET CROP OUTPUT/HA	(4) NET FARM OUTPUT/HA
Farm Size (ha)	-7.12**	-8.68***	-3.60	-4.58
Squared Farm Size (ha)	0.12**	0.14**	0.07	0.09*
Age HH head (years)	2.54**	2.52**	2.32**	2.39**
Household size	0.39	0.63	-1.17	-1.07
=1 if female headed HH	96.94	91.51	85.02	77.19
Years of education of HH head	2.14	2.05	1.40	1.40
=1 if Ogun state	-0.14	0.74	-37.67	-36.04
=1 if market access	26.84	31.49	14.79	15.87
=1 if extension access	-39.62	-36.59	-46.63*	-44.69*
=1 if agro-dealer access	23.83	18.35	26.15	22.70
Family labor days/ha	0.90*	0.84*	0.82*	0.78*
Hired labor days/ha	-0.04	-0.05	-0.90***	-0.90***
Fertilizer (kg/ha)	0.21***	0.21***	0.12**	0.11**
=1 if grains	-67.28	-77.06	-81.90	-87.67*
=1 if legumes	-21.69	-18.91	-27.53	-24.68
=1 if roots & tubers	103.44***	103.48***	97.76***	96.42***
=1 if fruits & vegetables	50.98*	50.67*	56.79**	58.36**
=1 if cash crop	24.84	27.52	34.83	34.87
HH assets (radio, TV, mobile phone, car, etc.)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality & types	Yes	Yes	Yes	Yes
=1 if HH 'stepped up' from small-scale	2.78	-3.69	-1.78	-4.71
'Stepped up'*farm size	0.98	1.21	1.38	1.49
Constant	72.21	90.44	71.99	81.71
Observations	972	972	972	972
R-squared	0.15	0.15	0.13	0.13
Turning point for cultivated farm size	29.1	30.4	24.7	26.7

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

APPENDIX

Table A.1a: Medium and Smallholder Farm Samples in Ogun State

		Medium/large Farms		Smallholder Farms	
Local Government Authority [LGA]	*Ward*	*Population*	*Sample*	*Population*	*Sample*
Obafemi Owondo	Owode	169	71	264	16
	Alapako	109	46	1,154	72
	Oba	64	27	330	20
	Obafemi	57	24	939	58
		399	167	2,687	167
Ijebu East	Owu	181	76	309	41
	Itele	157	66	254	33
	Imobi	33	14	340	45
	Ikija	27	11	368	48
		398	167	1,271	167
Imeko – Afon	Imeko	275	102	635	63
	Atapele	94	35	544	54
	Obada	54	20	286	28
	Agberiodo	28	10	219	22
		451	167	1,684	167
	Total	1,248	500	5,642	500

Table A.1b: Medium and Smallholder Farm Samples in Kaduna State

		Medium/large Farms		Smallholder Farms	
Local Government Authority [LGA]	*Ward*	*Population*	*Sample*	*Population*	*Sample*
Chikun	Rido	228	93	1,127	65
	Kuriga	94	38	501	29
	Kunai	87	35	1,266	73
		409	167	2893	167
Kachia	Agunu	390	87	3301	105
	Gidan Tagwai	230	51	1202	38
	Bishini	129	29	727	23
		749	167	5230	167
Soba	Gami Gira	346	111	1694	59
	Dan Wata	116	37	1488	52
	Garu	60	19	1593	56
		522	167	4775	167
	Total	1,680	500	12,899	500

Table A.2: CONTROL FUNCTION ESTIMATES OF GROSS CROP OUTPUT/HA CULTIVATED ('000 NGN)

VARIABLES	(1) Reduced Form Estimates	(2) Structural Form Estimates
Residual		-7.38
Farm Size (ha)		-9.06
Squared Farm Size (ha)		0.20*
Years spent in current settlement	0.02**	
Land amount (ha) owned by HH head's father before subdivision	0.03***	
Age HH head (years)	-0.00	1.10
Household size	0.08***	-4.04
=1 if female headed HH	-0.75***	-34.75
Years of education of HH head	0.01	1.72
=1 if Ogun state	-0.52**	-60.96
=1 if market access	-0.45***	-29.42
=1 if extension access	-0.14	-36.18
=1 if agro-dealer access	-0.30***	-13.29
Family labor days/ha	-0.03***	0.73*
Hired labor days/ha	-0.01	1.83**
Fertilizer (kg/ha)	-0.00***	0.12**
=1 if grains	0.29*	-29.58
=1 if legumes	0.24**	45.97*
=1 if roots & tubers	0.74***	139.13***
=1 if fruits & vegetables	0.90***	66.74**
=1 if cash crop	0.82***	90.24**
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes
Soil quality & types	Yes	Yes
=1 if HH 'stepped up' from small-scale	-3.60***	-74.08
'Stepped up'*farm size	0.90***	1.73
Constant	0.28	166.82**
Observations	2,001	2,001
R-squared	0.41	0.17
Turning point		22.3

