Feed the Future Innovation Lab for Food Security Policy

Research Paper 85 November 2017

Nigeria Agricultural Policy Project

CONSTRAINTS FOR SMALL-SCALE PRIVATE IRRIGATION SYSTEMS IN THE NORTH CENTRAL ZONE OF NIGERIA: INISGHTS FROM A TYPOLOGY ANALYSIS AND A CASE STUDY

By

Hiroyuki Takeshima and Hyacinth Edeh

Food Security Policy *Research Papers*

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AUTHORS' ACKNOWLEDGMENT

This paper has been prepared as part of the Feed the Future Nigeria Agricultural Policy Project through the Nigeria Strategy Support Program (NSSP) managed by the International Food Policy Research Institute (IFPRI). The research presented here was conducted as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) which is led by IFPRI.

This Research Paper was prepared for USAID/Nigeria by Michigan State University (MSU), Federal Ministry of Agriculture and Rural Development (Nigeria), and the International Food Policy Research Institute (IFPRI) under the USAID/Nigeria funded Food Security Policy Innovation Lab Associate Award, contract number AID-620-LA-15-00001.

This study was made possible by the generous support of the American people through the United States Agency for International Development (USAID). This publication has not been independently peer reviewed and the contents are the responsibility of Michigan State University and the International Food Policy Research Institute. Any opinions expressed here belong to the authors and do not necessarily reflect those of MSU, IFPRI, PIM, CGIAR, USAID or the United States Government.

We would like to thank Hiroshi Kodama, Abdullahi Oshioke Salami, Hua Xie, Ephraim Nkonya, Liangzhi You, and George Mavrotas for constructive comments on the background issues for this paper.

This Food Security Policy Research Paper has also been published as Nigeria Strategic Support Program Working Paper No. 47 in September 2017.

This study is made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the Feed the Future initiative. The contents are the responsibility of the study authors and do not necessarily reflect the views of USAID or the United States Government

Published by the Department of Agricultural, Food, and Resource Economics, Michigan State University, Justin S. Morrill Hall of Agriculture, 446 West Circle Dr., Room 202, East Lansing,

ABSTRACT

Agricultural transformation has been slow in Nigeria despite relatively fast growth in the non-agricultural sector of the economy. The limited contributions of irrigation in the agricultural sector have been considered to be one of the causes of slow agricultural transformation in Nigeria. Irrigation is used in both public-sector and private-sector irrigation schemes. Information is, however, often limited regarding small-scale private irrigation systems and their expansion potential and constraints, as compared to information on public irrigation schemes. This paper aims to provide various qualitative indicators which can shed light on irrigation system diversity and its recent evolution in Nigeria, as well as key economic characteristics of a selected private irrigation system as a case study.

Altogether, private irrigation systems will likely need to be expanded if overall irrigation areas in Nigeria are to grow substantially. However, relatively more intensive irrigators have declined recently in Nigeria as compared to less intensive ones, thus, potentially limiting the role of irrigation in agricultural transformation. Raising the competitiveness of private irrigation systems may require significant reductions in production costs through efforts to increase overall productivity. This includes reducing the costs of labor, which accounts for the majority of production costs in private irrigation systems, rather than simply reducing the costs of non-labor material inputs like fertilizer, seeds, and pumps through subsidies, as has conventionally been done.

Keywords: private irrigation system, typology, modified cluster analysis, farm budgets, Nigeria.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Agricultural transformation has been slow in Nigeria despite the relatively fast growth in non-agricultural sectors of the economy. The low contributions of irrigation to production in the agricultural sector have been considered one of the causes of slow agricultural transformation in Nigeria. Despite irrigation potential in the order of several million ha or about 10 percent of Nigeria's cultivated area (You et al. 2011; Xie et al. 2017), only about one percent of cultivated land in Nigeria is irrigated (Takeshima et al. 2016). Irrigation development and identifying strategies to raise the contributions of irrigation in agricultural growth and food security therefore has become one of the Nigerian government's areas of interest (FAO et al. 2014).

Both public-sector and private-sector irrigation systems contribute to irrigation expansion in sub-Saharan African countries like Nigeria. While public irrigation schemes provide benefits through economies of scale (Otsuka & Larson 2016), small-scale private irrigation systems can be more efficient in meeting the varying needs of individual farmers (Burney et al. 2013; Woodhouse et al. 2017). As is described in this paper, private irrigation systems often have led the expansion of irrigation in some countries, preceding the development of public sector irrigation schemes. The limited development of small-scale private-irrigation systems in Nigeria suggests, therefore, that expansion is constrained by the relatively low returns to irrigation, rather than by the high costs of building public irrigation facilities. Compared to public irrigation schemes, knowledge is often limited regarding the characteristics of small-scale private irrigation systems, their diversity, and economic structure.

Earlier assessments of typologies of farm households in sub-Saharan Africa in general (e.g., Erenstein et al. 2003; Dorward 2006) and irrigating households in Nigeria (Takeshima 2016b), have been cross-sectional and offered relatively few insights into how they are changing over time. Similarly, past assessments of the economic structures of irrigation systems either focused on public schemes (Kimmage 1991; ENPLAN 2004; Jamala et al. 2011; Akanbi et al. 2011; Takeshima & Adesugba 2014), did not consider fully the labor-use intensity of many irrigation systems in countries like Nigeria, or were limited to only a handful of samples (Takeshima 2016b). This study seeks to partly fill these gaps. It first constructs a typology of irrigator farm households in Nigeria to better characterize the diversity of irrigation systems in countries like Nigeria that exhibit significant heterogeneity in agricultural production environments. Specifically, it extends the earlier typology of Takeshima (2016), by adding the dimension of temporary and permanent irrigators and types of irrigators from 4 to 6, in total, taking advantages of the availability of three waves of data from the Living Standards Measurement Survey-Integrated Surveys for Agriculture (LSMS-ISA) farm household datasets for Nigeria.

It then describes in greater detail the characteristics of a particular irrigation system to better understand the economics of these systems. Information is scarce in countries like Nigeria regarding the economic characteristics of private irrigation systems. The LSMS-ISA data do not provide full information because they provide relatively little information regarding the uses of key inputs for irrigation-specific activities, particularly labor use for dry season irrigation. This is particularly so in the North Central zone, where current irrigation practices are quite limited compared to other zones with higher irrigation adoption, such as the North West zone, but has a fairly arid dry season, just like the North West or North East zones, during which returns to irrigated agriculture potentially may be high.

We then discuss some potential policy implications of the findings. In particular, we highlight key characteristics of current private irrigation systems in Nigeria, including the declining share of relatively more intensive irrigators, the high production costs faced, and the significant labor cost share. We find that productivity improvement is more important than reducing the costs of non-labor inputs through subsidies in order to raise the competitiveness of small-scale private irrigation systems in Nigeria, if such schemes are to contribute significantly to agricultural transformation and food security.

The paper is structured in the following way. Section 2 provides international perspectives on private irrigation systems. Section 3 discusses the typology of irrigation households in Nigeria and key implications of their characteristics. Section 4 briefly describes the economic structure of small-scale private irrigation systems through a case study. Lastly, section 5 discusses the overall policy implications that can be drawn from this study.

