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Agricultural Policy Research in Africa

THE FARM SIZE-PRODUCTIVITY RELATIONSHIP: EVIDENCE FROM PANEL DATA ANALYSIS OF SMALL- AND MEDIUM-SCALE FARMS IN NIGERIA

Oluwatoba Omotilewa, Thomas S. Jayne and Milu Muyanga

Working Paper

WP | 94
August 2022

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ACKNOWLEDGEMENTS

This work benefitted from financial support from APRA, the Guiding Investments in Sustainable Agricultural Intensification in Africa funded by the Bill & Melinda Gates Foundation, and the Feed the Future Nigeria Agricultural Policy Project funded by USAID-Nigeria. We are grateful for this generous support. We sincerely appreciate all valuable comments and suggestions received from reviewers, which helped us to improve the quality of the working paper.

Oluwatoba Omotilewa is a senior research economist at African Development Bank while Thomas S. Jayne and Milu Muyanga are professors at Michigan State University in the US.

This working paper is funded with UK aid from the UK government (Foreign, Commonwealth & Development Office – FCDO, formerly DFID). The opinions are the authors and do not necessarily reflect the views or policies of IDS or the UK government.

ACRONYMS

ANOVA	analysis of variance
CPI	Consumer Price Indices
CRE	correlated random effects
IR	inverse relationship
LGA	local government area
LSF	large-scale farm
MSF	medium-scale farm
NBS	National Bureau of Statistics
SSA	sub-Saharan Africa
SSF	small-scale farm
TFP	total factor productivity

EXECUTIVE SUMMARY

The observed inverse relationship (IR) between farm size and farm productivity has been a persisting controversy in the agricultural and development economics literature. The finding that smaller farms are more productive than larger farms has long been documented, dating back to Chayanov (1966) in Russia and later established by Sen (1966) in India. This relationship has also been observed in other developing economies, particularly in sub-Saharan Africa (SSA). At present, evidence in the SSA region has been largely limited to data from farms operating 5ha and below. To analyse how changes in farm size distributions may affect agricultural productivity and equity in SSA, new updated datasets involving a wider variety of farm sizes are required. Examining these changes in farm size distributions and their relationship with agricultural productivity is important not only for agricultural economists and development researchers but also for evidence-based policymaking which goes beyond the current smallholder-led strategies for development in the region.

This study examined the dynamics of farm operations between small-scale farms (SSFs) and medium-scale farms (MSFs) over time in different farm size categories and their relationship with agricultural productivity using a panel analysis of farming household data spanning 0–40ha in Nigeria. Two states, Ogun and Kaduna in southern and northern Nigeria, respectively, were purposively selected for the study due to efforts made by both states to promote medium- and large-scale commercial agricultural development. We accounted for observed and unobserved heterogeneities suspected for commonly observed variables in the literature. We also considered the dynamic movement between SSF and MSF operations and their productivity over time. Our findings show that there was little difference in mean productivity across various farm size categories up to at least 40ha. However, there was substantial heterogeneity in productivity within farm size categories. We also found that a non-trivial percentage of farms grew or shrunk in size with little observed change in productivity over time after accounting for external factors including weather. We therefore conclude that productivity does not depend on farm size, rather, non-size related factors are much more important drivers of productivity.

Overall, our findings suggest that any apparent relationship observed between farm size and productivity in SSF or MSF samples is relatively small and that non-size related factors are much more important drivers of productivity. The results further suggest that there is great potential to raise productivity across farms of all sizes in Nigeria. We find that if farms below the mean total factor productivity (TFP) – a measure of returns to all the factors of production – level in each farm size category were to be pulled up to their means, this would raise average gross output/ha by 125 per cent in Ogun and Kaduna states.

The results of this study have important implications for policy. The findings show that development practitioners and researchers must recognise that both smallholders and medium-scale operators alike vary in potential productivity. The current IR literature risks focusing on a relatively minor factor influencing national agricultural productivity – farm size – and diverting attention away from more impactful programmes and policy options to raise productivity. The fact that there is high variation in productivity across all farm size categories suggests that public spending which emphasises new technologies and practices that can be adopted by farms of all sizes, such as productivity-raising seed varieties, improved agronomic and soil health practices that raise yield response to inputs, and practices that stabilise crop yields in the face of variable weather may hold the greatest potential for raising farm productivity for farms of all sizes, and hence for aggregate farm productivity in Nigeria and similar countries.

1 INTRODUCTION

The controversy over the observed IR between farm size and farm productivity, defined as output per unit of land, has been perennial in agricultural and development economics literature. The stylised fact that smaller farms are more productive than larger farms was first documented by Chayanov (1966) in Russia and was later established by Sen (1966) in India. Moreover, this relationship has been further observed in other developing economies particularly in SSA, where evidence has been largely limited to data from farms operating 5ha and below (e.g., Kimhi, 2006; Barrett, Bellemare and Hou, 2010; Carletto, Savastano and Zezza, 2013; Collier and Dercon, 2014; Larson et al., 2014; Ali and Deininger, 2015; Julien, Bravo-Ureta and Rada, 2019). If smaller farms are indeed more productive as implied by IR, land policies favouring access to remaining unused arable land for smallholder famers may not only enhance equity but also efficiency in food production and improved livelihood for smallholder farmers (Hazell et al., 2010).

Following the IR stylised fact and the historical preponderance of SSFs in SSA, many development partners have focused on smallholder-led strategy as key for food security, agricultural development, and economic development in general, in the region (Mellor, 1995; Hazell et al., 2010). However, the recent growth in the share of cultivated farmland under MSFs and large-scale farms (LSFs) in many parts of Africa (Jayne et al., 2016; Jayne et al., 2019; Lowder, Sanchez and Bertini, 2019) has raised major concerns about the inclusivity, equity and productivity of agricultural growth. Unfortunately, most IR analyses for African settings have seldom used datasets that can confidently make conclusions about farms beyond 10ha (Muyanga and Jayne, 2019). There has been lack of clarity or very limited evidence of IR on the yield of large vs small farms in Africa (Collier and Dercon, 2014; Rada and Fuglie, 2019; Omotilewa et al., 2021). Therefore, analysis of how changes in farm size distributions may be affecting the equity and productivity of African agriculture requires new datasets with sufficient observations among relatively large farms to explore these issues with a reasonable degree of statistical precision.

Clearly, the limited empirical evidence showing the relationship between farm size and productivity over the MSFs to LSFs (say >5ha) in developing countries in general and SSA in particular creates both policy and literature gaps (Julien, Bravo-Ureta and Rada, 2019; Muyanga and Jayne, 2019; Rada and Fuglie, 2019; Omotilewa et al., 2021). The present study intends to further address these gaps using farm/household panel data for a relatively wide range of farm sizes (0-40ha) in Nigeria. We address some important questions in the agricultural and development economics literature. First, is farm size an important determinant of agricultural productivity? Second, if so, does the IR hold beyond the commonly observed narrow range of farm sizes (generally between 0 and 5ha)? Third, given the panel data from two rounds of surveys, are there changes in farm size categories operated by farmers across years and how does productivity vary within different farm size categories over time? That is, what are the changing and productivity dynamics within the farm size categories (SSF or MSF) operated? Addressing these questions is important not only for agricultural economists and development researchers but also for evidence-based policymaking beyond the current development model of smallholder-led strategies for development in Africa.

The literature on IR is robust but largely limited to SSFs in developing countries. Many factors have been identified as contributors to the IR. Broadly, these factors are: (i) imperfect factor market leading to under-valuation of family labour used on smallholder farms (Carter, 1984; Binswanger, Deininger and Feder, 1995); (ii) principal-agent or moral hazard problem where the cost of supervising hired labour is high relative to the use of family labour (Feder, 1985; Eswaran and Kotwa, 1986), implying that larger farms are less productive than smaller ones as they tend to use more hired labour; (iii) omitted variable bias including omission of soil quality characteristics and other unobserved heterogeneity from both farm operators and plots (Bhalla and Roy, 1988; Benjamin, 1995; Lamb 2003; Kimhi, 2006; Assunção and Braido, 2007); (iv) risk aversion where land market imperfections and lack of insurance markets may lead to labour misallocation among farm operators (Barrett, 1996); and (v) measurement errors in self-reported farm size (Lamb, 2003; Carletto, Savastano and Zezza, 2013; Carletto, Gourlay and Winters, 2015) or output (Desiere and Jolliffe, 2018; Gourlay, Kilic and Lobell, 2019). It would be a useful contribution to the IR literature to test whether these explanations still hold over a broader range of farm size categories.

To our knowledge, only Muyanga and Jayne (2019) and Omotilewa et al. (2021) have examined the IR relationship over a relatively wide range of farms in SSA (Kenya and Nigeria, respectively). Both of these studies used cross-sectional data and found that IR exists among SSFs (up to 3ha in Kenya and 5ha in Nigeria), confirming what has been mostly observed for smaller farms in the literature. Beyond SSFs, both studies further found a U-shaped relationship between farm productivity and farm size as farm size increased, suggesting that as farm size grows, productivity increases.[1] However, due to the limitations of cross-sectional data, few African studies have been able to speak to the dynamics of productivity within or across SSFs vs MSFs or cross-movements across farm categories over time. In addition, the use of panel data enables us to control for time-invariant unobserved heterogeneities that may bias estimates derived from cross-sectional analyses.

Therefore, the present study builds upon and expands these two prior studies, using panel data from 0-40ha farms in Nigeria, providing further empirical evidence and contributing to sparse literature that have examined IR beyond smallholders in Africa. To our knowledge, this is the first study to use panel data to analyse the IR over a wide range of farm sizes including small- and medium-scale or relatively bigger farms in Africa. Limited studies have performed panel analysis to investigate farm or plot-size IR albeit for SSFs. For instance, Julien, Bravo-Ureta and Rada (2019) used panel data from Uganda, Malawi, and Tanzania, and concluded that IR exists. Desiere and Jolliffe (2018) and Gourlay et al. (2019) investigated IR with panel data from Ethiopia and Uganda, respectively, using crop cuts methods to determine yield but found no evidence of IR. This suggests that IR is a construct of measurement errors in self-reported yields. However, although the mixed findings from these panel studies further imply a need for more empirical evidence using panel analyses, all of these studies were limited to SSFs. Inference therefore cannot be made to bigger farm sizes.

In addition to using panel data techniques to control for unobserved heterogeneity in testing for IR hypothesis beyond SSFs in SSA, this study further examines the dynamics of farm operations between SSFs and MSFs over time in different farm size categories. These dynamics include transitions from SSF operations to MSF operations over time, and vice versa, as well as changes in productivity within any given farm category over time. Thus, the present study not only provides additional checks on the robustness of findings from the cross-sectional analyses presented in Muyanga and Jayne (2019) and Omotilewa et al. (2021), it further provides insights regarding how operated farm sizes and levels of productivity might change between SSF operators and MSF operators over time.

1 A U-shaped farm size-productivity relationship has also been found in other recent studies involving other regions (e.g., Aragón, Restuccia and Rud, 2022; Foster and Rosenzweig, 2022).

