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Agricultural Mechanization Patterns in Nigeria

Insights from Farm Household Typology and Agricultural Household Model Simulation

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ABSTRACT

Anecdotal evidence indicates labor costs for farming in Nigeria are rising while levels of mechanization remain low. Information is scarce regarding the types of farm households that use mechanization in Nigeria and the potential demand for mechanization services among farmers. We apply cluster analysis to data from the Living Standards Measurement Study—Integrated Surveys on Agriculture project in Nigeria to identify associations between mechanization and farm household types. We then simulate an agricultural household model to assess the potential demand for mechanization services in southern Nigeria. We find the following: (1) current tractor use is associated with input-intensive crop production; (2) tractor use in northern Nigeria is associated with increased nonfarm income-earning activities rather than area expansion and is emerging, albeit slowly, across many farm household types; (3) tractor use in the South is highly concentrated among medium-scale rice producers; (4) many smallholder farmers growing staple crops in the South may be willing to pay for a mechanized land preparation service if the service were available at the same market price charged in other locations; and (5) using mechanization services, such farmers may cultivate a smaller area and allocate more labor for off-farm income-earning activities.

Keywords: agricultural mechanization, farm household typology, cluster analysis, household model, mechanization service, Nigeria

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1. INTRODUCTION

In Africa south of the Sahara (SSA), such as in Nigeria, anecdotal evidence indicates that on-farm labor costs have been rising. Reasons potentially include a growing urban sector and the rural nonfarm economy (Oseni and Winters 2009)—factors that often raise rural farming wages (Reardon et al. 2000). Although rising rural wages may benefit some farmers through increased off-farm income-earning activities, farmers who receive a higher return from farming than nonfarm activities may lose from the higher labor costs. Effective support for mechanization may be critical when high labor costs have negative effects on agricultural productivity and the welfare of smallholder farm households.

The demand for mechanization may be determined by various factors including farming systems, population density, and labor wages (Pingali 2007). Given the heterogeneity in the agroecological environment and socioeconomic characteristics of farm households common in SSA, farm mechanization may play diverse roles. For example, farm mechanization may be more effective at reducing labor costs than expanding area cultivated. In such a case, the goal for an effective mechanization policy may be to raise incomes of smallholder farm households through reduced production costs rather than to grow large-scale farmers.

The market for mechanization services is underdeveloped in countries such as Nigeria, with an uneven supply across locations. Tractor services in Nigeria are mostly provided by the government through either subsidized direct sales or public tractor-hiring services, and to a lesser extent by the private owner-operators (PrOpCom 2011). Although a commercial market exists in Nigeria where imported tractors are sold, the effective demand may be small and limited to private owner-operators who have managed to accumulate sufficient capital through expansion of business after acquiring subsidized tractors. Given the low operational capacity and poor maintenance of equipment in public tractor-hiring services, the suboptimal distribution of subsidized tractors, and the high fixed costs for starting a private mechanization service, current mechanization may be highly constrained by the lack of supply, leaving potential demand unmet for the majority of smallholder farmers.

We investigate two hypotheses: first, the use of mechanization, particularly tractors through the supply of mechanized land preparation services, may affect the characteristics of Nigerian farm households in heterogeneous ways; second, such use can potentially raise the income of smallholder semisubsistence farmers growing traditional staple crops. We use two methods. First, we employ cluster analysis to assess how the use of mechanization may be associated with distinct characteristics of farm household types, and how it may affect their production behavior. We assess for what types of households mechanization is emerging, and seek logical explanations for any pattern. Correlations between the use of mechanization and farm household characteristics may indicate how important a role mechanization can play in transforming agriculture and farm household livelihoods. Second, we use a simple linear programming method to simulate a farm household model to assess the potential demand for and effect of mechanized land preparation by and on major types of smallholder farmers in Nigeria, given their level of seasonal labor demand for crop production, their liquidity constraints, and their off-farm income-earning opportunities.

Our results generally support the hypotheses. Current tractorization in Nigeria is generally confined to a few types of farm households with distinctive characteristics, indicating that either demand for tractorization is highly affected by farmers' agroecological environment and resource constraints or use of tractorization can highly transform their production behavior. The characteristics of tractorized farm households differ from those of other types of households in somewhat complex ways, such as farm size and labor wages. Demand for a tractorized land preparation service is potentially high among smallholder farmers growing staple food crops. Overall, demand for mechanization may be high among many farmers including smallholder semisubsistence staple crop growers, who constitute a significant majority in Nigeria, whereas, at the same time, tractorization can affect production behavior in somewhat complex ways, with important implications for policymakers aiming for agricultural growth through support for mechanization.