2. PRIVATE IRRIGATION SYSTEMS: INTERNATIONAL PERSPECTIVE

In Asia and Latin America, in early stages of irrigation development, the private sector was heavily involved in investments into irrigation, including communal systems in Japan, Philippines (Kikuchi et al. 1978; Barker et al. 1985, p. 101), Malaysia (Short & Jackson 1971), Nepal (Small et al. 1986) and Sri Lanka (Chambers 1980; Panabokke et al. 2002). These systems were usually developed by mobilizing community resources or by landlords (Hayami & Kikuchi 2000, p176). In early 20th century Colombia, irrigation was introduced and facilities constructed by private entrepreneurs (Leurquin 1967, p. 227). Even in the early-1990s, the irrigated area under privately funded projects still accounted for 60 percent of the total irrigated area in Colombia (Dinar & Keck 1997). In Bangladesh, 90 percent of irrigated area in 1998 was in privately owned and operated minor-irrigation schemes (Mondal & Saleh 2003).

Communal irrigation systems built and maintained by village communities and often constructed using locally available materials have been the dominant form of irrigation in the Philippines (Kikuchi et al. 1978; David 1995). This was partly because construction of communal systems was usually cheaper per ha than government systems (Kikuchi et al. 1978). In the 1960s, when the irrigation sector was still growing in the Philippines, more irrigated area was under private-systems (about 450,000 ha) than under public systems (220,000 ha). Between 1964 and 1992 the irrigated area grew by 870,000 ha, approximately half of which was in private-irrigation systems. In the Philippines, private irrigation systems led the expansion of irrigated areas up to 1960s and have continued to contribute significantly since.

The earlier growth of private irrigation in Asia and elsewhere was accompanied by endogenous innovations of common resource management. Within irrigation systems in many countries, effective community-management of common resources often mitigated the tragedy of commons (Hayami & Kikuchi 2000 p134; Feeny et al. 1990; Ostrom 1990, 1992; Baland & Platteau 1996). Within irrigation systems, communal management sustained the initial success of the Asian green revolution (Hayami & Kikuchi 1982; Otsuka & Kijima 2010) with little external support for institution building. With clear mutual dependencies and long-term relationships within the community, farmers can often craft rules over uses of common resources that lead to higher yields (Ostrom & Gardner 1993). Cooperation can be more successfully organized when water supplies are modest, rather than deficient (Bardhan 1993). Villages at the tail end of a system tend to organize collective action better to economize on the use of water, because of higher rates of return to such actions when water constraints are stronger (Wade 1990).

3. TYPOLOGIES OF IRRIGATOR FARM HOUSEHOLDS IN NIGERIA

Data

The primary data used for developing a typology of irrigating households in Nigeria are from the LSMS-ISA, collected jointly by the Nigeria's National Bureau of Statistics (NBS) and the World Bank in three waves in 2010/11, 2012/13 and 2015/16. The first wave of LSMS-ISA interviewed 5,000 households that were nationally representative, with the second and third waves interviewing the same households, although some households were dropped due to the security concerns in certain areas. Each wave contains approximately 3,000 farm households that report on the uses they make of their farm plots. Among them, approximately 200 farm households reported using irrigation in at least one wave, also reporting on the size of the irrigated areas. Aggregating their observations over three waves, and dropping households that were not interviewed due to attritions or missing information, 530 data points are used to categorize these farm households into different types of irrigator households.

Not all of these farm households irrigated some of their crops in all waves. Some report the use of irrigation in all three waves (called *permanent irrigators* hereafter), while the others report the use of irrigation in only some of the waves while not reporting the use of irrigation in other waves (called *temporary irrigators* hereafter). We include *temporary irrigators*, and not only *permanent irrigators*, because the former account for significant shares of areas irrigated each year. Specifically, *temporary irrigators* account for almost 90 percent of irrigator households, and 70 to 80 percent of the total area irrigated (**Error! Reference source not found.**). This indicates that irrigation in Nigeria is largely practiced by *temporary irrigators*, rather than *permanent irrigators*.

Table 1. Permanent and temporary irrigators – share of farmed area irrigated and share of all farming households that irrigate in Nigeria

	Area irrigated, %		Share of households, %	
	All households	Smallholders < 1 ha	All households	Smallholders < 1 ha
Permanent irrigators	19	28	11	12
Temporary irrigators	81	72	89	88

Source: Authors' calculations based on three-waves of LSMS-ISA combined.

The LSMS-ISA data are supplemented by various agroecological data. A soil map was obtained from FAO et al. (2012). Historical rainfall variation is calculated as an average within each LGA, using data obtained from the University of East Anglia (2017). Distances to the major rivers and dams are Euclidean distances measured in geographical minutes, calculated as the averages for each LGA using the locations of major rivers in Nigeria based on Lehner et al. (2006) and locations of dams based on AQUASTAT (2012), respectively. We also use LGA-level population density and LGA average distance to towns of 20,000 inhabitants, each of which was constructed using data obtained from the Nigeria 2006 Population Census (National Population Commission 2010) and Harvest Choice (2017), respectively.

Key characteristics of irrigation households in the data

Table 2 summarizes key characteristics of irrigator households in Nigeria, reported in the LSMS-ISA. Since the sample size of irrigators in each wave of LSMS-ISA is fairly small, Table 2 reports the aggregate statistics from all three waves, which capture average irrigator characteristics during the period covered by the three waves, 2010 to 2016.

Less than 5 percent of farm households in Nigeria used irrigation recently. The share of irrigated area to total farm area is even lower, generally less than 2 percent. This is because irrigator households also use irrigation on only some of their plots, not all their plots. Irrigator households in Nigeria are also typically smallholders, with the farm size of about 0.5 ha and irrigated areas of about 0.3 ha.

Irrigator households are generally concentrated in the North West and North East zones, where 70 to 80 percent of irrigators in Nigeria are located. The North Central zone generally accounts for 10 to 20 percent of irrigators in Nigeria. The zones in the south generally account for 10 percent or less of irrigators in Nigeria. Use of irrigation among irrigators varies widely across crops. Rice, maize, and vegetables are common irrigated crops. Among vegetable crops, pepper is the most commonly irrigated crop. Banana/plantains, and legumes (cowpeas, groundnuts) are some of the other crops relatively widely irrigated. Other crops like sugarcane account for relatively small shares of irrigation use in Nigeria.

Table 2. General characteristics of irrigator households in Nigeria

Categories	**Value**
% of farm households irrigating	3.4
% of farm area irrigated	1.6
Area irrigated per irrigating household (ha, median)	0.3
Average farm size per irrigating household	0.5
Regional distributions of irrigated area (%)	
North West	60
North East	19
North Central	15
South East	1
South South	2
South West	4
Common crops irrigated (% of irrigators irrigating each crop)	
Rice	25
Maize	29
Vegetables (onion, okra, pepper, tomato)	33
Pepper	22
Banana / plantain	13
Legumes	22
Sugarcane	4

Source: Authors' calculations based on three-waves of LSMS-ISA combined.

The information in Table 2 suggests that most irrigators in Nigeria are smallholders and that irrigation is used for diverse groups of crops, motivating the construction of a typology of irrigators, as is done in the next section. It also shows that relative to the North West zone, use of irrigation in other zones is generally limited, suggesting that investigating the economic constraints to the use of irrigation in these other zones, as is done for the North Central zone in a later section, is important.

The share of private irrigators who do not rely on the infrastructure provided by public irrigation schemes (dams, canals, etc.) cannot be assessed from the LSMS-ISA data. However, available information indicates that most irrigators in Nigeria are private irrigators. Based on LSMS-ISA, the total area irrigated is approximately 290,000 ha per year on average. Based on Enplan (2004), the area irrigated under public irrigation schemes in Nigeria was 55,000 ha in 2004. While this figure is old, the irrigated area under public irrigation schemes is likely to have remained similar to this level, given that relatively few large irrigation dams have been newly constructed in Nigeria since 2004 (Takeshima et al. 2016), and there has been little rehabilitation of existing public irrigation schemes recently. Therefore, the typology constructed using the sample of irrigator households in LSMS-ISA is likely to apply to most small-scale private irrigators.