2 CONCEPTUAL FRAMEWORK AND ESTIMATION STRATEGY

Our conceptual approach follows from Kimhi's (2006) modelling of farm decisions as a sequential two-stage process where farmers first allocate land among different crops and thereafter, can only change outcomes by influencing yields. More specifically, we use a production function $Y=f(X,A,Z)$ where Y is output quantity, X is a vector of variable inputs including hired and family labour, seed and fertiliser; A is land size operated, a fixed input; Z is a vector of household characteristics and assets, soil quality, soil type, crop type cultivated, market access, and other environmental variables including constraints, weather, location, etc. Conceptually, these factors (such as inputs, land size operated, soil quality or type, and environmental variables) all impact yield, but other unobserved factors also play critical roles. To estimate the shadow wage from the family labour used in computing net productivity, we estimated marginal productivity of labour following Abdulai and Regmi (2000) and Sakketa and Gerber (2020).

2.1 Estimation strategy

To operationalise the production function above, empirically, we estimated the relationship between farm size and productivity as follows:

$$Y_{itr} = \beta_o + \beta_1 A_{it} + \beta_2 A_{it}^2 + \boldsymbol{\beta_3 X_{it}} + \boldsymbol{\beta_4 Z_{it}} + \boldsymbol{\beta_5 S_i} + \theta_r + c_i + \varepsilon_{it} \quad (1)$$

Let Y_{itr} be the outcome variables (i.e., the self-reported measures of productivity in monetary terms) for household i at time t in region r. The main explanatory variables of interest were farm size area cultivated in hectares (A_{it}) and its squared term (A_{it}^2). Other explanatory variables were X_{it}, a vector of inputs used as defined above; Z_{it} which included household characteristics and assets, access to information and output market; soil types and quality; and binary indicator variables for the five different crop categories cultivated (grains, legumes, roots and tubers, fruits and vegetables, and cash crops).

Also included in equation (1) is a vector of two binary indicator variables in S_i: the first equals one if a farm operator had been cultivating SSFs but stepped up into MSF farming operations prior to wave 1 data collection in 2018; while the second indicator variable equals one if a farm operator stepped up directly into medium-scale farming. The first binary indicator may proxy for household farming experience prior to 2018 given that we suspect households who were primarily engaged in small-scale farming prior to stepping-up to medium-scale farming may be more experienced farmers than those entering farming afresh who were formerly primarily involved in non-farm employment.[2]

The θ_r component is state fixed effects while the c_i component is the unobserved time-invariant factors or unobserved heterogeneity influencing the farm operator's farm size allocation and farm productivity. These may include farmer's management ability or degree of risk aversion. Lastly, ε_{it} is the error term. The βs (Greek beta) are a vector of parameters to be estimated where β_1 and β_2 are jointly parameters of interest, vectors β_3 and β_4 are vector of parameters associated with the vectors X_{it} and Z_{it}, respectively. The first parameter in β_5 captures the impact of the SSF experience on MSF size-productivity. If β_1 is negative and β_2 (from the quadratic term) is not statistically significant, it confirms the existence of IR and vice versa if β_1 is positive. However, if β_1 and β_2 are jointly significant, then β_2's magnitude and sign together with that of β_1 can determine if a U-shaped or inverse U-shaped relationship exists between farm size and productivity. If β_1 and β_2 are not jointly statistically significant, the squared term and associated parameter (β_2) can be dropped and we draw conclusions based on the sign and significance of β_1 alone.

To relax the strong assumption of independence between c_i and the covariates as would be in the random effects model and to prevent all other time-

2 For IR analysis using a balanced panel, we kept household observations that consistently operated small-scale or MSFs in both waves 1 (2018) and 2 (2020). Thus, the term "stepping-up" as used here refers to stepping up from small-scale to medium-scale crop operations prior to 2018.

invariant covariates predicting productivity from getting wiped out or introducing attenuation bias from potential measurement errors in some covariates (across waves) as would be from using the fixed effects model, we model equation (1) as correlated random effects (CRE), which models dependence between c_i and $\boldsymbol{X}_{it}$. This is implemented by including a vector of variables containing the means for farm operating household i of all time-varying covariates (see Mundlak (1978), Chamberlain (1984) or Wooldridge (2010) for more details on CRE). By including a vector of all time-averaged covariates, all time-invariant unobserved heterogeneity is controlled for as in the fixed effects model while the effects of all other time-invariant covariates on productivity are still captured as in the random effects model (Wooldridge, 2010).

All variables measured in monetary terms including output and all inputs are deflated to 2018 prices using Consumer Price Indices (CPIs) obtained from the National Bureau of Statistics (NBS), Nigeria.

3 DATA, SAMPLING DESIGN, AND VARIABLES USED

3.1 Data

Because the main objective of this study was to assess farm size/productivity relationship over a relatively broad range of farm sizes that include MSFs, it was necessary to collect primary data considering that available nationally representative farm household survey datasets in SSA, including the Living Standards Measurement Study – Integrated Surveys in Agriculture, contain very few farms over 10ha and hence do not allow for inferential conclusions about such MSFs.[3] In addition, urban-based households are now more involved in commercialised MSFs but these urban-based operators are typically excluded from currently existing nationally-representative farm surveys. Thus, an important and growing segment of the population of MSFs may be exempted without new surveys covering these operators (Jayne et al., 2016). For these reasons, an exhaustive listing and sampling of small-scale and MSF households within the study area was implemented prior to wave 1 data collection.

This study used panel data with wave 1 data collected between April and May 2018 from a survey of about 2,000 smallholders and MSF operators in Nigeria. The wave 2 data from a follow-up survey was conducted in December 2020, about 2.5 years after the wave 1 data collection. However, due to budget constraints, the follow-up (wave 2) survey was limited to about 1,300 households that were randomly selected from the households sampled from the wave 1 survey. Of these, only 1,268 households had harvested crops at the time of survey.[4] The survey instrument used to collect data in both rounds of survey was a structured questionnaire designed to capture socio-economic information on households operating farms, agricultural inputs used, crops cultivated, animals raised and costs, output, revenue, and marketing information. Often, farm operators cultivated multiple fragmented plots of land and we aggregated these multiple plots up to the farm household level.

3.2 Sampling design

Nigeria has 36 states and the Federal Capital Territory however only two states, Ogun and Kaduna in southern and northern Nigeria, respectively, were purposively selected because both states have made efforts to promote medium- and large-scale commercial agriculture development (see Figure 3.1 for an administrative map of Nigeria with Ogun and Kaduna states highlighted). These two states represent the climatic, vegetation, rural livelihoods, biophysical and socio-economic conditions under which 75 per cent of Nigerians live. The second stage sampling involved the purposive selection of three local government areas (LGAs) in each of the two states. To obtain a sampling frame for MSF households, the population of households operating a farm size of 5ha and above (MSF households) in each of the six selected LGAs were listed. In the third stage of sampling, three and four wards were selected from each LGA in Kaduna State and Ogun states respectively, using a stratified random sampling procedure. Stratification was based on the concentration of MSF households in each ward.[5] The fourth stage involved the selection of 500 MSF households from each state through a proportional random sampling procedure. A similar process was

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

4 For the IR analysis, we simply used a balanced panel of 1,131 households with consistent farm size operations (MSF or SSF) across waves.

5 States in Nigeria are administratively divided into LGAs, which are further divided into wards comprising many communities, villages or towns.

followed in selecting 500 SSF households for the study from each state. The exercise was implemented by a team of trained enumerators.[6] See Omotilewa et al. (2021) for more details of sampling and listing exercise.

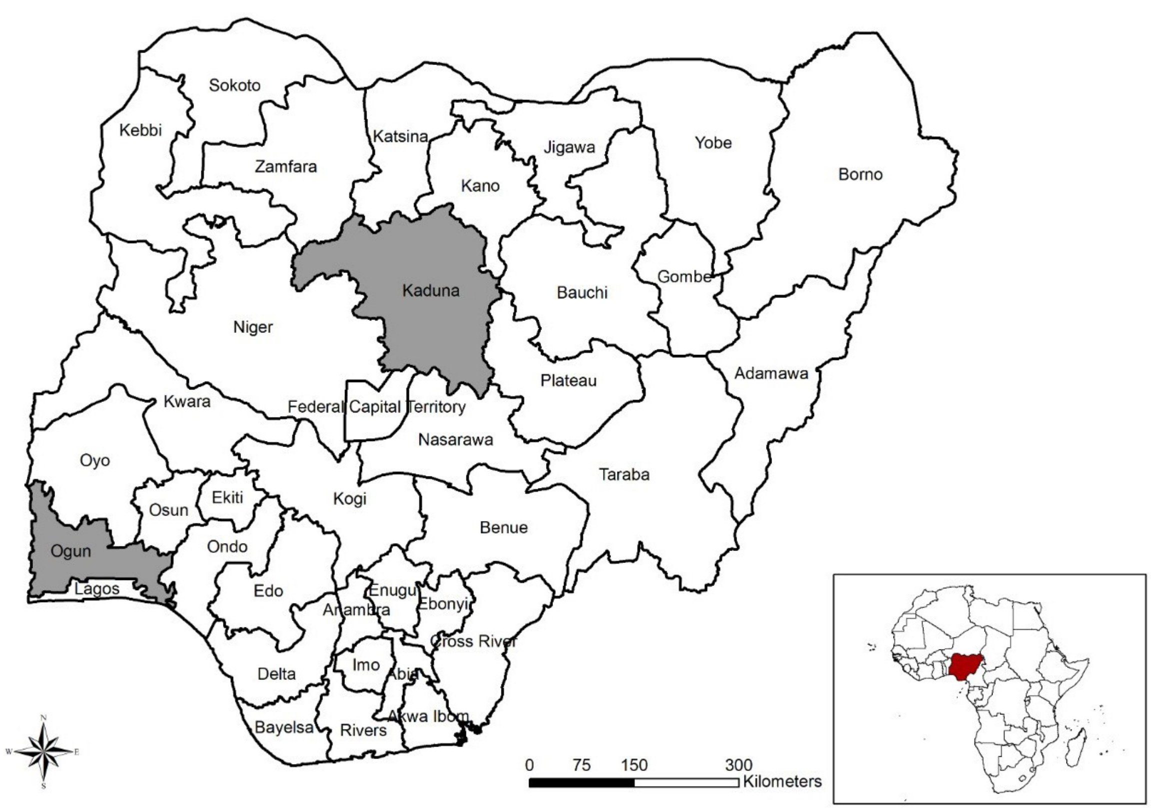
In the wave 2 data collection, a subset of 325 SSF households and 325 MSF households per state were randomly selected from the original sample of farm households, due to budget constraints. For descriptive purposes, we categorised farm sizes into four categories: a small-scale (<5ha) category; and three separate medium-scale categories: (5≤ha<10), (10≤ha<20), and (20≤ha<40), respectively (see Table 3.1 for breakdown and characteristics of each category in both waves 1 and 2 data).