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A.3: QUANTILE REGRESSION OF GROSS FARM OUTPUT/HA OPERATED ('000 NGN)

VARIABLES	Q10	Q25	Q50	Q75	Q90
	(1)	(2)	(3)	(4)	(5)
Farm Size (ha)	-7.86***	-9.70***	-9.09***	-9.05**	-20.39***
Squared Farm Size (ha)	0.11***	0.16***	0.12**	0.09	0.36**
Age HH head (years)	0.08	0.20	0.16	-0.09	1.25
Household size	1.04	2.26	3.47**	5.13*	1.16
=1 if female headed HH	-16.62	-26.94*	-13.49	-7.44	37.76
Years of education of HH head	0.20	0.75	0.49	1.05	1.66
=1 if Ogun state	-10.43	7.23	24.69	35.01	-6.55
=1 if market access	11.45	1.30	11.37	19.03	-41.83
=1 if extension access	-22.04***	-34.17***	-18.21	-38.38**	-4.91
=1 if agro-dealer access	2.97	7.37	15.31	8.34	-23.22
Family labor days/ha	0.01	0.07	0.46	1.10***	0.79
Hired labor days/ha	0.11	0.13	0.28	1.52	4.97***
Fertilizer (kg/ha)	0.07***	0.10***	0.14***	0.15***	0.25***
=1 if grains	23.62**	24.21**	-0.11	8.17	-7.20
=1 if legumes	4.60	1.96	-8.80	-4.20	-9.06
=1 if roots & tubers	16.78**	37.79***	42.68***	89.53***	272.37***
=1 if fruits & vegetables	12.13	25.71**	24.36*	56.61**	43.07
=1 if cash crop	40.22***	40.42***	50.45***	58.37**	175.61**
Soil quality & types	Yes	Yes	Yes	Yes	Yes
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes	Yes
=1 if HH 'stepped up' from small-scale	-34.68**	-25.51**	-2.42	-15.57	31.83
'Stepped up'*farm size	3.71**	2.95**	2.66	5.11	0.19
Constant	51.80*	63.56**	133.56***	170.82**	223.56
Observations	2,095	2,095	2,095	2,095	2,095
Pseudo R-squared	0.07	0.06	0.06	0.08	0.12
Turning point for cultivated farm size (ha)	35.40	31.05	37.08	50.89	28.07