Typology of irrigator households in Nigeria

Methodology – modified cluster analysis

Various typologies of households have been developed using cluster analysis methods in Nigeria and other countries in Africa (Erenstein et al. 2003; Dorward 2006; Takeshima 2016). These methods classify agents based on the similarity or dissimilarity of their characteristics. No studies, however, have developed typologies of irrigator households in Nigeria by considering their changes over time and using the second and third waves of the LSMS-ISA.

Cluster analysis is a statistical tool used for classifying agents into various types (Anderberg 1973). The literature provides detailed technical presentation of clusterization methods (Hansen and Jaumard 1997). We apply the modified cluster-analyses method, described in detail in Takeshima (2016). Cluster analysis methods typically rely on dissimilarities (such as in numerical values) among observations. Our cluster analysis proceeds in the following steps: First, we select a sample $O = \{O_1, O_2, \ldots, O_N\}$ of N observations for analyzing clusters. We then measure p characteristics of the sample, yielding an $N \times p$ data matrix X. From matrix X, we compute an $N \times N$ matrix $D = d_{k\ell}$ of dissimilarities between samples, where $d_{k\ell}$ usually satisfies

$$d_{k\ell} \geq 0,\ d_{kk} = 0,\ d_{k\ell} = d_{\ell k} \text{ for } k, \ell = 1, 2, \ldots, N. \quad (1)$$

We then apply cluster analysis to the dissimilarity matrix D by selecting (a) the types of clustering (partitioning and constructing hierarchy of partitions) and (b) the criteria for expressing homogeneity or separation of clusters and particular algorithms. Hierarchical partitions and k-mean partitions are two commonly used partitioning methods. For selecting the type of clustering, we combine the hierarchical partitions with k-mean partitions, as proposed by Punj and Stewart (1983) and Siou et al. (2011), because combining two partition methods can significantly improve the accuracy of clustering. We follow Punj and Stewart (1983) and Siou et al. (2011) regarding selection of the criteria for expressing homogeneity and separation of clusters., Specifically, the standard deviations of p are minimized within the cluster, whereas the standard deviations of the cluster mean of p are maximized across clusters. (See the Appendix for a detailed description of the approach.) Although the methodology by Punj and Stewart (1983) and Siou et al. (2011) suggests that the more clusters, the better, we limit the maximum number of clusters to be generated, since interpretation becomes difficult if there are too many types of households. Using hierarchical partitions is useful because the samples tend to be clusterized in a hierarchical structure; thus, increasing the number of clusters may not affect the other clusters that are already identified.

Table 3 summarizes the variables used to create the dissimilarity matrix D in the cluster analysis of irrigators. Variables are selected to capture both the resource constraints (consisting of agroecological and socioeconomic factors) and the production behaviors of the farm households. We include measures of human resources, assets, production scale (both rainfed and irrigated), production intensity, income, nonfarm activities, and labor resources. These variables are also selected to capture comprehensive types of resource constraints defining the economic activities of agricultural households, constraints which play an important role in households' choices of crop production methods and input use intensity.

In the cluster analysis, variables are standardized after dropping outliers, so that their distributions have zero mean and one standard deviation. Cluster analysis is conducted independent of sample weights, because the application of sample weights has not been widely discussed in the literature on cluster analysis. Sample weights are used, however, when calculating the proportion of farm households falling into each type.

Table 3. Variables used in cluster analysis of irrigators

Categories	Variables
Agroecological (natural resources)	Whether alluvial soil is the majority of soil types in the area
	Historical rainfall variation (LGA average)
	Euclidean distance to the nearest major river
	Euclidean distance to the nearest dam
Market access	Population density in the LGA where the household is located
	Distance to towns of 20,000 or 50,000 inhabitants
Human resources	Household size
	Level of education and literacy of household head
	Gender of household head
Resources (assets)	Total value of assets, not including land
	Size of livestock-equivalent stock or value of animal stock owned
	Whether owning a portion of farm land
Production scale	Total rainfed area
	Total irrigated area
Production intensity	Overall input intensity, measured as the total value of inputs per farm household
	Fertilizer
	Seed (value of purchased seed only)
	Agrochemicals (pesticide, herbicide)
	Whether using animal traction
	Whether using tractor
	Whether hired harvesting labor

Categories	Variables
	Whether the household took out any loan or credit (including non-agricultural credit) from either formal or informal sources
	Whether selling surplus crops to the market
Income, nonfarm activities	Total expenditure per person
	Whether having non-farm income sources or not
Labor resource	Real LGA median wage of land clearing or preparation (standardized by maize price)
Cropping systems	Whether irrigating maize
	Whether irrigating rice
	Whether irrigating legumes
	Whether irrigating vegetables
	Whether irrigating bananas / plantains
Mode of irrigation	Whether using stream as irrigation water source
	Whether irrigating in dry season only

Source: Authors.

Results of modified cluster analysis

Table 4 summarizes the characteristics of six types of farm households that are reported to have used irrigation in at least one of the three waves of LSMS. All variables shown in Table 4 were used in the modified cluster-analyses. Table 5 summarizes the regional distributions of each type of irrigator households.

Six types of irrigator households are identified: type 1 (medium-scale mechanized irrigators), type 2 (intensive pump irrigators), type 3 (intensive stream irrigators), type 4 (pump irrigators), type 5 (resource-poor temporary irrigators), and type 6 (temporary irrigators). Roughly speaking, Types 1 to 3 are relatively more intensive, specialized irrigators, while Type 4 to 6 are relatively less input-intensive and engage in irrigation only occasionally.

Medium-scale mechanized irrigators (Type 1) are perhaps the most distinctive type. Their operational sizes are relatively larger, and more mechanized, typically using tractors, commonly irrigating rice, combined with other crops. They tend to be located in relatively remote areas where population density is low and wages are high, further inducing mechanized irrigation farming.

Intensive pump irrigators (Type 2) are almost exclusively found in the North West where irrigation adoption is the highest. They are similar to Type 3 in terms of irrigation intensity, relying on ground water sources rather than streams, extracted by pumps including motorized pumps (Table 6). Maize is much less commonly irrigated by this type, compared to Type 3.

Intensive stream irrigators (Type 3) typically irrigate rice, maize, or vegetables. They, however, engage in more labor-intensive irrigation, and are found in areas that are more densely populated with relatively lower wages. In terms of irrigation frequency and area irrigated, this type consists of the most intensive irrigation users.

Table 4. Characteristics of different types of irrigator households

	Type 1 (medium-scale mechanized irrigators)	Type 2 (intensive pump irrigators)	Type 3 (intensive stream irrigators)	Type 4 (pump irrigators)	Type 5 (resource-poor temporary irrigators)	Type 6 (temporary irrigators)
% of sample	5	10	9	17	24	35
Alluvial soils, %	25	2	71	100	25	0
Annual rainfall risk, historical standard deviation, mm	162	149	135	135	150	167
Euclidean distance to the nearest major river, degree-minutes	.005	.005	.010	.015	.005	.010
Euclidean distance to the nearest dam	0.5	1.3	0.8	1.8	1.0	0.4
Population density of the area, per km^2	84	146	219	219	141	169
Distance to the nearest town with population of 20,000, hours	3.3	2.4	1.6	1.6	3.3	2.5
Household size	7.0	7.7	7.6	7.2	6.7	7.0
Household head is literate, %	69	39	96	89	8	94
Household head received no formal education, %	26	75	18	0	96	2
Female household head, %	7	0	0	3	8	2
Household asset value, in kg of staple	580	574	416	242	403	370
Livestock value, in kg of staple	0	1142	552	0	437	392
Own portion of land, yes = 1	40	29	28	7	15	20
Area irrigated, ha	0.40	0.45	0.53	0.27	0.18	0.13
Area rainfed, ha	1.80	0.39	0.33	0.46	0.94	1.20
Expenditure on chemical fertilizer use, worth kg of staple	183	390	170	13	92	168
Expenditure on seed use, worth kg of staple	0	0	3	0	0	0
Expenditure on agricultural chemical use, worth kg of staple	83	9	31	0	0	0
Animal traction users, %	14	85	19	29	34	27
Tractor users, %	98	2	0	8	5	0
Hiring labor, %	85	81	80	43	56	55
Whether receiving any credit	0.17	0.91	0.60	0.17	0.14	0.21
Sell surplus crops to markets, %	89	69	88	60	53	70
Consumption, per capita expenditure	0.714	0.821	0.688	0.455	0.561	0.707
Has non-farm income, %	57	81	77	38	28	48
Real daily wages, in kg of staple foods	6.0	4.6	4.9	5.9	5.6	6.1
Irrigation methods						
Stream, %	44	14	85	6	9	6
Irrigate in dry season only, %	0	16	0	14	7	11
Cropping – irrigate:						