3.3 Dependent and explanatory variables

For dependent variables, we derived two measures of agricultural productivity namely i) the gross value of crop output per hectare cultivated and ii) the net value of crop output per hectare cultivated.[7] These measures are arguably more relevant measures of farm productivity than just crop-specific yield as commonly used in most IR studies in Africa to date. As alluded to in both Desiere and Jolliffe (2018) and Gourlay et al. (2019), self-reported yields could be prone to errors, whereas these errors might be removed from monetary values or revenue from crop sales given that households are more likely to have an accurate assessment of their incomes. Nevertheless, as a robustness check, in addition to these productivity measures, we also estimated IR using TFP. The net value of cultivated crop output was computed as the gross value less the total cost including input costs, hired labour cost, and family labour input valued at the estimated shadow wage for family labour. Previous studies show that the IR tends to vanish when profit measures deducting the costs of inputs including family labour are used to estimate relationships between farm size and productivity (Carter and Wiebe, 1990).

The principal explanatory variables of interest are the self-reported land area cultivated or operated by farms and its squared term. Using self-reported operated acreage rather than GPS-assessed value could raise

Figure 3.1 Administrative map of Nigeria with Kaduna and Ogun states highlighted



Source: Authors' own

6 The listing protocol used by enumerators is available upon request.

7 As a robustness check, we further estimated IR using TFP as a dependent variable.

questions of accuracy of self-reported data, 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, Savastano and Zezza, 2013; Carletto, Gourlay and Winters, 2015; Dillon et al., 2019). Additional explanatory variables include 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 fertiliser use and labour (hired and family). Further explanatory variables include information on access to market and/or input dealers, and access to and use of extension services. These access variables were derived from asking survey respondents whether they have access to these services. Lastly, a binary indicator variable equal to one (1) when a farm operator stepped up into medium-scale farming from prior small-scale operations and zero (0) otherwise was included in the model. Previous studies have shown these two very distinct pathways into medium-scale farming, with distinct socio-demographic conditions for the two groups (Jayne et al., 2019; Muyanga et al., 2019).

4 MOVEMENT BETWEEN FARM SIZE CATEGORIES OVER TIME

Before presenting econometric estimations of the relationship between farm size and productivity, first, we present findings about two of our research questions: (i) are there changes in farm size categories operated by farmers across years? And (ii) how does productivity vary within and across specific farm size categories over time?

4.1 Variation in farm sizes over time

Findings show dynamic movements across farm size categories. In the first wave of our panel data, SSF operators constituted 52 per cent of our sample but had increased to 58 per cent by the second wave of data collected 2.5 years later, while the proportion of MSF operators cultivating between 5–20ha decreased from 43 per cent to 39 per cent over the same period. Lastly, the proportion of MSFs operating above 20ha had declined from 5 per cent in wave 1 to 3 per cent in wave 2.

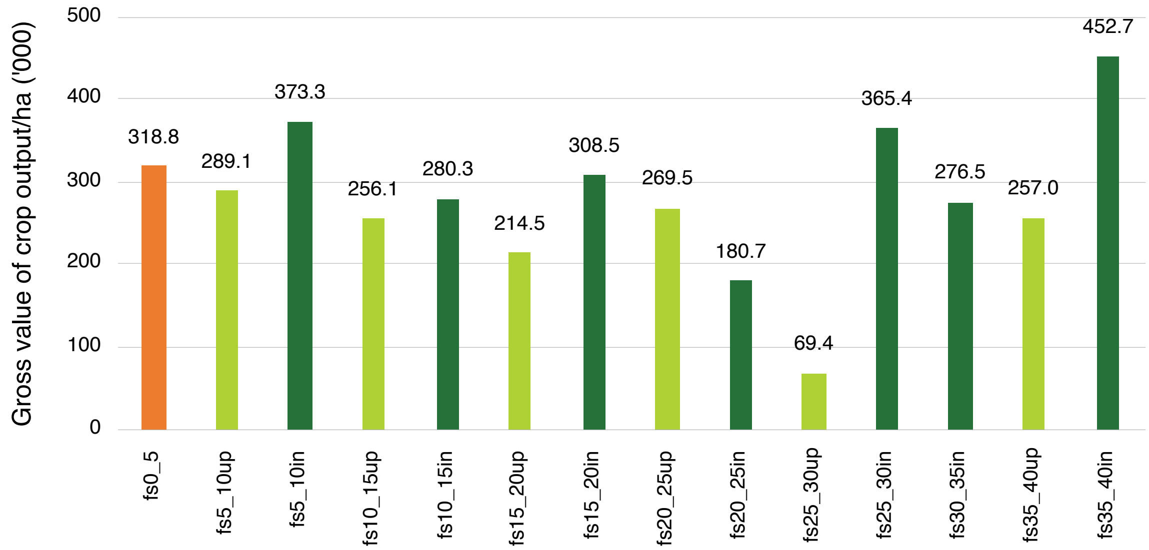
Further examination reveals that overall, 18 per cent (109/609) of the MSF operators during wave 1 were now small-scale operators by wave 2. The majority (83.5 per cent) of these 'stepped-down' operators moved from cultivating between 5–10ha in wave 1 to cultivating less than 5ha in wave 2 (see Transition Matrix in Appendix Table A1 and breakdown of movement across farm size categories in Appendix Table A2). Likewise, a few SSFs (4.2 per cent or 28/659 operators) had stepped up from cultivating less than 5ha in wave 1 to cultivating MSFs in wave 2. The majority (93 per cent) of these stepped-up farmers moved from operating less than 5ha in wave 1 to operating 5–10ha in wave 2 (see Appendix Table A3). These findings show that there were movements across farm size categories but suggest that the MSF operators were more likely to fall back into small-scale farming than for small-scale operators to move up into medium-scale farming albeit close to the SSF vs. MSF thresholds. However, there are two points which should be considered. First, the negative impact of the COVID-19 pandemic on the access of farm households to land, labour, and agrochemicals could be responsible for the relatively low rate of stepping up observed in 2020 relative to 2018 (see Aromolaran et al., 2021). Second, there are substantially more SSFs than MSFs in Nigeria, hence even with a relatively low rate of stepping up, the total number of new MSFs that stepped up from small-scale operations should have increased relative to the existing population of MSFs.

4.2 Variation in productivity over time by farm sizes and pathways of emergence for MSFs

In addition to examining the dynamic movement of farm operators across small- and MSF operations, we further investigated the productivity of these farms over time. Overall, we found that on average, gross output per hectare remained largely consistent for operators who were consistently small-scale or medium-scale operators over time (across both waves 1 and 2). For operators who switched between small-scale and medium-scale operations across the waves, there were relative increases in productivity – from wave 1 to wave 2 but the reverse happened for operators switching from medium- to small-scale farming (see Appendix Table 4).

Figure 4.1 presents a refined distribution of productivity (gross crop output per hectare) by farm size, over a 5ha interval, while distinguishing between stepped-up and stepped-in farm operators. From the pooled data across both waves, stepped-in operators of farm sizes between 5–40ha were significantly more productive except in the 15ha–20ha range (Figure 4.1). Moreover, when the pooled panel data is disaggregated by waves 1 and 2 of the panel data, it becomes clear that stepped-up and stepped-in farmers had flipped productivity over time. Initially, farmers who stepped-up from small-scale farming into medium-scale farming were more productive than their stepped-in counterparts as at the first wave of data collected in 2018 (Figure 4.2). However, 2.5 years later, farms operated by farmers who had initially stepped-in into medium-scale farming without prior small-scale farming operations were now significantly more productive (Figure 4.3). There are two possible reasons for these findings. First, the finding suggests that stepped-in MSFs in early 2018, without prior SSF operations, had become more productive by the end of the year 2020 likely because they gained experience over time. Second, the decline in productivity among stepped-up farmers between 2018

Figure 4.1: Distribution of gross crop output per hectare by mode of entry into MSF: Pooled data

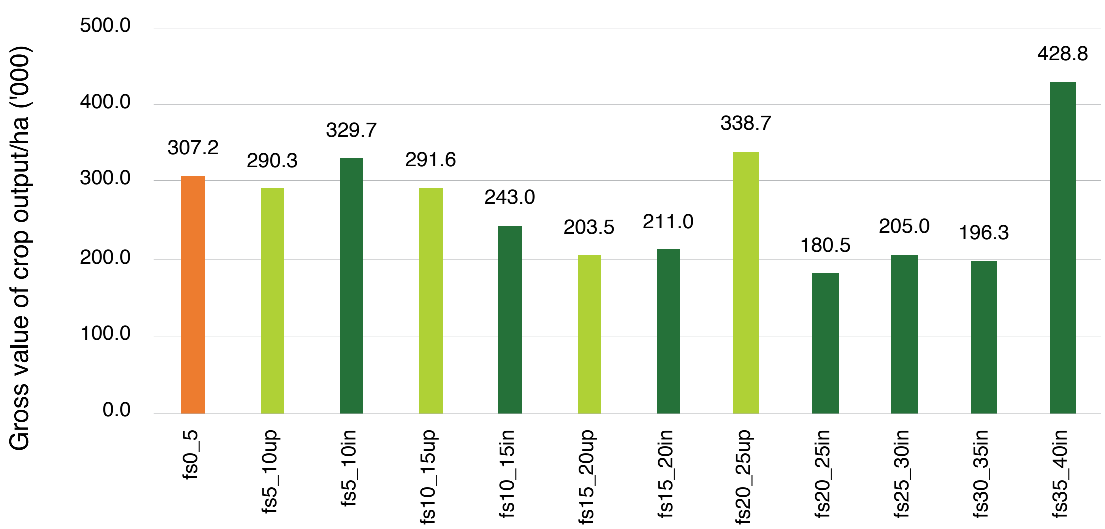


Farm size	f5–10	f10–15	f15–20	f20–25	f25–40
Step-up (N)	396	83	19	25	1
Step-in (N)	383	108	51	26	35

Note: fs*_**up represents farm size ranging from * to ** for a stepped-up operator
fs*_**in represents farm size ranging from * to ** for a stepped-in operator

Source: Authors' own

Figure 4.2: Distribution of gross crop output per hectare by mode of entry into MSF: Wave 1 (May 2018)