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

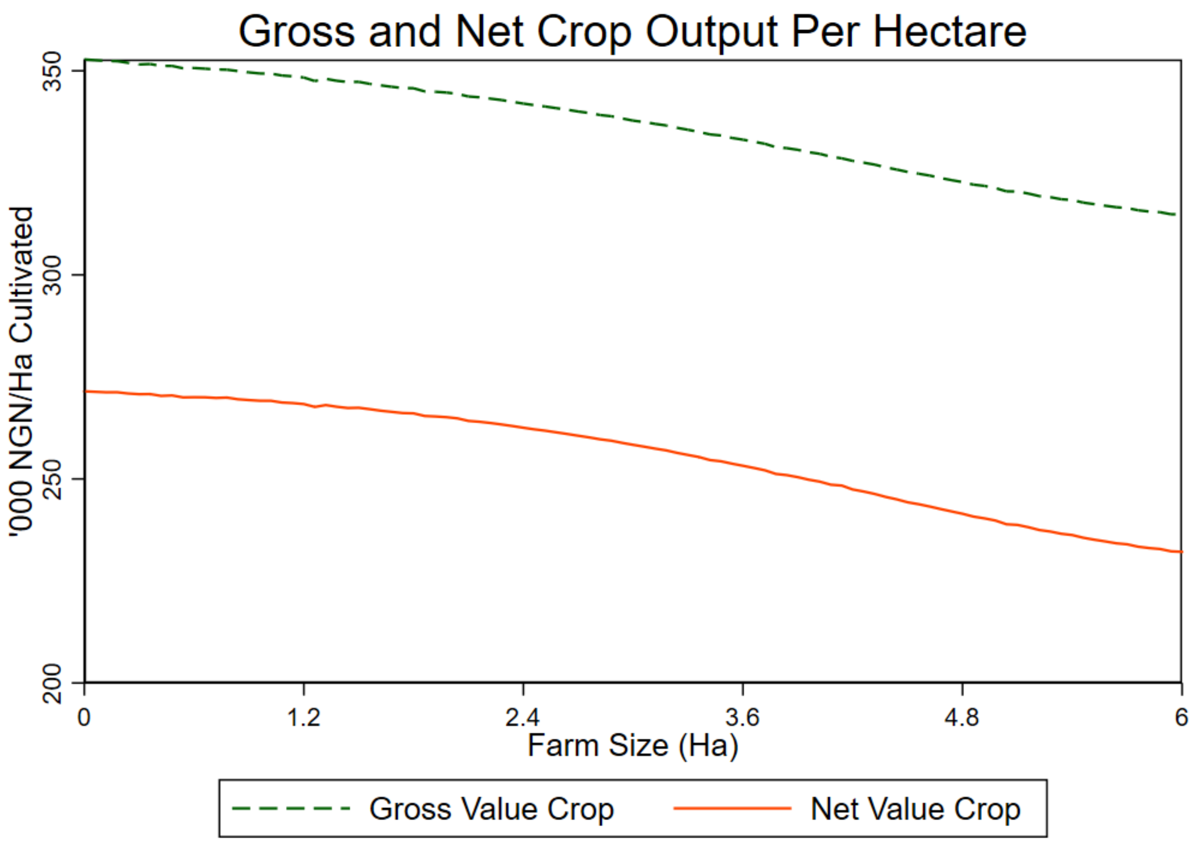

Figure 1: Gross and net output per hectare of crop cultivated

Note: Non-parametric regression using Nadaraya-Watson Approach, bandwidth=2.0

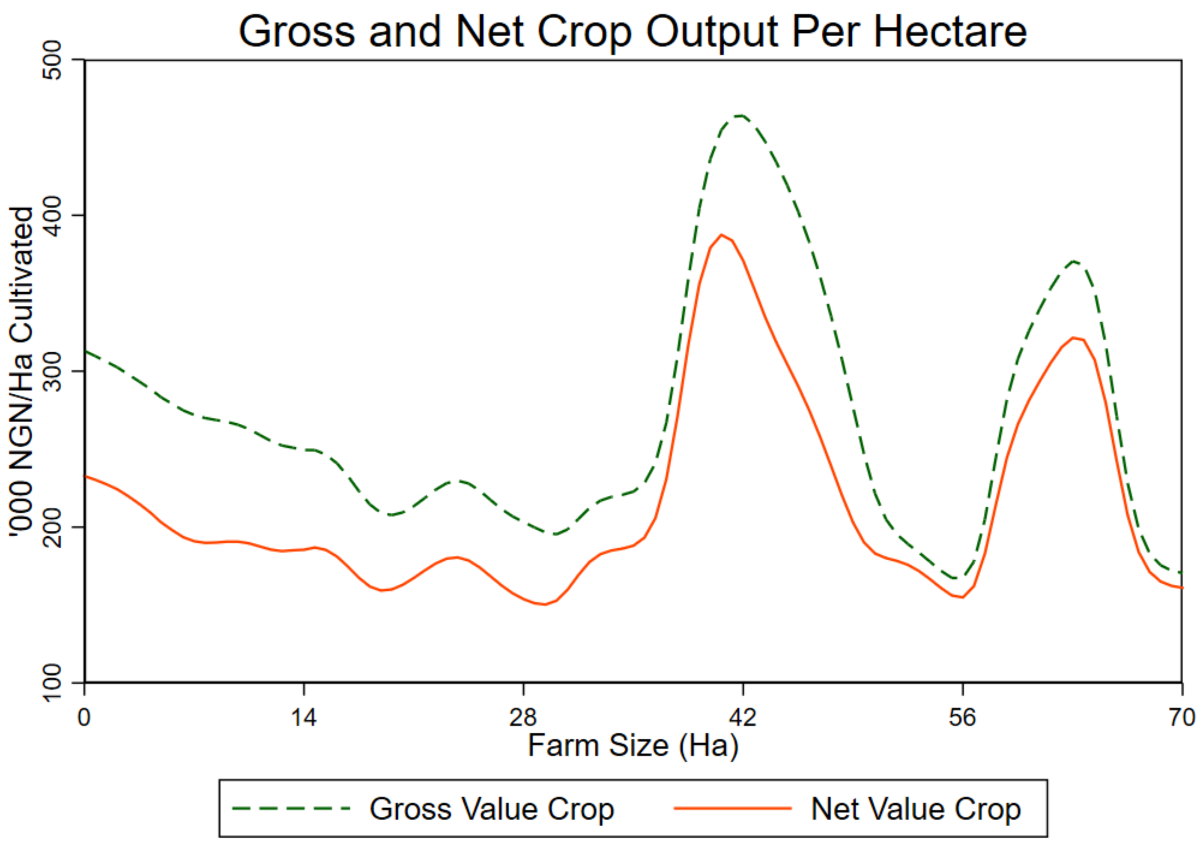

Figure 2: Gross and net output per hectare of crop cultivated over a wide range of farm size

Note: Non-parametric regression using Nadaraya-Watson Approach, bandwidth=2.0