Maize, %	13	8	37	23	6	10
Rice, %	34	25	42	12	7	4
Legumes, %	13	27	21	7	5	12
Vegetables, %	0	30	30	16	2	19
Banana / plantains, %	0	1	0	6	2	7

Source: Authors' estimations through modified cluster-analyses.

Table 5. Distributions of different types of irrigators across geopolitical zones, count

	Type 1 (medium-scale mechanized irrigators)	**Type 2 (intensive pump irrigators)**	**Type 3 (intensive stream irrigators)**	**Type 4 (pump irrigators)**	**Type 5 (resource-poor temporary irrigators)**	**Type 6 (temporary irrigators)**	**Observ-ations**
North Central	21	5	17	6	40	62	151
North East	11	5	2	6	32	44	100
North West	8	91	67	91	127	132	516
South East	8	0	0	9	11	17	45
South South	0	0	0	59	21	13	92
South West	7	0	0	0	8	79	95
Observations	54	102	86	172	239	347	1,000

Source: Authors' estimations through modified cluster-analyses.

Table 6. Irrigation methods and source of water, by irrigator type, percent of type

	Type 1 (medium-scale mechanized irrigators)	**Type 2 (intensive pump irrigators)**	**Type 3 (intensive stream irrigators)**	**Type 4 (pump irrigators)**	**Type 5 (resource-poor temporary irrigators)**	**Type 6 (temporary irrigators)**
Method						
Bucket	0	17	22	3	26	23
Hand pump	0	13	1	22	8	19
Treadle pump	0	2	1	5	1	5
Motor pump	6	46	6	53	26	33
Diverted stream	94	22	70	16	38	21
Water source						
Well	6	33	10	0	13	17
Borehole	3	39	3	10	25	17
Lake / natural pond	16	12	35	0	11	18
Created pond	5	6	7	14	3	2
Stream	71	10	46	76	49	46

Source: Authors' estimations through modified cluster-analyses.

Pump irrigators (Type 4) are similar to Type 2 irrigators (Intensive pump) in terms of significant reliance on motorized pumps (Table 6), are found farthest from dams, but are less intensive than Type 2 in terms of general inputs uses – hired labor, fertilizer, purchased seeds, agrochemicals, animal tractions, and credit – and irrigation frequency and are more likely to be irrigating maize. They are also typically the poorest among all types of irrigator households. These types are mostly found in the South-South, where most irrigators are of this type, and the North West zones.

Resource-poor temporary irrigators (Type 5) are the second most common type, accounting for one-quarter of all irrigators. They are the least intensive irrigators in terms of input use and irrigation frequency. Their engagements in irrigation are also highly temporary, irrigating only about 30 percent of the time (Table 7). They tend to be located in relatively remote areas with low population density, and are relatively uneducated compared to other types of irrigators. Like Types 2 and 3, Type 5 irrigators are mostly found in the North (Table 5).

Lastly, **temporary irrigators (Type 6)** are the most common type, accounting for about one-third of households. They typically irrigate relatively small area, compared to the rainfed areas they farm. They are also found in areas with the greatest rainfall variability, indicating that irrigation may be used to supplement rainfall.[1] Their irrigation is often temporary, as these households irrigate only 43 percent of the time, or less than once in every 2 years (Table 7). Their input use intensities, particularly of hired labor, improved seed, agrochemicals, and credit, are also relatively modest compared to the more intensive irrigators. This is possibly because irrigation is used by these farmers as supplementary to rainfall to mitigate rainfall risks, rather than as the primary source of water. Most irrigators in the South West zone, as well as significant shares of those in the North Central and North East zones belong to this type.

Table 7. Irrigation frequency of different types of irrigators, percent of time having crops under irrigation

	Type 1 (medium-scale mechanized irrigators)	**Type 2 (intensive pump irrigators)**	**Type 3 (intensive stream irrigators)**	**Type 4 (pump irrigators)**	**Type 5 (resource-poor temporary irrigators)**	**Type 6 (temporary irrigators)**
Irrigation frequency	58	76	88	53	29	43

Source: Authors' estimations through modified cluster-analyses.

Over three waves of the LSMS-ISA, 2010-11, 2012-13 and 2015-16, the composition of irrigators shifted slightly. In particular, the shares of Types 4, 5, and 6 irrigator households increased during this period, while shares of Types 2 and 3 irrigator households decreased (Table 8). Combined with the descriptions of each type of irrigators above, these patterns suggest that the share of relatively less intensive, temporary irrigator households increased, while the share of more intensive, permanent irrigator households declined over this period. While investigating the causes of such changes is beyond the scope of this study, such trends indicate that the characteristics of irrigation systems and, thus, potentially the contribution of irrigation to agricultural

[1]Such a rainfall-risk mitigating motive was one of the factors driving farm households' investments in irrigation pumps in Nigeria (Takeshima & Yamauchi 2012).

intensification can change in a relatively short period. The contribution of irrigation might have slightly declined over the last several years, which can be a cause for concern for the Nigerian government.

Table 8. Distribution of different types of irrigators over time, count

	Type 1 (medium-scale mechanized irrigators)	Type 2 (intensive pump irrigators)	Type 3 (intensive stream irrigators)	Type 4 (pump irrigators)	Type 5 (resource-poor temporary irrigators)	Type 6 (temporary irrigators)	Observ-ations
2010-11	71	193	104	190	177	272	1,007
2012-13	32	130	120	105	230	372	988
2015-16	69	few [a]	49	250	351	456	1,175

Source: Authors' estimations through modified cluster-analyses.
[a] No households in the LSMS-ISA data in wave 3 were identified as Type 2. However, we cannot rule out the possibility that some households that were not covered under LSMS-ISA might have been of this type. Therefore, we describe the number of this type in Wave 3 as "few" rather than 0.

4. CASE STUDY OF A PRIVATE IRRIGATION SYSTEM IN NORTH CENTRAL ZONE

Discussion in the previous sections suggest that irrigation use, including in private irrigation systems, in zones other than the North West zone have been particularly limited across Nigeria. This section describes in more detail the economic characteristics of small-scale private irrigation systems in the North Central zone to provide general information on resource use in private irrigation systems, particularly of labor and water, differentiated across a few key crops. Such information is generally scarce in countries like Nigeria, and particularly in the North Central zone, often impeding accurate assessments of irrigation potential and the development of effective irrigation sector strategies (Xie et al. 2017). Based on the economic characteristics, we then develop hypotheses regarding current constraints to expanding private irrigation systems in the North Central zone of Nigeria.