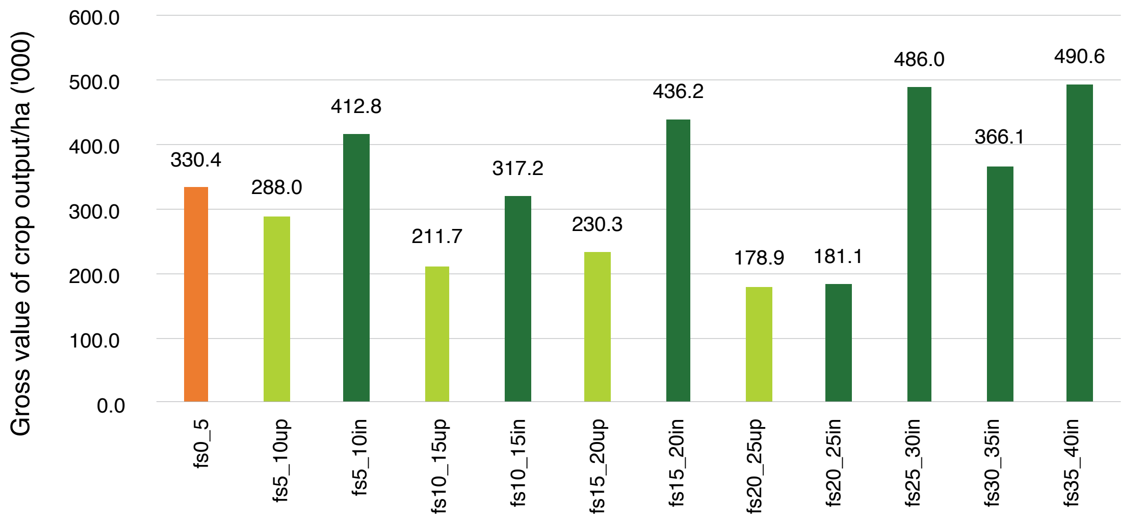


Farm size	f5–10	f10–15	f15–20	f20–25	f25–40
Step-up (N)	206	49	11	15	0
Step-in (N)	200	54	30	18	18

Note: fs*_**up represents farm size ranging from * to ** for a stepped-up operator
fs*_**in represents farm size ranging from * to ** for a stepped-in operator

Source: Authors' own

Figure 4.3: Distribution of gross crop output per hectare by mode of entry into MSF: Wave 2 (Dec 2020)



Farm size	f5–10	f10–15	f15–20	f20–25	f25–40
Step-up (N)	190	34	8	10	0
Step-in (N)	183	54	21	8	17

Note: fs*_**up represents farm size ranging from * to ** for a stepped-up operator
fs*_**in represents farm size ranging from * to ** for a stepped-in operator
Source: Authors' own, based on APRA panel data

and 2020 could have resulted from lower resilience to the negative impact of the COVID-19 pandemic on input availability and prices, as reported in Aromolaran et al. (2021).

These new findings do not align with the original findings presented in Omotilewa et al. (2021) based on cross-sectional analysis of data, demonstrating the power of observing farmers or participants over multiple seasons. The implication in the Omotilewa et al. (2021) study is that by empowering small-scale operators to access more land and step up into medium-scale farming, productivity would likely increase. However, as shown in the present study, the variations observed over time suggest that stepped-in farmers may become more productive with experience and perhaps because they tend to have greater resources at their disposal as suggested by household assets (see Table 5.1).

5 ECONOMETRIC RESULTS AND DISCUSSIONS

5.1 Descriptive statistics

Table 5.1 shows a comparison of household-level and farm-level characteristics by farm size categories, for each round of panel data. To help develop a better understanding of the distribution of farm sizes within the broad classification of SSFs (<5ha) and MSFs (5–40ha), we divided the MSFs into three different categories. That is, farms between 5–10ha (lower MSF), 10–20ha (middle MSF), and 20–40ha (higher MSF). The dependent variables of interest (productivity) are presented in Panel A, farm- and household-level characteristics presented in Panel B, assets of operators are presented in Panel C, while self-assessed soil type and qualities are presented in Panel D. Lastly, the production practices and inputs used are presented in Panel E.

In general, the average productivity increased over time across waves.[8] That is, the average gross and net outputs/ha as well as TFP increased from wave 1 to wave 2. Moreover, some nuanced differences were observed. For instance, the average gross output/ha appeared relatively equal for each farm size category in wave 2 whereas in wave 1, the average gross output/ha appeared larger for smallholders and lower MSFs. This suggests inverse productivity with SSFs to lower MSFs more productive. For the net value of crop output per hectare, farms in the 10–20ha range were the least productive however productivity appeared constant across other farm size categories. Likewise, TFP appeared similar across farm size categories but on average, an increase in productivity was observed over time.

Panel B shows that, consistent across waves, the age of farm household head and household size tended to increase with increase farm size, for farm size categories ranging from 0–20ha. We observed that the proportion of female-headed farm households appeared to decline with increasing farm size, for farm sizes ranging between 0–20ha. The results also showed that farm size did not seem to vary with number of years of schooling of household head.

Panel C shows that household assets are largely constant over time except for motorcycle and plough ownership with a significant decrease in these assets observed for all operators across waves. For instance, 69 per cent of smallholders owned a motorcycle in 2018 but only 38 per cent reported ownership in 2020. This could suggest economic hardship and households selling off such assets. Alternatively, the assets were broken and no longer functional. Panel D reports the self-assessment of soil types and qualities. These binary indicators (= 1) indicate whether a household assesses the soil types or qualities on any of the plots they cultivated. Hence, a single household may report different or multiple soil qualities or types if they cultivated multiple plots with different characteristics. Largely, self-assessed soil qualities and types were consistent across waves. There were some marginal changes particularly for smallholders cultivating sandy or sandy soil, but nothing significant.

Panel E reveals that the share of land operated as a fraction of total landholdings remains high for all farm-size categories across both waves with most operators owning the land they operate. While 11 per cent of farmers rented-in land in 2018, this share had increased to 19 per cent in 2020 driven by increased rented-in lands across all farm categories. Panel E also shows that the total cost of production/hectare decreased from wave 1 to wave 2, which may suggest efficiency but could also be linked to lockdown effects of COVID-19 limiting supply (see Aromolaran et al., 2021). Nevertheless, the per unit cost was higher for smallholders than MSFs indicating economies of scale.

On labour use, the average family labour days per hectare was significantly higher for smallholders than MSFs, further buttressing imperfect labour market conclusions from prior literature where household expends excess labour on farming activities (Sen, 1966; Carter, 1984.). Overall, family labour days per hectare increased across waves but this increase was most prominent for smallholders with an increase of nearly five days/ha of additional family labour. In addition, the

8 To control for inflation and make accurate comparisons across the panel data, all wave 2 monetary values were deflated by the consumer price index obtained from the NBS, Nigeria, with 2018 as base year.

Table 5.1: Descriptive statistics for variables by farm sizes and category, wave 1 (2018) and wave 2 (2020)

	SSF (mean)		MSF (mean)						Full sample (mean)	
	(ha<5)		(5≤ha<10)		(10≤ha<20)		(20≤ha<40)		(0–40ha)	
	Wave 1 (1)	Wave 2 (2)	Wave 1 (3)	Wave 2 (4)	Wave 1 (5)	Wave 2 (6)	Wave 1 (7)	Wave 2 (8)	Wave 1 (9)	Wave 2 (10)
A. Dependent variables										
Gross value of crop output/hacultivated*	307	330	313	360	246	311	252	329	305	332
Net value of crop output/ha cultivated*	208	265	208	307	158	271	193	291	207	269
TFP	1.18	1.24	1.27	1.46	1.07	1.34	1.18	1.52	1.18	1.27
B. Farm household characteristics										
Age of household head (years)	41.75	43.71	44.42	47.01	49.12	51.36	50.08	49.43	42.24	44.20
Adult equivalent	5.24	5.22	5.96	6.03	6.37	6.46	8.04	7.89	5.35	5.34
=1 if female-headed household	0.05	0.07	0.03	0.05	0.03	0.01	0.01	0.03	0.05	0.06
Years of education of household head	7.08	8.98	7.77	8.83	7.38	9.18	7.64	8.37	7.15	8.97
C. Assets										
=1 if household has a radio	0.81	0.80	0.87	0.82	0.86	0.93	0.91	0.87	0.82	0.80
=1 if household has a TV	0.27	0.31	0.44	0.31	0.50	0.40	0.54	0.53	0.30	0.31
=1 if household has a mobile phone	0.94	0.97	0.95	0.93	0.96	1.00	0.98	1.00	0.94	0.97
=1 if household has a motorcycle	0.69	0.38	0.63	0.51	0.78	0.60	0.82	0.55	0.69	0.39
=1 if household has a car	0.07	0.05	0.09	0.10	0.13	0.11	0.43	0.29	0.07	0.05
=1 if household has a water pump	0.02	0.02	0.07	0.06	0.10	0.04	0.18	0.11	0.03	0.03
=1 if household has a plough	0.18	0.08	0.12	0.09	0.14	0.06	0.16	0.03	0.17	0.08
=1 if household has a sprayer	0.51	0.49	0.52	0.70	0.65	0.65	0.89	0.73	0.52	0.51
D. Self-assessment of soil types and qualities										
=1 if any plot cultivated is sandy soil	0.03	0.09	0.12	0.08	0.13	0.12	0.15	0.17	0.04	0.09
=1 if any plot cultivated is clay soil	0.04	0.03	0.09	0.03	0.11	0.06	0.07	0.05	0.04	0.03
=1 if any plot cultivated is loamy soil	0.96	0.93	0.93	0.94	0.96	0.88	0.95	0.89	0.96	0.93
=1 if any plot cultivated is stony soil	0.02	0.04	0.04	0.05	0.10	0.11	0.05	0.06	0.03	0.04
=1 if any plot cultivated is forest soil	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.03	0.00	0.00
=1 if good	0.90	0.95	0.94	0.93	0.95	0.97	0.92	0.99	0.91	0.95
=1 if fair	0.15	0.10	0.15	0.12	0.13	0.08	0.13	0.12	0.15	0.10
=1 if poor+	0.01	0.00	0.01	0.01	0.04	0.02	0.05	0.01	0.01	0.00
E. Production and input use practices										
Operated farm size (ha)	2.43	2.37	6.41	6.34	13.08	12.70	27.92	28.45	3.31	3.13
Total landholding accessed (ha)	3.18	3.33	9.24	9.82	16.82	18.85	33.42	37.52	4.34	4.47
Total landholding owned (ha)	2.96	2.75	8.52	8.73	15.71	15.89	31.17	32.33	4.04	3.76
Share of households who rented in land (%)	0.11	0.19	0.13	0.18	0.11	0.20	0.14	0.22	0.11	0.19
Total landholding rented in for renters (ha)	1.98	2.99	5.75	6.09	9.97	14.79	15.70	24.15	2.70	3.68
Ratio operated farm size/total landholdings (%)	89.76	84.97	88.74	83.01	89.01	81.00	88.94	83.04	89.66	84.70
Total cost of crop production/ha planted*	99.20	65.68	105.21	52.70	88.09	40.40	59.65	38.25	98.89	63.83
Family labour days/ha	13.46	18.27	7.06	8.19	5.19	5.91	2.69	3.63	12.64	17.05
Hired labour days/ha	5.89	5.93	6.84	3.56	13.38	2.77	6.38	1.78	6.17	5.63
Estimated family labour cost/ha*	4.77	4.76	4.29	4.19	4.13	4.08	4.18	4.03	4.72	4.69
Hired labour cost/ha*	39.60	30.46	46.79	25.16	38.33	18.29	24.41	12.08	39.98	29.47
=1 if household used inorganic fertiliser	0.66	0.64	0.63	0.63	0.62	0.52	0.64	0.62	0.66	0.63
=1 if household used organic fertiliser	0.15	0.19	0.24	0.17	0.15	0.18	0.13	0.13	0.15	0.19
Inorganic fertiliser quantity (kg/ha)	165.43	165.41	140.51	116.09	113.77	88.61	97.57	104.32	161.42	159.15
Organic fertiliser quantity (kg/ha)	64.95	112.41	77.07	64.28	68.14	71.76	48.30	38.11	65.74	106.97
Inorganic fertiliser price/kg (₦)	165	146	166	146	168	144	167	147	165	146
Inorganic fertiliser cost (₦/ha)*	295	248	139	105	104	67	55	36	276	232
No. of agriculture related trainings attended by household members	5.48	4.66	1.26	3.64	0.00	10.00	0	0	5.45	4.64
=1 if household has access to market	0.41	0.46	0.27	0.52	0.23	0.43	0.14	0.56	0.39	0.47