2. MECHANIZATION PATTERNS, TRACTORIZATION POLICY, AND THE EVOLUTION OF PRIVATE MECHANIZATION SERVICES IN NIGERIA

The use of tractors is still relatively rare in Nigeria. In the 2010 rainy season, only 6 percent of the country's farmers used tractors, either their own or rented (Table 2.1). The share was the highest at 15 percent in the North Central zone. The area cultivated by tractors also accounts for a relatively small share, about 8 percent at the national level, with the highest at 20 percent in the North Central zone (Table 2.2). Animal traction is still more commonly used, particularly in the North West and North East, where 60 percent of farmers used either their own animals or rented animals for traction. Although animal traction can typically reduce labor needs by half in Nigeria (Jansen 1993), it is intermediary compared with tractors with more than 10 horsepower (hp). As a result, the level of mechanization has remained low in Nigeria (Takeshima and Salau 2010). Mechanization may be low also because significant tractorization is observed only for rice, which accounts for a small share of cultivated area (less than 10 percent) in Nigeria (Table 2.3). Approximately half of the rice area, or some 0.5 to 1 million hectares (ha), seems tractorized in Nigeria, and that area accounts for about 40 to 50 percent of the total tractorized area in Nigeria.

Table 2.1 Percentage of farmers using tractors or animal traction in 2010 rainy season in Nigeria[abc]

	Share (%) of farm households using tractors or animal traction						
	Tractor			Animal traction			No tractor/ animal traction
Region	Total	Owned tractor	Rented tractor only	Total	Owned animal	Rented animal only	
Total	**6**	**2**	**4**	**27**	**17**	**10**	**68**
	[5, 7]	[1, 2]	[3, 5]	[25, 29]	[15, 18]	[9, 12]	[66, 70]
NW	**2**	**1**	**1**	**62**	**36**	**26**	**36**
	[1, 4]	[0, 2]	[0, 2]	[58, 66]	[32, 40]	[22, 30]	[32, 40]
NE	**16**	**5**	**11**	**58**	**40**	**19**	**33**
	[12, 19]	[3, 7]	[8, 14]	[54, 62]	[35, 44]	[15, 22]	[29, 37]
NC	**15**	**4**	**12**	**5**	**3**	**2**	**80**
	[10, 20]	[1, 6]	[7, 16]	[3, 7]	[2, 5]	[1, 3]	[75, 85]
SE	**0**	**0**	**0**	**0**	**0**	**0**	**100**
SS	**0**	**0**	**0**	**0**	**0**	**0**	**100**
SW	**4**	**3**	**1**	**0**	**0**	**0**	**96**
	[2, 6]	[1, 4]	[0, 2]				[94, 98]

Source: Authors' calculations based on the LSMS-ISA (2010).

Note: [a] The denominator is all the households that report at least one farm plot. The percentages are calculated using the sample weights. Numbers in brackets are 95% confidence intervals.

[b] Figures are calculated using the sample weights. Numbers in brackets are 95% confidence intervals.

[c] Animal traction owned or rented is based on those who reported the actual number of days using animal traction.

Table 2.2—Share (percentage) of areas receiving tractors or animal traction (January–August 2010)[abc]

Region	Total cultivated area (million hectares)	Share (%) cultivated with tractors or animal traction						
		Tractor			Animal traction			No tractor/ animal traction used
		Total	Owned tractor used	Only rented tractor used	Total	Owned animal used	Only rented animal used	
Total	**21.5**	**8**	**3**	**6**	**30**	**20**	**11**	**62**
	[19.2, 23.8]	[6, 11]	[2, 4]	[4, 8]	[26, 35]	[16, 23]	[7, 14]	[57, 66]
NW	**5.0**	**1**	**0**	**1**	**59**	**38**	**22**	**40**
	[3.8, 6.2]	[0, 1]	[0, 1]	[0, 1]	[46, 73]	[27, 49]	[16, 28]	[26, 54]
NE	**6.0**	**12**	**3**	**9**	**46**	**34**	**12**	**43**
	[5.0, 7.1]	[8, 16]	[2, 5]	[5, 12]	[37, 54]	[27, 41]	[8, 15]	[33, 53]
NC	**4.1**	**20**	**5**	**15**	**11**	**2**	**9**	**69**
	[3.1, 5.1]	[12, 29]	[0, 10]	[8, 22]	[0, 26]	[1, 3]	[0, 24]	[55, 82]
SE	**0.5**	**1**	**0**	**1**	**0**	**0**	**0**	**99**
	[0.4, 0.6]							
SS	**2.9**	**0**	**0**	**0**	**0**	**0**	**0**	**100**
	[1.8, 3.9]							
SW	**3.1**	**5**	**4**	**1**	**0**	**0**	**0**	**95**
	[2.2, 4.0]	[3, 7]	[2, 6]	[0, 2]				[93, 97]

Source: Authors' calculations based on the LSMS-ISA (2010).