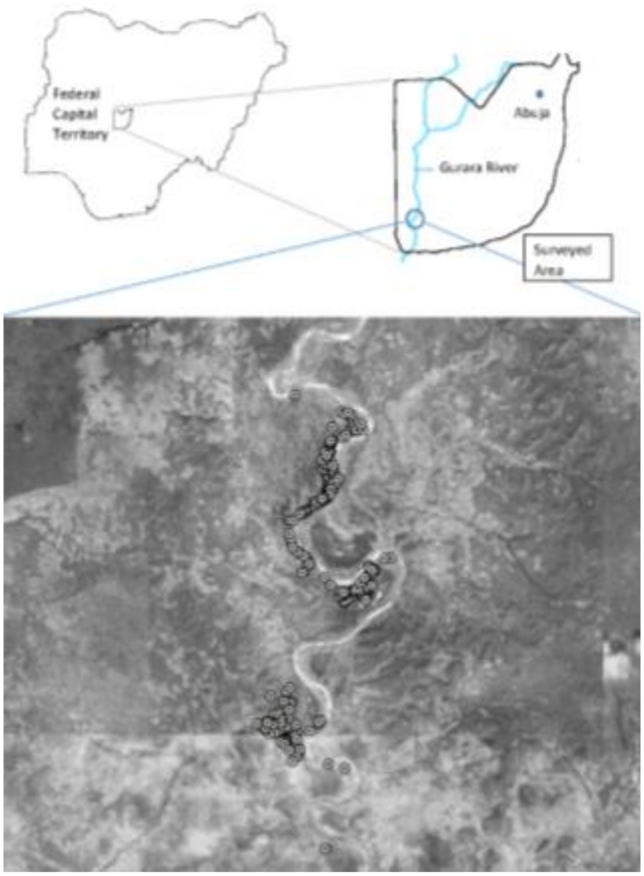
General characteristics of surveyed households

Study sites

The sites studied in this section are located in Abaji Area Council in the southern part of the Federal Capital Territory (FCT), along the Gurara river, which is a tributary of the Niger River (Figure 1). The area was selected in consultation with the FCT Agricultural Development Program (ADP) office. According to the FCT-ADP extension officer, approximately 2,000 ha of the area along Gurara river within FCT is under private irrigation, primarily by small-scale farmers who either divert the water from the stream or extract river water by motorized pumps to irrigate their plots. The area is also relatively close to Abuja, allowing for closer monitoring and frequent visits to obtain more accurate information.

A total of 178 farmers practicing irrigation were interviewed. The locations of their irrigated plots are shown in Figure 1. Farmers were selected for interviewing by listing the irrigated plots in these villages, identifying the cultivators of these plots, and randomly drawing 178 cultivators from the list. The listing was conducted in September 2016. In May 2017, at the end of the dry season, information on irrigation practices during the dry season was collected. It is difficult to establish the representativeness of the interviewed farmers within these villages, because, as is described below, a considerable share of irrigation in the area is practiced by migrants, and their composition changes depending on the time of the year. However, given the scarcity of prior information on irrigation practices in the area, the information obtained from our small survey still provides useful insights.

Figure 1. Location of surveyed irrigated plots in the Federal Capital Territory



Source: Authors' field work and Google Earth.

Household characteristics

Table 9 summarizes key characteristics of the irrigator households surveyed in the area. These households are generally small-scale, irrigating between 0.4 and 0.6 ha in the season.[2] Most them are male-headed. They typically have been farming for 15 to 18 years. Household sizes typically consist of 8 to 9 members. Three-quarter of them have received some formal education, and 70 percent of them have non-farm income sources. Lastly, 20 percent of them obtained the plots through outright purchase, while 42 percent of them inherited the land. Thirty-eight percent rent the irrigated plots from local indigenes.

[2]Plot sizes were measured by GPS unit.

Table 9. Characteristics of interviewed irrigator households

Categories	Mean	Median
Irrigated area per season, ha	0.6	0.4
Distance from the plot to the water source, meter	81	46
Female-headed,%	0.6	
Years of farming experiences	18	15
Household size, greater than 15 years old	4.6	4
Household size, less than or equal to 15 years old	4.4	4
No formal education,%	24	
Non-farm income source,%	68	
Obtained irrigated plots through purchase,%	20	
Obtained irrigated plots through inheritance,%	42	
Rented irrigated plots from local indigenes,%	38	
Observations	*178*	

Source: Authors (based on the field work).

Common types of irrigation methods in the area

Four crops – rice, maize, peppers and okra – are the most common crops that are irrigated in the studied area. Most irrigators irrigate their plots by drawing water through an intake from nearby channels they create to divert river water. Many of them also rely on motorized pumps to extract water from the river and convey it to their plots, or to apply supplementary irrigation by directly pumping water into the plots. The use of pumps is more common among pepper irrigators, followed by okra and maize irrigators, and less common for rice irrigators (**Table 10**). Rice is irrigated mostly through river diversion, because of its higher water requirements than for maize or peppers, which makes pumping uneconomical. Thus, rice irrigation is practiced on lowland plots to which river water can be diverted easily by gravity. Irrigation of maize, peppers, and okra is practiced on higher ground, commonly with basin irrigation methods whereby plots are divided into many small basins – typically not more than a few meters in diameter – to which irrigation water is drawn through intakes created for each of these basins. Surface water is the dominant water source in the area – few irrigators use ground water. Similarly, Gurara river is the predominant source of surface water, and few irrigators use natural ponds or tanks.

Table 10. Irrigation methods by crops in the surveyed area, percent

	Rice	Maize	Pepper	Okra
Through intake from river	91	87	92	94
With pump	47	82	97	84
Both intake and pump	37	69	90	77
Observations [a]	*58*	*118*	*64*	*31*

Source: Authors' compilations based on the small survey of irrigators in the Abaji area, Nigeria.
[a] Sample size is the number of plots on which the crop is irrigated. Since multiple crops may be irrigated on certain plots, the total sample over all four crops exceeds the number of farmers interviewed, which is 178.

A rough indicator of water use intensity may be obtained by the average water depth on the plots throughout the production seasons (**Table 11**), which were approximated using crude measures.[3] Typically, rice is more water intensive than maize or peppers. For rice, irrigation water is provided so that, on average, the water depth of the plot is about 6.6 cm between land preparation and planting periods, and 6.4 cm between planting and harvesting periods. For maize and peppers, depths are around 3.6 to 3.9 cm between land preparation and planting periods, and 2.4 to 2.7 cm between planting and harvesting periods. The amount of irrigation water required to realize this level will depend on various factors, including evapotranspiration and the permeability of soils, among others, and is not easily measured. However, maintaining greater water depth may generally require a greater amount of irrigation water, suggesting a greater water use requirement for rice, than maize or peppers.[4]

Table 11. Dry season irrigation water depth

	Between land preparation and planting			**Between planting and harvesting**		
Crop	**Maximum depth (cm)** [a] mean / median	**# of days of the week plot is covered with water**	**Average water depth (cm)**	**Maximum depth (cm)** [a] mean / median	**# of days of the week plot is covered with water**	**Average water depth (cm)**
Rice	29 / 23	3.2	6.6	27 / 16	3.3	6.4
Maize	18 / 17	2.8	3.6	14 / 17	2.7	2.7
Pepper	21 / 17	2.6	3.9	14 / 18	2.4	2.4

Source: Authors' compilations based on the small survey of irrigators in the Abaji area, Nigeria.
[a] Depth is assessed by assigning typical heights to each category of response asked; below ankle = 5 cm; Above ankle and below knee = 27.5 cm (assuming knee height of 50 cm, and ankle height of 5 cm); knee = 50 cm; waist = 90 cm height.