=1 if household has access to agro-input dealer	0.34	0.34	0.27	0.30	0.16	0.26	0.10	0.20	0.33	0.34
=1 if household has access to extension agents	0.00	0.00	0.42	0.42	0.33	0.30	0.26	0.23	0.04	0.04
=1 if household has access to agro-input dealer	0.18	0.18	0.21	0.22	0.35	0.35	0.31	0.35	0.19	0.19
=1 if household has access to extension agents	0.82	0.82	0.79	0.78	0.65	0.65	0.69	0.65	0.81	0.81
=1 if household has access to agro-input dealer	631	631	315	347	128	115	57	38	1131	1131

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

* Values reported in ₦'000 . Exchange rate is US$1= ₦306 as at time of wave 1 survey and US$1=₦410 at wave 2 survey. To control for inflation, all wave 2 monetary values were deflated by price index (using CPIs obtained from the NBS, Nigeria) with 2018 as base year.

This ratio was computed at household level and mean results presented here.

+Many households cultivated more than one plot and may report different soil quality on different plots. Thus, summing the share of households reporting of soil qualities (poor, fair or good) or soil types (sandy, loamy, clay, stony, or forest) may exceed 100%. It is also possible that some households operated different or separate plots or plot proportions in different years (waves).

Source: Authors' own

use of hired labour remained constant over time for smallholders but significantly decreased for the MSFs likely due to COVID-19 contributing to reduction in hired labour for LSFs (Aromolaran et al., 2021). On labour cost per hectare, the estimated value of family labour was substantially less than the hired labour wage rate observed in the data, further supporting the imperfect market assertion.

On fertiliser input use and access to services, we found that the average kilogram per hectare of inorganic fertiliser use decreased with farm size, suggesting economies of scale in fertiliser acquisition and use. Although the average price/kg remained relatively constant across farm categories, the average cost/ha for the smallholders was significantly higher than the medium-scale operators. Lastly, access to market, extension services, and input dealers as well as sample representation were fairly consistent over time.

5.2 IR results and discussion

Table 5.2 presents panel estimates of the relationship between farm size and gross value of crop output/ha operated, while Table 5.3 presents the same relationship for net value of crop output/ha. The first two columns present the IR relationship for smallholder farms, while the last two columns present findings for the entire sample covering SSFs and MSFs.

5.2.1 Gross crop output per hectare

Column (1) in Table 5.2 presents the parsimonious model estimates, which do not control for endogenous use of inputs including fertiliser and labour or the decision on what crop type to cultivate. Column (2) controls for these input use and decision variables. This approach (parsimonious vs inclusion of full controls) is repeated for the full sample.

Interestingly, we found that contrary to the prevalent findings of IR among smallholders operating <5ha in the development literature on Africa (e.g., Kimhi, 2006; Carletto, Savastano and Zezza, 2013; Ali and Deininger, 2015; Julien, Bravo-Ureta and Rada, 2019; Muyanga and Jayne, 2019; Omotilewa et al., 2021), the IR vanished after accounting for time-invariant unobserved heterogeneity from land quality or operator characteristics, even when the sample was confined to SSFs operating under 5ha. Although the signs on the parameters associated with the farm size variable and its squared term would suggest the existence of IR, these were statistically insignificant in both parsimonious and full-control estimates.

To answer two of the main questions asked in this study, i.e., does farm size really play an important role in agricultural productivity and does the IR hold beyond popularly observed SSFs in Africa, we present the IR estimates for farm sizes over the 0-40ha range of farm sizes after accounting for the usual IR suspects (market imperfection, soil qualities and excess family labour use) in the literature as well as time-invariant unobserved heterogeneity. Columns (3) and (4) in Table 5.2 show that there was no statistically significant impact of farm size on gross crop output/ha. That is, when time-invariant unobserved heterogeneities were accounted for, farm size played no role in farm productivity and there was no evidence of IR in SSFs let alone MSFs. These results do not align with the findings of Omotilewa et al. (2021) and Muyanga and Jayne (2019), both of which performed cross-sectional analysis and found a U-shaped relationship between farm size and productivity over a wide range of farms in Nigeria and Kenya, respectively. Thus, findings from the panel analysis presented in the present study suggest that any apparent relationship observed between farm size and productivity in SSFs or MSFs might be driven by individual operator heterogeneity in productivity within groups rather than farm size difference itself (we return to this point later when discussing robustness checks).

Table 5.2: CRE regression estimates of gross crop output/ha cultivated (₦'000)

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Operated farm size (ha)	-76.88 (71.21)	-47.07 (67.52)	-7.54 (8.88)	-9.02 (8.54)
Operated farm size squared (ha)	9.10 (10.86)	2.79 (10.69)	0.14 (0.15)	0.17 (0.14)
Age of household head (years)	-7.21* (4.20)	-10.88** (5.16)	-9.53*** (3.14)	-9.55*** (3.50)
Household size (adult equivalent)	-0.42 (11.17)	-2.87 (12.63)	5.04 (9.98)	4.18 (10.28)
=1 if female-headed household	-54.21 (55.94)	-97.86* (54.02)	-110.01* (61.50)	-145.35** (57.27)
Years of education of household head	0.47 (1.82)	1.31 (1.89)	1.65 (1.47)	1.94 (1.50)
=1 if Ogun State	-123.43*** (38.17)	-123.43*** (38.44)	-135.73*** (29.21)	-135.73*** (29.33)
=1 if household has access to market	-3.72 (17.22)	-10.49 (18.64)	28.07** (14.20)	18.35 (14.54)
=1 if household has access to agricultural extension services	-71.44*** (25.70)	-34.44 (24.37)	-17.27 (20.29)	-2.71 (20.72)
=1 if household has access to agro-input dealer	38.52** (18.65)	57.55*** (19.09)	41.92*** (14.89)	53.15*** (15.10)
Family labour days/ha		-0.45 (0.57)		0.04 (0.55)
Hired labour days/ha		1.18* (0.62)		0.51* (0.29)
Inorganic fertiliser (kg/ha)		0.37** (0.15)		0.37*** (0.11)
Organic fertiliser (kg/ha)		0.03 (0.07)		0.00 (0.05)
=1 if grains		-17.24 (41.17)		3.78 (31.74)
=1 if legumes		-0.26 (31.70)		-20.08 (23.05)
=1 if roots and tubers		60.47 (46.67)		101.14*** (39.14)
=1 if fruits and vegetables		-67.75* (36.84)		-63.22** (27.36)
=1 if cash crop		58.38 (51.71)		9.84 (36.49)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if household stepped up from SSF	-	-	14.54 (16.56)	14.54 (16.62)
=1 if household stepped in directly into MSF	-	-	4.55 (16.72)	4.55 (16.78)
Constant	492.54*** (88.20)	492.54*** (88.82)	269.19*** (63.23)	269.19*** (63.47)
Observations	1,262	1,262	2,262	2,262
No of households	631	631	1,131	1,131
R-squared	0.15	0.19	0.14	0.17
Turning point for cultivated farm size (ha)	-	-	-	-

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own

Overall, the factors negatively associated with productivity (gross crop output/ha) include having a farm household headed by a female, age of household head, operating a farm in Ogun State relative to Kaduna State, and cultivating fruits and vegetables. On the other hand, factors positively associated with productivity include access to input dealers, number of hired labour days/ha, use of inorganic fertiliser, and cultivation of roots and tubers.

5.2.2 Net crop output per hectare

It is well documented in the literature that when the relationship between farm profit (gross output minus total costs including all inputs cost and estimated shadow wage for family labour) per hectare and farm size is investigated, IR generally weakens or no longer holds (Carter and Wiebe, 1990; Lamb, 2003). In fact, Carter and Wiebe (1990) show that instead of IR associated with gross output, profit increases monotonically with farm size given the intensity of family labour use on SSFs. In addition, Omotilewa et al. (2021) also find that IR is weakened or vanishes for net values of farm (crop cultivation plus livestock rearing) output/ha among smallholder farms, but a U-shaped relationship holds, which turns positive for farms beyond 5ha. Given these findings and the obvious advantage of lower production cost/ha that bigger farm operators possess from economies of scale, we estimated the relationship between net crop output per hectare (profit) and farm size over a wide range of farm sizes using panel analysis.

Table 5.3 shows that for SSFs, there was evidence of a positive relationship between farm size and net output/ha albeit imprecisely estimated (Column (1)). The magnitude of the positive coefficient on farm size operated increased when full control variables were included in the model estimated (Column (2)), however this was still not statistically significant even though the standard error decreased. In columns (3) and (4), we present the results of IR estimates over the full sample of farms ranging from 0–40ha. Findings show that like the gross output/ha productivity measure, there was no statistically significant relationship between farm size and the profit measure. The estimated parameter on land operated was negative but far from statistical significance. The magnitude also reduced with the addition of variables on input use, decision, and soil quality, suggesting that these all played a role in explaining productivity. These findings are consistent with the literature that the IR either tends to weaken or vanish when profit is used to estimate relationship between productivity and farm size (Wiebe and Carter, 1990). However, the uniqueness of our findings is that this pattern holds even when the range of farm sizes is expanded to roughly 40ha of operated land.

5.3 Robustness checks

To explore the robustness of our results to alternative measures of productivity and model specifications, we performed several checks. First, one can argue that a single factor (land) productivity measure is of limited relevance. For example, Rada and Fuglie (2019) point out that even if land productivity were higher for smallholder farms, there is frequently much lower labour productivity coupled with varying use of other inputs by farm sizes. TFP represents a measure of returns to all the factors of production.[9] Hence, TFP could be considered a more meaningful measure of productivity for farm operators. Thus, we further explored the farm size-productivity relationship using TFP to account for productivity when overall input use is considered for all farms. Second, we present the findings from pooling the panel data and testing the relationship without accounting for potential unobserved heterogeneities that might be correlated with productivity. Third, we present estimates from a simple bivariate non-parametric model without controlling for any input use, labour market imperfections, soil qualities, and unobserved heterogeneity. Lastly, we present findings from analysis of variance (ANOVA) to understand variations within and between farm size categories. We also present a box plot showing median of gross output/ha for each farm size category.