Irrigator types

The characteristics and irrigation practices of interviewed households suggest that they are likely to be a mixture of Types 2 and 3, identified in the previous section. These types of irrigators are relatively more intensive irrigators in terms of inputs used and irrigation frequency, but have been declining in numbers in the past several years. Understanding the economic characteristics of irrigators in the surveyed areas therefore is relevant in understanding the constraints in stimulating the growth of more intensive irrigation use in Nigeria.

Irrigation farming budgets

Table 12 presents crop budgets for irrigated productions of rice, maize, and pepper in the 2017 dry season. To avoid mixing information across different crops, only information from mono-cropped plots is considered. Thus, the figures are based on smaller sample sizes than the total number of plots covered. The figures are

[3]The amount of water used is one of the important parameters of irrigation practices. However, irrigation water use intensity is difficult to measure in the small-scale private irrigation systems like the ones surveyed, because the amount of water used is not measured in these systems, unlike in modern, public irrigation schemes equipped with meters. The information is, however, important in future studies for measuring the water productivity in small-scale private irrigation systems in countries like Nigeria.
[4]Studies at the public irrigation schemes in the North Central zone of Nigeria suggest that the total water requirements are around 1100 mm/ha for rice, some of which is provided by rainfall, and 500 mm/ha for maize and peppers (Adeniran et al. 2010), consistent with the hypotheses that rice requires more irrigation water.

sample averages, weighted by the size of irrigated plots. To avoid mixing figures for multiple crops, information is based on the largest mono-cropped plots irrigated by the households. Figures are expressed as Naira/ha, with plot sizes measured by GPS.

Total production costs per hectare of irrigated areas are highest for peppers, reaching around 1.4 million Naira/ha, followed by rice (about 720,000 Naira/ha), and maize (440,000 Naira/ha). While converting these figures to US dollars is challenging because Nigeria experienced large exchange rate volatility lately, using the rate of 1 USD = 300 Naira leads to about USD 4,500/ha, USD 2,400/ha, and USD 1,500/ha for pepper, rice, and maize, respectively. However, these dollar figures are only illustrative. It is important to note that these costs are likely to vary over different plot sizes. In a later section, we argue that production costs in North Central Nigeria are likely to be high compared to other countries, based on more comparable farmgate prices reported by FAO during periods when exchange rates have been relatively more stable.

Table 12. Irrigation crop budgets on the monocropped plots for rice, maize and pepper, sample average weighted by the irrigated area, Naira/ha

Categories	Rice	Maize	Pepper
Labor costs			
Nursery	5,250	2,250	138,750
Land clearing	38,250	24,000	41,250
Harrowing	3,750	16,500	15,750
Land leveling	17,250	20,250	57,750
Plowing	1,500	6,000	0
Puddling	1,500	3,750	2,250
Ridge / mound-making	5,250	8,250	13,500
Bunding	6,750	23,250	40,500
Planting	25,500	15,750	34,500
Thinning	14,250	12,000	3,750
Pruning	2,250	2,250	0
Mulching	0	0	18,750
Weeding	171,000	26,250	39,750
Applications of fertilizer	750	1,500	3,750
Applications of herbicide	750	750	1,500
Applications of pesticide	750	750	1,500
Bird scaring	44,100	25,200	6,750
Harvesting	47,250	21,000	246,750
Threshing	38,250	3,000	0
Winnowing	23,250	750	0
Bagging	12,000	9,750	222,750
Irrigation related labor costs			
Building water intake channel (not drainage)	15,938	15,938	15,938
Maintaining the water intake channel	10,875	10,875	10,875

Categories	Rice	Maize	Pepper
Setting up motor pumps, pipes to lift water from the river	3,469	3,469	3,469
Maintaining motor pump, pipes during production season	2,625	2,625	2,625
Building drainage channel	5,250	5,250	5,250
Maintaining drainage channel	3,563	3,563	3,563
Building basins on the plot	22,688	22,688	22,688
Building furrows on the plot	13,688	13,688	13,688
Costs of maintaining the water sources	788	788	788
Assisting water flows on the plot	7,781	21,000	17,813
(A) Total labor costs	***572,231***	***298,294***	***960,844***
Non-labor costs			
Costs of maintaining the water sources – material costs	8,164	8,164	8,164
Urea	19,000	35,000	74,600
NPK	14,000	19,600	49,800
Agrochemicals for land clearing	19,669	22,086	16,172
Any other fertilizer	2,781	2,914	10,552
Herbicide	14,503	14,034	14,669
Pesticide	7,592	9,005	36,810
Seeds	25,725	5,022	27,074
Mechanization services			
Tractors for land clearing	2,454	369	6,863
Tractors for land preparation	2,734	1,107	7,034
Renting irrigation pump	3,744	8,156	3,020
Pumping cost	34,147	17,140	191,666
(B) Total non-labor costs	***154,513***	***142,597***	***446,424***
(C) Total cost	**726,744**	**440,891**	**1,407,267**
Revenues	**840,322**	**450,434**	**1,447,771**
Profit margin, %	16	2	3
Labor cost share (A / C), percent	79	68	68
Sample size (limited to mono-cropped plots)	33	46	19

Source: Authors' compilations based on the small survey of irrigators in the Abaji area, Nigeria.
Note: Labor wage is assumed to be N750/day.

Profit margins are relatively small, particularly for maize and pepper (2 and 3 percent, respectively), while it is slightly higher for rice (16 percent). These figures are, however, based on competitive market prices of inputs without subsidies. Positive profits on average indicate that these irrigation systems are economically sustainable given current market conditions.

Importantly, labor costs account for a significant share of total production costs (79 percent for rice, and 68 percent for maize and peppers). A substantial share of labor costs is for activities not directly associated with irrigation, such as managing a seedling nursery, clearing, weeding, harvesting, and bagging.

Migration and irrigation knowledge transfer

Informal conversations with the surveyed farmers indicated that irrigation initially was brought into the area by Hausa migrants from the North West zone, particularly Katsina, Kaduna, and Zamfara states, as well as migrants from other states in the North Central zone, including Nasarawa state. Sixty percent of the interviewed irrigators had migrated to the area. While some of them are seasonal migrants who come to the area only part of the year to be engaged in dry season irrigation and return to their home districts after harvests, the majority, 80 percent, of these migrant irrigators have permanently settled in the area. They reported that irrigation had not been practiced in the area originally, but was introduced to the area by these migrants since 2008, possibly in response to increases in crop prices induced by the international price spike of food commodities in 2007 and 2008. It is not clear whether public sector initiatives played any role in facilitating the migration of these Northerners to FCT to engage in irrigated farming.

The migrant status of the irrigators varied across the types of crops they irrigate. In particular, rice tends to be irrigated more by migrants, as compared to maize or peppers. However, while more than 80 percent of rice irrigators in the area are migrants (= 49 / 59), the share of migrants that irrigates rice is less than half (**Table 13**). In contrast, while about half of maize, pepper, or okra irrigators are non-migrants, most non-irrigators of these crops are migrants. These patterns may indicate that irrigation practices for rice, which are somewhat more sophisticated agronomically than are those for the other crops, have been introduced locally by the migrants. The patterns also suggest that irrigation of rice may still be relatively more complicated and that many of the non-migrant irrigators have not yet master the skills,[5] while irrigation of the other crops may be relatively less complicated and can be mastered relatively more easily.

Table 13. Irrigators of each crop and their migration history, count

	Migrated	Did not migrate
Rice – irrigate	49	10
– does not irrigate	57	62
Maize – irrigate	63	55
–does not irrigate	43	17
Pepper – irrigate	30	33
– does not irrigate	76	39
Okra – irrigate	13	18
–does not irrigate	93	54
Observations	*106*	*72*

Source: Authors' compilations based on the small survey of irrigators in the Abaji area, Nigeria.