Table 5.4 presents the IR estimates from TFP. For the full sample (0–40ha farm size) estimates, the findings are consistent with the other two measures of productivity showing there is no evidence of IR (see Columns (3) and (4) for parsimonious and full-control estimates). Factors positively associated with productivity included inorganic fertiliser use, and cultivation of roots and tubers and cash crops; while negative factors included female-headed households, cultivation of legumes or grains, as well as being a farmer in Ogun State. These findings are largely consistent with results from the other measures used to estimate productivity. For the SSFs (<5ha), however, there was some evidence

9 TFP is estimated as the portion of output not explained by the total inputs used in production. Empirically, it is derived from the Cobb-Douglas production function as the exponential of the ratio of log ofoutput to log of aggregate inputs used (see Aragón, Restuccia and Rud, 2022 for more details on TFP model specification).

Table 5.3: CRE regression estimates of net crop output/ha cultivated (₦'000)

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Operated farm size (ha)	10.99 (75.72)	52.66 (71.43)	-5.25 (8.82)	-1.77 (8.64)
Operated farm size squared (ha)	-3.95 (12.20)	-11.25 (11.94)	0.09 (0.15)	0.04 (0.14)
Age of household head (years)	0.38 (4.99)	-3.73 (6.76)	0.42 (3.44)	-0.48 (4.04)
Household size (adult equivalent)	-6.52 (12.47)	-9.43 (14.42)	2.40 (10.35)	0.81 (10.71)
=1 if female-headed household	-32.26 (57.11)	-84.39 (59.71)	-91.78 (73.58)	-124.08* (68.43)
Years of education of household head	2.07 (1.95)	2.82 (2.07)	2.17 (1.53)	2.42 (1.58)
=1 if Ogun State	-122.30*** (37.16)	-122.30*** (37.42)	-148.97*** (29.06)	-148.97*** (29.17)
=1 if household has access to market	-4.25 (20.21)	-10.16 (20.46)	33.97** (14.90)	22.97 (15.43)
=1 if household has access to agricultural extension services	-77.86*** (24.68)	-43.19* (23.70)	-13.86 (21.22)	1.79 (21.88)
=1 if household has access to agro-input dealer	35.30** (17.98)	50.07*** (18.78)	43.16*** (14.77)	50.52*** (15.12)
Family labour days/ha		0.07 (0.55)		0.22 (0.59)
Hired labour days/ha		-0.15 (0.44)		-0.96** (0.42)
Inorganic fertiliser (kg/ha)		0.36** (0.14)		0.28*** (0.11)
Organic fertiliser (kg/ha)		-0.03 (0.07)		-0.04 (0.06)
=1 if grains		-33.93 (37.46)		-10.18 (30.07)
=1 if legumes		-21.58 (30.04)		-37.37 (22.75)
=1 if roots and tubers		10.78 (44.82)		82.59** (38.24)
=1 if fruits and vegetables		-100.89*** (36.66)		-81.38*** (26.75)
=1 if cash crop		147.34* (79.37)		60.39 (52.30)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if household stepped up from SSF	-	-	-0.85 (16.83)	-0.85 (16.89)
=1 if household stepped in directly into MSF	-	-	-12.82 (16.89)	-12.82 (16.96)
Constant	447.70*** (88.01)	447.70*** (88.64)	243.52*** (62.47)	243.52*** (62.72)
Observations	1,262	1,262	2,262	2,262
No of households	631	631	1,131	1,131
R-squared	0.15	0.18	0.13	0.16
Turning point for cultivated farm size (ha)	-	-	-	-

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own

that IR exists based on using TFP as a measure of productivity, but these were limited to those under 3ha. Columns (1) and (2) in Table 5.4 show that the turning point at which IR becomes reversed among smallholders is 2.8ha, consistent with other findings that limited estimates to SSFs in Africa (Kimhi, 2003; Muyanga and Jayne, 2019).[10]

To examine what role unobserved heterogeneity plays in explaining IR, we estimated IR from a pooled OLS estimator. Indeed, the findings presented in Tables 5.5 and 5.6 and Appendix Table A5 show that without accounting for unobserved heterogeneities, estimates would be inconsistent and wrongly conclude that the IR exists when there is none. This was the case for both smallholder farms and the MSFs using gross and net crop outputs/ha (Tables 5.5 and 5.6, respectively) and TFP (Table A.5) to estimate the IR. Likewise, non-parametric binary estimates of the relationship between farm size and productivity measures suggest a U-shaped relationship indicating there is IR up until certain acreage (turning point) beyond which bigger farms become more productive (Figure 5.1). However, these non-parametric estimates fail to control for both observed and unobserved factors affecting productivity.

Furthermore, we also checked our findings for robustness against function form specification using log-log transformed estimates in addition to the level-level estimates presented in Tables 5.2 and 5.3. We present the results of the log-log estimates in Appendix Tables A6 and A7. These log-log results suggest that our findings were largely consistent regardless of whether level-level or log-log functional forms are estimated. For the gross crop output/ha, the log-log transformed estimates showed some limited evidence of IR for all farms, however, with the turning points being around 1ha for all farm size categories, the overall conclusion was that there was no IR beyond SSFs. For the log-log estimates of the relationship between net value of crop output/ha and farm size, the findings showed no statistical evidence of IR for either SSFs or MSFs, consistent with the level-level estimates.

Lastly, a simple ANOVA test of variation for the between and within estimated productivity (gross crop output/ha) showed that the between group variation was significantly lower than the within group variations. The F-statistic was 1.05 and p-val was 0.37 ($>\alpha=0.05$), thus we failed to reject the null hypothesis of equal means across all farm categories (groups). For gross output/ha, the proportion of explained variation due to within-farm size group variation was 718 times larger than that of between group variation or 99.9 per cent of the total explained variation. Likewise, for net crop output/ha, the proportion of explained variation due to within-farm size group variation was 1,071 times larger than that of between group variation or 99.9 per cent of total explained variation. That is, overall, there were no significant differences in the means of crop output/ha across the farm size categories as presented in Table 5.1 (<5ha, 5-10ha, 10-20ha, and >20ha). In addition to formally testing the differences in mean productivity across different farm size categories, for visualization purpose, we present a box plot showing the distributions of crop output/ha for each farm size category below (Figure 5.2). This figure supports the finding of limited difference in mean estimates of productivity across farm size categories.

10 The bivariate non-parametric estimations of farm size and TFP as well as box plot of mean TFPs across all farm size are very similar to Figures 5.3 and Figure 5.4, respectively. Thus, we did not present these in this paper.

Table 5.4: IR estimates from TFP

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Operated farm size (ha)	-0.28** (0.13)	-0.39*** (0.12)	-0.01 (0.01)	-0.02 (0.01)
Operated farm size squared (ha)	0.05** (0.02)	0.07*** (0.02)	0.00 (0.00)	0.00 (0.00)
Age of household head (years)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Household size (adult equivalent)	0.02 (0.01)	0.02 (0.01)	0.01 (0.01)	0.00 (0.01)
=1 if female-headed household	-0.13 (0.09)	-0.18* (0.10)	-0.20** (0.08)	-0.26*** (0.08)
Years of education of household head	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)
=1 if Ogun State	0.15** (0.07)	-0.31** (0.13)	0.14** (0.05)	-0.45*** (0.11)
=1 if household has access to market	-0.09* (0.05)	-0.11** (0.05)	-0.02 (0.04)	-0.04 (0.04)
=1 if household has access to agricultural extension services	-0.18*** (0.07)	-0.11 (0.07)	-0.09 (0.06)	-0.02 (0.07)
=1 if household has access to agro-input dealer	-0.00 (0.05)	0.00 (0.05)	0.01 (0.04)	-0.00 (0.04)
Family labour days/ha		-0.00** (0.00)		-0.00 (0.00)
Hired labour days/ha		0.00 (0.00)		-0.00 (0.00)
Inorganic fertiliser (kg/ha)		0.00* (0.00)		0.00*** (0.00)
Organic fertiliser (kg/ha)		-0.00 (0.00)		-0.00 (0.00)
=1 if grains		-0.10 (0.08)		-0.17** (0.07)
=1 if legumes		0.02 (0.07)		-0.12** (0.05)
=1 if roots and tubers		0.62*** (0.09)		0.71*** (0.07)
=1 if fruits and vegetables		0.06 (0.08)		-0.04 (0.05)
=1 if cash crop		0.29*** (0.10)		0.26*** (0.07)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if household stepped up from SSF	-	-	0.02 (0.07)	0.09 (0.07)
=1 if household stepped in directly into MSF	-	-	0.04 (0.08)	0.05 (0.07)
Constant	1.25*** (0.18)	1.32*** (0.23)	0.89*** (0.13)	1.08*** (0.18)
Observations	1,262	1,262	2,262	2,262
No of households	631	631	1,131	1,131
R-squared	0.03	0.13	0.02	0.12
Turning point for cultivated farm size (ha)	2.8	2.8	-	-

Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Source: Authors' own

Table 5.5: Naive OLS estimates of gross crop output/ha cultivated (₦'000)

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Operated farm size (ha)	-99.26*** (33.24)	-108.47*** (31.21)	-6.30*** (2.31)	-6.78*** (2.23)
Operated farm size squared (ha)	18.33*** (6.14)	18.07*** (5.66)	0.09** (0.04)	0.10** (0.04)
Age of household head (years)	0.14 (0.71)	0.15 (0.68)	0.80 (0.51)	0.84* (0.49)
Household size (adult equivalent)	5.16* (2.87)	4.61 (2.96)	2.47 (2.17)	1.07 (2.10)
=1 if female-headed household	-35.09 (23.40)	-50.86** (23.79)	-45.25** (18.64)	-64.03*** (17.85)
Years of education of household head	1.34 (1.23)	0.84 (1.16)	2.31** (1.05)	1.30 (0.99)
=1 if Ogun State	19.27 (17.25)	-100.31*** (32.56)	16.92 (12.32)	-120.98*** (25.52)
=1 if household has access to market	-22.37* (11.95)	-27.60** (12.31)	-5.49 (9.82)	-6.35 (9.84)
=1 if household has access to agricultural extension services	-28.69 (18.82)	-15.31 (18.48)	-13.65 (14.99)	-1.21 (15.29)
=1 if household has access to agro-input dealer	-0.42 (13.45)	1.08 (12.85)	4.45 (10.84)	1.60 (10.51)
Family labour days/ha		-0.12 (0.36)		0.55* (0.31)
Hired labour days/ha		0.65 (0.62)		0.24 (0.28)
Inorganic fertiliser (kg/ha)		0.27** (0.13)		0.32*** (0.10)
Organic fertiliser (kg/ha)		0.05 (0.04)		0.03 (0.04)
=1 if grains		-23.18 (19.41)		-40.54** (16.84)
=1 if legumes		2.45 (17.20)		-29.99** (11.84)
=1 if roots and tubers		171.54*** (22.88)		181.22*** (16.33)
=1 if fruits and vegetables		31.86 (20.95)		1.74 (13.31)
=1 if cash crop		83.46*** (22.61)		67.33*** (16.95)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if year is 2020 (wave 2)	-13.76 (13.28)	-14.78 (13.13)	-23.61** (10.63)	-19.49* (10.41)
=1 if household stepped up from SSF	-	-	-2.50 (16.77)	17.18 (16.19)
=1 if household stepped directly into MSF	-	-	4.10 (17.62)	10.99 (16.45)
Constant	371.56*** (46.80)	335.36*** (62.83)	244.88*** (32.40)	255.31*** (45.56)
Observations	1,262	1,262	2,262	2,262
R-squared	0.03	0.14	0.02	0.14
Turning point for cultivated farm size (ha)	2.71	3.00	33.29	34.99