[5]Earlier studies on production knowledge transfer on rice and other crops in Asia suggest that self-learning is particularly important for rice, compared to other crops for which the knowledge of optimal agronomic practices can be more easily transferred (e.g., Munshi 2004).

The origins of migrants also vary by the crops they irrigate (**Table 14**). Most migrants irrigating rice are originally from North Central zone, particularly Nasarawa state (28 out of 50). In contrast, a significant share of migrants irrigating maize are originally from North West zone, particularly Katsina state, although those from Nasarawa state also account for about 20 percent. The shares of those migrating from the North West are even higher among pepper irrigators. These patterns are somewhat consistent with the hypotheses that the performance of irrigated rice tends to be more sensitive to the agroecological environment, compared to maize or peppers, partly due to the relative complexity of rice irrigation practices. Consequently, only migrants from other areas within the North Central zone, in which the surveyed area is also located, can effectively transfer rice irrigation practices to other farmers.

Table 14. Origins of migrants and crops they irrigate, count

Origins	Irrigators of rice	Irrigators of maize	Irrigators of pepper	Irrigators of okra
Abuja / FCT	3	1	1	
Bauchi	2	1		
Benue	2			
Plateau / Jos	2	4		1
Kaduna	6	4		
Kano	1	2	1	2
Katsina	4	28	25	5
Nasarawa	28	15	1	3
Zamfara		7	2	
Other	2	2	1	2
Total	50	64	31	13

Source: Authors' compilations based on the small survey of irrigators in the Abaji area, Nigeria.
Note: If the irrigators irrigate more than one crops, they are counted multiple times. Therefore, the total count (158) in the table exceeds the total number of migrant irrigators in the sample, 106.

Key challenges for private irrigation systems in the North Central zone

While the irrigation practices in the surveyed area are by no means necessarily representative of small-scale private irrigation in Nigeria or even of the North Central zone of the country, they provide useful insights regarding the challenges in raising the competitiveness of these systems in Nigeria. One of the major challenges is the high production costs, particularly the difficulty of reducing these costs by simply reducing the costs of non-labor material inputs.

Profit margins under these systems are relatively small (**Table 12**), indicating that per unit production costs are close to farmgate output prices. In Nigeria, farmgate prices of the commonly irrigated crops, rice, maize, and peppers, have generally been higher than those in other major developing countries in Asia or countries like the USA (**Table 15**). While it is widely known that farmgate prices of agricultural commodities in African countries are considerably lower than the domestic end-market prices, when farmgate prices are compared across countries, those in Africa are often still higher than farmgate prices outside Africa. Production costs under these irrigation systems therefore are also likely to be higher in Nigeria, compared to these other countries. Furthermore, **Table 15** suggests that production costs are even higher in the North Central zone than in the North West or North East zones of Nigeria.

Table 15. Farmgate prices of rice (paddy), maize and peppers in Nigeria and other countries, USD per mt

	Rice (paddy)	Maize	Pepper
Bangladesh	180	181	499
China	313	276	611
India	200	123	
Philippines	281	220	633
Thailand	231	182	
USA	251	146	834
Nigeria	394	380	1071
North Central [a]	571	563	1344
North West and North East [a]	359	340	1075

Source: Authors' calculations based on FAOSTAT. Rice (paddy) and maize prices are average prices between 2001 and 2015, while pepper prices are average prices between 2010 and 2013.
[a] Figures for North Central and North West + North East are extrapolated by first calculating the ratios of median farmgate prices reported in LSMS-ISA, and applying the same proportions to the farmgate price reported by FAOSTAT.

As seen in **Table 12**, small-scale private irrigation systems are considerably labor-intensive with labor costs accounting for 70 to 80 percent of all production costs in these systems. For the case of rice irrigators, these findings are similar to earlier studies based on a smaller sample of farmers in the North Central zone (Takeshima 2016b). The costs of non-labor inputs and mechanization services account for a relatively small share of the costs. The high labor cost shares suggest that returns to labor in these small-scale private irrigation systems are higher than the returns to other inputs, given the greater use of labor relative to other inputs. However, such high labor costs suggest that reducing overall production system costs, which are higher than in many other countries, will be difficult through reducing the costs of non-labor inputs like fertilizer, seeds, agrochemical, unless labor costs are significantly reduced. Similarly, many labor-saving inputs, including machinery, are often introduced by the private sector (compared to other inputs, like improved crop varieties, that generally are developed initially by the public sector). Thus, their adoption depends more on the relative profitability of labor versus machines. The relatively low use of machinery in current small-scale private irrigation systems suggests that feasible mechanization options that can reduce the labor costs are not available. Directly reducing the costs of labor by reducing wages is difficult because, unlike other tradable inputs, labor is non-tradable. Thus, wages are more endogenously determined within the domestic economic sector.

Differences in production costs between Nigeria and other countries may be attributed to higher costs of inputs in Nigeria, like chemical fertilizer. However, given the weaker agricultural research and development system in Nigeria and lower varietal technology levels (e.g., as exemplified for rice, see Diagne et al. (2015) and Takeshima and Maji (2016)), overall production technologies are likely to be inferior to those in other

Asian developing countries, with potentially low yield responses to intensive agroeconomic practices.[6] Therefore, an effective way of reducing per-unit production costs is to increase production without increasing overall input use from current levels. This will require the development of improved crop varieties and improved efficiencies in inputs use, among others. Significant efforts in raising overall production technologies are critical for raising the competitiveness of small-scale private irrigation systems in Nigeria, particularly in the North Central zone.

Strengthening the extension systems can potentially contribute to reduced production costs as well. However, the scope for significantly improving the efficiency of input use through public extension may be limited if there is already fairly effective informal knowledge transfer among farmers. The survey indicates that such informal knowledge transfer may be common, with migrants bringing knowledge on irrigation practices to local farmers.

Potentially limited effects of subsidized distributions of irrigation equipment

The constraints to expanding private irrigation systems in Nigeria through the supply of subsidized irrigation equipment and other inputs, as indicated above, can also be seen in the gap between the typical coverage of such and the number of machines needed to substantially expand the irrigated area.[7] The extent of public support to irrigation is inherently low due to the generally low share of public funds allocated to the agricultural sector in Nigeria (Mogues et al. 2012). For example, the number of pumps distributed by state ADPs generally is in the range of a few hundred per year.[8] Assuming all 37 states in Nigeria did the same, about 10,000 pumps would be distributed every year. Assuming the pumps last five years, this mean there are 50,000 operational pumps provided by the government across the country. This is still small compared to the number of irrigation pumps existing in Asian countries (**Table 16**). Moreover, Nigeria's arable land is often larger than in these countries except India. These patterns suggest that substantial private investment in pumps, much beyond the levels that can be supported by the public sector, is required if pump-based irrigation in Nigeria is to expand to levels like those in Asia.

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[6]Currently labor is intensively used, but it may be more the result of relatively high farmgate prices, rather than due to high yield responses to intensive labor use.

[7]Public support for agricultural water management in Nigeria is mostly provided by the Agricultural Development Programs (ADP) in the states and the National Fadama Development Program (NFDP) (Takeshima et al. 2010). While the extent and modes of operations of these programs may vary slightly, the type of support each provides is fairly common across states. Both ADPs and NFDPs support irrigation and other water management through various activities, including (1) subsidized distributions of irrigation equipment (pumps, boreholes, tubewells, washbores); (2) assistance in access to complementary inputs (improved seeds, fertilizer, agrochemicals, land, credit); (3) extension services; (4) information dissemination; (5) support to private sector; and (6) monitoring and evaluation (Takeshima et al. 2010).

[8]For example, in one of the North Central states, the Benue ADP, during the first National Fadama Development Project (Fadama I), procured and distributed irrigation pumps, tube wells and washbores, and other inputs, like seeds and fertilizers, to farmers. It has provided irrigation pumps on a hire-purchase basis. Under Fadama I, the national fadama facility provided for 500 washbores and 250 tube wells for Benue State. 500 water pumps were procured and distributed to irrigation farmers and Fadama Users Association in 1994. The third National Fadama Development Project (Fadama III) funded over 20 Fadama User Groups with 500 members and 40 water pumps between 2009 and 2014. Since 1998, the ADP has procured 500 pumps and is distributing them to irrigation farmers for direct pumping on a hire-purchase basis (personal communications with Benue state ADP).

Table 16. Number of irrigation pumps or tubewells in Asian countries and Nigeria, thousands

Country	Equipment	1971-80	1981-90	1991-2000	2001-10	2011-14	Arable land (2011, '000 ha)
Bangladesh	Pump		51	42	119	120	7,628
Bangladesh	Tubewell		164	350	1,211	1,230	
Cambodia	Pump				120	208	4,000
India	Electric Pump	1,030	4,330	8,910	15,200		157,350
India	Diesel Pump	1,540	3,100	4,650	8,300		
Indonesia	Pump			158	202		23,500
Iran	Pump				264		17,541
Pakistan	Tubewell					922	20,714
Thailand	Pump		500	3,000			15,760
Vietnam	Pump				1,614		6,500
Nigeria	Pump					50?	36,000

Source: Authors' compilation based on CSAM (2014) for Asian countries. Exact years within each 5-year period vary.

5. POLICY IMPLICATIONS

While the findings in this paper are generally qualitative, they collectively offer useful insights into the constraints to stimulating the growth of small-scale private irrigation systems in Nigeria, particularly in the North Central zone. Various international perspectives suggest that a significant share of future expansion in irrigated areas must come from such private irrigation systems, although investments into public irrigation schemes will also remain important.

A typology analysis of irrigating households in Nigeria suggests that there are several different types, which differ in terms of input-use intensity and irrigation frequencies and which also are associated with specific agroecological and socio-economic environments. More importantly, despite past government efforts in stimulating the growth of small-scale private irrigation systems, the typology analysis suggests that between 2010 and 2016 the numbers of relatively more intensive, permanent irrigators have been declining, replaced by less-intensive, temporary irrigators.

A closer investigation of the economic structure of these relatively more intensive irrigators in the Federal Capital Territory indicates that these systems are highly labor-intensive. This suggests that the returns to non-labor inputs in such irrigation systems are relatively low, even as machines that raise labor-productivity are not available in the market. Production costs per unit of output are likely to be considerably higher in Nigeria than those in other major developing countries and in countries like the USA. The high cost structure among small-scale private irrigators in Nigeria is not likely to be due to the potentially high costs of non-labor inputs, like fertilizer, given the relatively small share in total costs of irrigated production of these inputs. Rather, the high costs are more likely due to the use of inferior production technologies, including low use of improved crop varieties. Such a finding is consistent with the insufficient public support given to agricultural research and development in Nigeria historically as well as in recent years.

These findings have several policy implications.

- Having international and historical perspectives is important for assessing gaps in the status of small-scale private irrigation systems in Nigeria. These perspectives are often neglected when designing strategies for expanding these irrigation systems. In particular, it should be born in mind that a major difference between Nigeria and major developing countries in Asia, including many of Nigeria's competitors, is that production costs of private irrigation systems in Nigeria are high. Policy should focus on reducing these costs.
- Farmgate prices for irrigated crops in Nigeria, even if they are likely to be considerably lower than end-market prices, are still higher than in many developing countries in Asia or in the USA. While such prices benefit producers, they ultimately hurt the poor, including many smallholder farmers who are often net food buyers. Unless production costs are reduced, the contribution of irrigation to food security in Nigeria will be limited.
- Further research is necessary to better understand the diversity in types of small-scale irrigator households, and how the compositions of different types of irrigating households may be changing over time.
- Further research is also important for delving deeper into the economic characteristics of existing private irrigation systems and their implications on agricultural sector growth, so that the relatively important constraints can be identified and addressed.
- While further studies are needed to improve our understanding of the challenges facing private irrigation systems in more areas within Nigeria, the conditions covered under the case study here in FCT suggest that raising agricultural productivity in small-scale private irrigation systems through increased agricultural research and development, including the development of improved crop varieties, is likely to be an important factor for raising the competitiveness of these systems.
- Significant production cost reductions and improvements in the economic competitiveness of small-scale private irrigation systems cannot be expected from conventional approaches of subsidizing non-labor inputs, including fertilizer, seeds, pumps, among others.
- Finally, trying to raise labor use efficiency through the public extension systems will need to consider that migrants play an important role in informal knowledge transfers around irrigation, and that the constraints for knowledge transfer may be higher for certain irrigated crops like rice, as compared to other commonly irrigated crops like maize or vegetables.

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APPENDIX: CLUSTER ANALYSIS METHOD

The description here closely follows that found in the Appendix of Takeshima and Edeh (2013). We combine the hierarchical and *K*-mean methods of cluster analysis in the following way. First, we conduct hierarchical clustering using Ward's minimum variance method to obtain a first approximation of a solution. Second, we use the mean of *j* from the first step as a starting point for the subsequent *K*-mean method. In the *K*-mean method, we use Gower's dissimilarity measure (Gower 1971), which is appropriate for our data in which the variables *j* contain both binary and continuous data.

We conduct a statistical test to determine whether the number of clusters we select is better than any smaller number of clusters. For each *K* cluster identified through the cluster analysis, we calculate the between- and within-cluster variances for each variable *j*. Following Siou et al. (2011), between-cluster variance for *j* is defined as

$$V_{between-cluster\ K,j} = \frac{1}{K-1} \times \sum_{i=1}^{K} \left(\bar{x}_{ij} - \bar{\bar{x}}_j\right)^2, \qquad (A.1)$$

where $\bar{x}_{ij}$ is the sample average of variable *j* within cluster *i*, and $\bar{\bar{x}}_j$ is the average of $\bar{x}_{ij}$. In other words, $V_{\text{between−cluster}\ K,j}$ is the variance of the within-cluster mean of *j*.

$$V_{within-cluster\ K,j} = \frac{\sum_{i=1}^{K}(n_i - 1) \times s_{ij}^2}{\sum_{i=1}^{K}(n_i - 1)} \qquad (A.2)$$

According to Siou et al. (2011), the greater ratio of $V_{\text{between−cluster}\ K,j}$ to $V_{\text{within−cluster}\ K,j}$ indicates better clustering with respect to variable *j*. Siou et al. (2011) presented the natural log transformation of the ratio for each *j*. We calculate the statistic

$$\sigma_K = \sum_j ln\left(\frac{V_{between-cluster\ K,j}}{V_{within-cluster\ K,j}}\right) \qquad (A.3)$$

which proxies clustering performance across all *j*. Greater σ_K indicates that the cluster solution better identifies distinct farm household types across all dimensions of their characteristics.

Table A.1 summarizes σ_K corresponding to our cluster analysis results in **Table 4**. Clustering into six types is better than clustering into any fewer number of types.

Table A. 1. Cluster analysis statistics (σ_k) for different number of clusters

Number of clusters	2	3	4	5	6
Irrigators	- 134.66	– 105.87	– 88.50	- 82.66	- 71.62

Source: Authors.