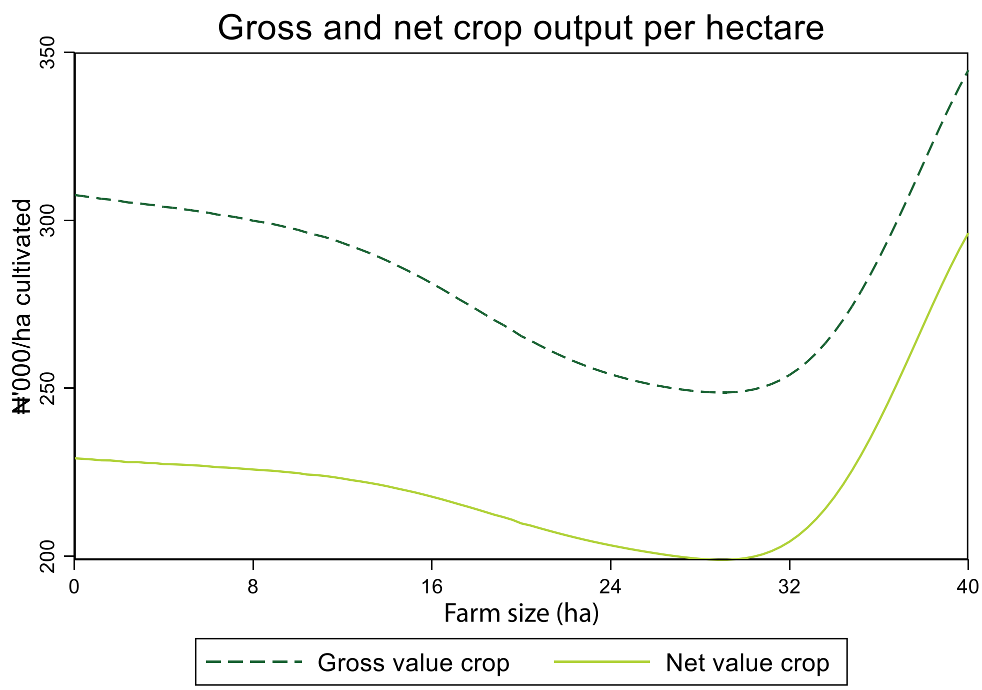
Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Source: Authors' own

Table 5.6: Naive OLS estimates of net crop output/ha cultivated (₦'000)

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Operated farm size (ha)	-52.27* (31.69)	-59.82* (30.96)	-1.87 (2.31)	-2.63 (2.21)
Operated farm size squared (ha)	10.95* (5.86)	10.84* (5.58)	0.03 (0.04)	0.04 (0.04)
Age of household head (years)	0.34 (0.69)	0.37 (0.67)	0.73 (0.51)	0.87* (0.49)
Household size (adult equivalent)	4.16 (3.00)	2.59 (3.06)	1.87 (2.19)	0.01 (2.11)
=1 if female-headed household	-19.04 (21.70)	-36.40* (21.78)	-44.95** (19.75)	-64.22*** (18.52)
Years of education of household head	1.71 (1.32)	1.12 (1.26)	2.01* (1.07)	0.95 (1.01)
=1 if Ogun State	44.18** (17.28)	-88.43*** (32.98)	31.35** (12.38)	-127.91*** (25.57)
=1 if household has access to market	-32.35*** (12.50)	-34.47*** (12.98)	-9.28 (9.88)	-8.17 (9.91)
=1 if household has access to agricultural extension services	-30.93* (18.59)	-22.68 (18.29)	-23.21 (14.82)	-9.72 (15.24)
=1 if household has access to agro-input dealer	-2.74 (13.74)	-2.71 (13.14)	2.94 (10.86)	-0.16 (10.53)
Family labour days/ha		0.43 (0.34)		0.76** (0.32)
Hired labour days/ha		-0.75* (0.43)		-1.13*** (0.33)
Inorganic fertiliser (kg/ha)		0.16 (0.13)		0.16* (0.09)
Organic fertiliser (kg/ha)		0.05 (0.04)		0.01 (0.04)
=1 if grains		-24.03 (19.10)		-43.61*** (16.69)
=1 if legumes		-8.69 (17.87)		-36.67*** (11.98)
=1 if roots and tubers		165.60*** (22.87)		179.65*** (16.32)
=1 if fruits and vegetables		20.84 (20.51)		-2.14 (13.17)
=1 if cash crop		81.40*** (22.20)		71.63*** (16.98)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if year is 2020 (wave 2)	7.50 (13.49)	5.67 (13.81)	10.70 (10.80)	10.16 (10.57)
=1 if household stepped up from SSF	-	-	-13.78 (16.91)	3.07 (16.61)
=1 if household stepped in directly into MSF	-	-	-9.80 (18.24)	-5.13 (16.80)
Constant	213.48*** (47.90)	239.58*** (62.65)	150.16*** (32.30)	205.45*** (44.80)
Observations	1,262	1,262	2,262	2,262
R-squared	0.03	0.13	0.02	0.13
Turning point for cultivated farm size (ha)	2.39	2.75	29.64	33.37

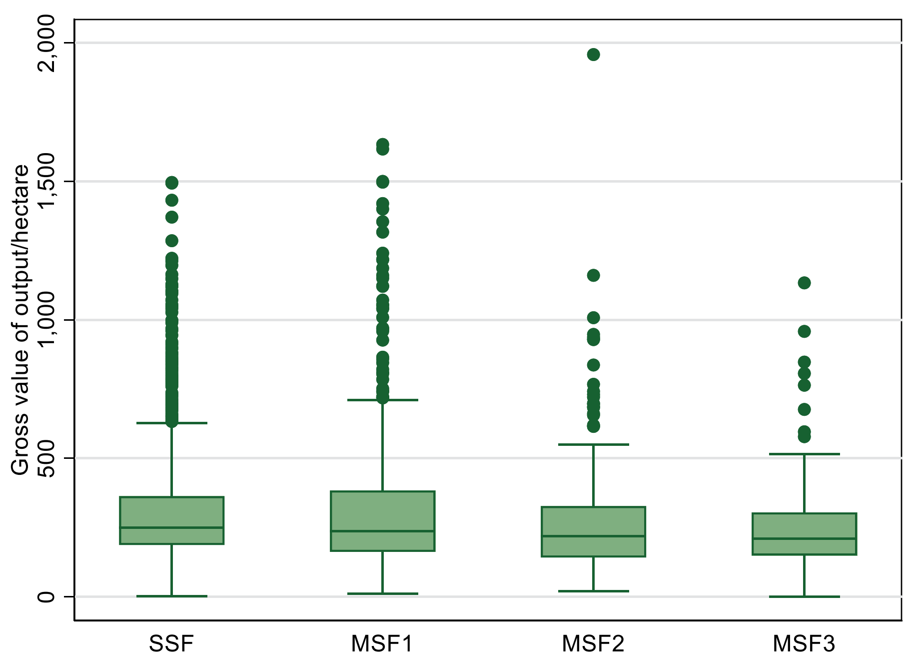
Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own

Figure 5.1: Bivariate non-parametric estimates of gross and net crop outputs per hectare



Source: Authors' own

Figure 5.2: Box plot showing gross value of crop output/ha by farm categories



Note: SSF→SSFs (<=5ha), MSF1→ MSFs (5–10ha), MSF2→ (10–20ha), and MSF3→(>20ha)
Source: Authors' own

6 CONCLUSION AND POLICY IMPLICATIONS

This study re-examined the relationship between farm size and farm productivity over a relatively wide range of farms sizes (0-40ha) in Nigeria, using panel data and panel estimation technique. The findings from this study are important due to rapidly changing farm size distributions in Africa, where farms in the 5-50ha range account for an increasingly large share of nationally cultivated land in many countries (Jayne et al., 2022). Most IR analyses to date are based on exceedingly limited ranges of farm sizes that seldom go above 10ha and therefore leave unanswered questions about the productivity impacts of changing farm size distributions in the region.

Our analysis also overcomes several limitations of prior analyses looking at a relatively wide range of farm sizes by employing household panel analysis accounting for factors associated with IR in prior literature as well as time-invariant unobserved heterogeneity.

Contrary to most prior findings documenting IR between farm size and productivity for SSFs in Africa, we found that the IR did not hold in the two Nigerian states examined, either when the sub-sample was confined to smallholders farming 0–5ha or when the full sample of 0–40ha farms was examined. In fact, farm size was a relatively weak indicator of a farm's productivity. We found that variations in productivity within farm size categories were 718 times greater than the variations between farm size groups. This suggests that there is great potential to raise productivity across farms of all sizes. In fact, if farms below the mean TFP level in each farm size category were to be pulled up to their means, this would raise average gross output/ha by 125 per cent in these two Nigerian states.

In terms of policy recommendations, first, development practitioners and researchers must recognise that both smallholders and medium-scale operators alike are heterogenous in potential productivity. Hence, the IR literature runs the risk of focusing on a relatively minor factor influencing national agricultural productivity and diverting attention away from more impactful programmes and policy options for raising productivity. The fact that there is great heterogeneity in productivity across all farm size categories suggests that public expenditures emphasising new technologies and practices that can be adopted by farms of all sizes, such as productivity-raising seed varieties, improved agronomic and soil health practices that raise yield response to inputs, and practices that stabilise crop yields in the face of variable weather may hold the greatest potential for raising farm productivity for farms of all sizes, and hence for aggregate farm productivity in Nigeria and similar countries.

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APPENDICES

Table A1: Transition matrix

	SSF in Wave 2		SSF in Wave 2		Total
	Number	%	Number	%	
SSF in Wave 1	631	96%	28	4%	659
MSF in Wave 1	109	18%	500	82%	609
Total	740		528		1268

Note: For perspective, the sample size of SSFs in wave 1 is 659, while the sample size for MSFs is 609. From this, 109/609 (17.9%) of MSFs stepped down their operations from wave 1 to wave 2, while only 28/659 or 4.2% stepped up their operations from SSF to MSF.
Source: Authors' own

Table A2: Breakdown of movements from MSF categories to SSFs

	$MSF_1 \rightarrow SSF_2$	From (5-10ha)	From (10-20ha)	From (>20ha)
Wave 1→wave 2	109	91 (83.5%)	17 (15.6%)	1 (0.9%)

Source: Authors' own

Table A3: Breakdown of movement from SSF to MSF categories

	$SSF_1 \rightarrow MSF_2$	To (5-10ha)	To (10-20ha)	To (>20ha)
Wave 1→wave 2	28	26 (92.9%)	2 (7.1%)	0

Source: Authors' own

Table A4: Gross and net crop output/ha (in ₦'000) for households across farm categories

	Gross output/ha Wave 1	Gross output/ha Wave 2	Net output/ha Wave 1	Net output/ha Wave 2	Sample size
$SSF_1 \rightarrow SSF_2$	307 (217)	330 (267)	208 (213)	265 (278)	631
$MSF_1 \rightarrow SSF_2$	317 (348)	255 (216)	230 (347)	200 (202)	109
$SSF_1 \rightarrow MSF^2$	203 (176)	240 (182)	141 (172)	194 (182)	28
$MSF_1 \rightarrow MSF_2$	291 (272)	348 (282)	194 (275)	299 (271)	500
Total					1268

Note: Subscript 1 indicates wave 1 while subscript 2 indicates wave 2. Standard deviations in parentheses.
Source: Authors' own

Table A5: Naive OLS estimates of TFP

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Operated farm size (ha)	-0.29** (0.12)	-0.39*** (0.12)	-0.01 (0.01)	-0.02* (0.01)
Operated farm size squared (ha)	0.06** (0.02)	0.07*** (0.02)	0.00 (0.00)	0.00 (0.00)
Age of household head (years)	0.00 (0.00)	0.00 (0.00)	0.00* (0.00)	0.00* (0.00)
Household size (adult equivalent)	0.02 (0.01)	0.02 (0.01)	0.01 (0.01)	0.00 (0.01)
=1 if female-headed household	-0.14 (0.09)	-0.19** (0.09)	-0.19** (0.08)	-0.26*** (0.08)
Years of education of household head	0.01 (0.00)	0.00 (0.00)	0.01** (0.00)	0.01 (0.00)
=1 if Ogun State	0.15** (0.06)	-0.33*** (0.13)	0.14*** (0.05)	-0.45*** (0.10)
=1 if household has access to market	-0.10** (0.05)	-0.12** (0.05)	-0.03 (0.04)	-0.03 (0.04)
=1 if household has access to agricultural extension services	-0.16** (0.07)	-0.10 (0.07)	-0.08 (0.06)	-0.02 (0.07)
=1 if household has access to agro-input dealer	-0.02 (0.05)	-0.01 (0.05)	0.00 (0.04)	-0.01 (0.04)
Family labour days/ha		-0.00* (0.00)		-0.00 (0.00)
Hired labour days/ha		0.00 (0.00)		-0.00 (0.00)
Inorganic fertiliser (kg/ha)		0.00* (0.00)		0.00*** (0.00)
Organic fertiliser (kg/ha)		0.00 (0.00)		-0.00 (0.00)
=1 if grains		-0.10 (0.08)		-0.18** (0.07)
=1 if legumes		0.01 (0.07)		-0.12*** (0.05)
=1 if roots and tubers		0.63*** (0.09)		0.71*** (0.07)
=1 if fruits and vegetables		0.07 (0.08)		-0.04 (0.05)
=1 if cash crop		0.30*** (0.09)		0.26*** (0.07)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if year is 2020 (wave 2)	-0.08* (0.05)	-0.07 (0.05)	-0.12*** (0.04)	-0.09** (0.04)
=1 if household stepped up from SSF	-	-	0.03 (0.07)	0.09 (0.07)
=1 if household stepped in directly into MSF	-	-	0.05 (0.07)	0.06 (0.07)
Constant	1.30*** (0.18)	1.39*** (0.24)	0.90*** (0.13)	1.09*** (0.18)
Observations	1,262	1,262	2,262	2,262
R-squared	0.04	0.13	0.02	0.13
Turning point for cultivated farm size (ha)	2.50	2.87	-	28.92

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own

Table A6: CRE regression estimates of log-log of gross crop output/ha cultivated

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Log of land area (ha) cultivated	-1.35** (0.57)	-1.46** (0.57)	-1.41*** (0.49)	-1.52*** (0.48)
Log of square of total plot size cultivated	0.59** (0.27)	0.60** (0.26)	0.63*** (0.24)	0.67*** (0.23)
Age of household head (years)	-0.02 (0.02)	-0.04* (0.02)	-0.02 (0.01)	-0.02 (0.01)
Household size (adult equivalent)	-0.02 (0.04)	-0.05 (0.04)	0.01 (0.03)	0.01 (0.03)
=1 if female-headed household	-0.20 (0.17)	-0.30 (0.18)	-0.16 (0.20)	-0.22 (0.20)
Years of education of household head	0.00 (0.01)	0.00 (0.01)	0.00 (0.00)	0.01 (0.00)
=1 if Ogun State	-0.37*** (0.10)	-0.37*** (0.10)	-0.34*** (0.07)	-0.34*** (0.07)
=1 if household has access to market	0.05 (0.06)	0.03 (0.06)	0.09* (0.04)	0.05 (0.05)
=1 if household has access to agricultural extension services	-0.29*** (0.07)	-0.21*** (0.08)	-0.09 (0.06)	-0.06 (0.06)
=1 if household has access to agro-input dealer	0.08 (0.06)	0.12** (0.06)	0.08* (0.04)	0.11** (0.05)
Family labour days/ha		-0.00 (0.00)		0.00 (0.00)
Hired labour days/ha		0.00 (0.00)		0.00 (0.00)
Inorganic fertiliser (kg/ha)		0.00 (0.00)		0.00*** (0.00)
Organic fertiliser (kg/ha)		0.00** (0.00)		0.00 (0.00)
=1 if grains		0.10 (0.15)		0.15 (0.10)
=1 if legumes		0.00 (0.09)		0.02 (0.07)
=1 if roots and tubers		0.31* (0.16)		0.34*** (0.12)
=1 if fruits and vegetables		-0.29*** (0.10)		-0.17** (0.07)
=1 if cash crop		0.15 (0.18)		0.02 (0.13)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if household stepped up from SSF	-	-	0.04 (0.05)	0.05 (0.05)
=1 if household stepped in directly into MSF	-	-	0.02 (0.06)	0.03 (0.06)
Constant	7.19*** (0.34)	7.22*** (0.34)	6.74*** (0.29)	6.79*** (0.29)
Observations	1,262	1,262	2,262	2,262
No of households	631	631	1,131	1,131
R-squared	0.14	0.17	0.13	0.16
Turning point for cultivated farm size (ha)	1.15	1.21	1.12	1.13

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own

Table A7: CRE regression estimates of log-log of net crop output/ha cultivated

Variables	SSF (0–5ha)		Full sample (0–40ha)	
	Model I (1)	Model I (2)	Model II (3)	Model II (4)
Log of land area (ha) cultivated	3.72 (3.20)	3.22 (3.31)	3.58 (2.82)	3.18 (2.91)
Log of square of total plot size cultivated	-1.43 (1.52)	-1.21 (1.57)	-1.63 (1.32)	-1.40 (1.36)
Age of household head (years)	0.06 (0.09)	0.04 (0.10)	0.15*** (0.06)	0.13** (0.06)
Household size (adult equivalent)	-0.19 (0.14)	-0.22 (0.14)	-0.02 (0.10)	-0.02 (0.09)
=1 if female-headed household	-0.01 (0.53)	-0.06 (0.55)	0.56 (0.82)	0.62 (0.67)
Years of education of household head	0.00 (0.02)	-0.00 (0.02)	-0.01 (0.01)	-0.01 (0.01)
=1 if Ogun State	-1.03*** (0.32)	-1.03*** (0.32)	-0.81*** (0.24)	-0.80*** (0.24)
=1 if household has access to market	0.20 (0.23)	0.19 (0.23)	0.41** (0.17)	0.29* (0.17)
=1 if household has access to agricultural extension services	-0.99*** (0.25)	-0.90*** (0.27)	-0.32 (0.20)	-0.21 (0.20)
=1 if household has access to agro-input dealer	0.14 (0.16)	0.12 (0.16)	0.16 (0.14)	0.15 (0.14)
Family labour days/ha		0.01 (0.01)		0.00 (0.01)
Hired labour days/ha		-0.02** (0.01)		-0.02*** (0.01)
Inorganic fertiliser (kg/ha)		-0.00 (0.00)		-0.00 (0.00)
Organic fertiliser (kg/ha)		0.00 (0.00)		-0.00 (0.00)
=1 if grains		0.39 (0.45)		0.50* (0.30)
=1 if legumes		-0.16 (0.31)		-0.06 (0.23)
=1 if roots and tubers		-0.22 (0.50)		0.07 (0.36)
=1 if fruits and vegetables		-0.65** (0.28)		-0.26 (0.17)
=1 if cash crop		1.25 (0.81)		0.46 (0.55)
Household assets (radio, TV, mobile phone, car, motorcycle)	Yes	Yes	Yes	Yes
Farm equipment (water pump, tractor, sprayer)	Yes	Yes	Yes	Yes
Soil quality and type		Yes		Yes
=1 if year is 2020 (wave 2)	-	-	-0.17 (0.16)	-0.20 (0.17)
=1 if household stepped up from SSF	-	-	-0.30* (0.17)	-0.33* (0.18)
Constant	5.05*** (1.66)	5.24*** (1.70)	4.04*** (1.39)	4.18*** (1.43)
Observations	1,262	1,262	2,262	2,262
No of households	631	631	1,131	1,131
R-squared	0.09	0.11	0.08	0.11
Turning point for cultivated farm size (ha)	-	-	-	-

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own

Omotilewa, O., Jayne, T.S. and Muyanga, M. (2022) *The Farm Size-Productivity Relationship: Evidence From Panel Data Analysis of Small- and Medium-Scale Farms in Nigeria*. APRA Working Paper 94. Brighton: Future Agricultures Consortium.

ISBN: 978-1-80470-019-8 DOI: 10.19088/APRA.2022.040

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Agricultural Policy Research in Africa (APRA) is a programme of the Future Agricultures Consortium (FAC) which is generating new evidence and policy-relevant insights on more inclusive pathways to agricultural commercialisation in sub-Saharan Africa. APRA is funded with UK aid from the UK Foreign, Commonwealth & Development Office (FCDO) and will run from 2016-2022.

The APRA Directorate is based at the Institute of Development Studies (IDS), UK (www.ids.ac.uk), with regional hubs at the Centre for African Bio-Entrepreneurship (CABE), Kenya, the Institute for Poverty, Land and Agrarian Studies (PLAAS), South Africa, and the University of Ghana, Legon. It builds on more than a decade of research and policy engagement work by the Future Agricultures Consortium (www.future-agricultures.org) and involves more than 100 researchers and communications professionals in Africa, UK, Sweden and USA.

Funded by

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This report is funded with UK aid from the UK government (Foreign, Commonwealth & Development Office – FCDO, formerly DFID). The opinions are the authors' and do not necessarily reflect the views or policies of IDS or the UK government.

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