Note: [a] Although most plots have areas reported, some plots do not. We assumed this unreporting is random, which allows us to assume that two types of plots are of equal sizes on average.

[b] Figures are calculated using the sample weights. Numbers in brackets are 95% confidence intervals.

[c] Animal traction owned or rented is based on those who reported the actual number of days using animal traction.

Table 2.3—Tractorized areas in Nigeria by crop (10,000 hectares, January–August 2010)

Methods	Rice	Maize	Sorghum	Millet	Cowpea	G nuts	Cassava	Yam	Veg[a]	Total[c]
LSMS	86	24	15	5	8	6	13	7	1	182
	[51, 121]	[16, 31]	[5, 25]	[2, 9]	[4, 12]	[2, 11]	[6, 20]	[0, 13]	[1, 2]	[138, 225]
FAO-adjusted[b]	118	35	25	8	11	12	34	16	1	
	[70, 166]	[24, 46]	[8, 42]	[3, 15]	[5, 16]	[4, 23]	[16, 53]	[0, 29]	[1, 2]	
% of cultivated area	49	9	5	2	4	4	10	5	2	

Source: Authors' calculations based on the LSMS-ISA (2010).

Note: [a] In some plots, although multiple crops are grown, only aggregate area was reported. We calculated the area per crop by simply dividing the total plot size by the number of crops grown.

[b] In FAO-adjusted figures, area is adjusted in the same proportion to the gap in total area estimated between the LSMS figure and figures estimated in FAO (2013).

[c]Total includes other crops not presented in the table.

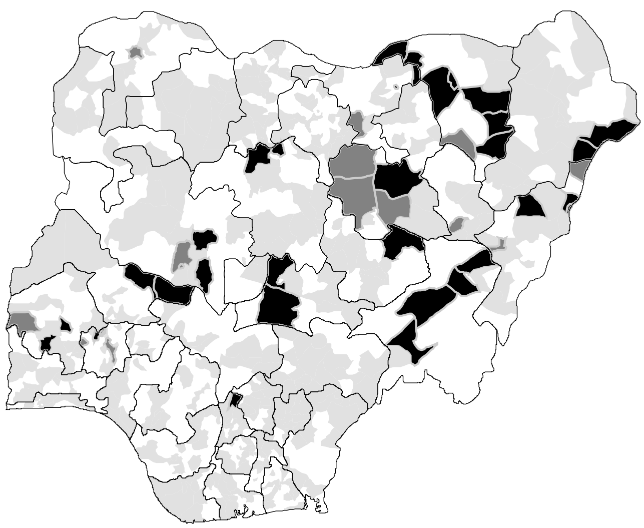
The Nigerian government has implemented various policies to increase the mechanization of agriculture, and increasing tractor use has been one of the focus areas. The government has provided tractor services in three ways (PrOpCom 2011): (1) the direct purchase and subsidized sale of tractors (including popular brands like Massey Ferguson and New Holland); (2) subsidized public-private partnership with bank loans; (3) publicly owned tractors for hire such as through the tractor hiring unit at the Agricultural Development Project (ADP) in each state.

Under the first strategy, state governments actively procure tractors or power tillers. For example, in 2012 the Federal Capital Territory (FCT) procured 80 tractors (New Holland, 70 hp), distributing 60 of them to six local area councils (10 each) and 20 to cooperatives. Nasarawa state procured 80 tractors in

2008 and 160 in 2009.[1] Similarly, Bauchi state and Yobe state obtained 1,300 power tillers from 2008 through 2011 and 700 tractors in 2011, respectively.[2] The provision of tractors has been inefficient. Interactions with some tractor owner-operators indicate that tractors are often sold to political party members.

Although various tractor brands, including Massey Ferguson, Steyr (Austrian), and Fiat (Italian), are sold on the open market in Nigeria, they seem to account for only a small share of tractors obtained in the country. The market for secondhand tractors also appears thin.[3] As a result, tractor use may still be confined to certain geographical areas, and its spatial distribution may be unequal across regions. Using results from the Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA) project in Nigeria, [4] Figure 2.1 illustrates the location of local government areas (LGAs) where one or more observations are found reporting use of tractors. Although the sample in each LGA is small, Figure 2.1 weakly suggests that tractor use is geographically concentrated, potentially due to differences in state-level tractor policies.

Figure 2.1—Number of observations using tractors (by local government area))



Source: Authors' calculations.
Note: Light gray = sampled LGA; dark gray = at least one observation; black = more than one observation.

Examples of Private Mechanization Services

Supporting private mechanization services has become increasingly important (PrOpCom 2011), and the Nigerian government has also described it as one of the goals of its future mechanization policy (Nigeria, FMARD 2011, 2012). Although the provision of mechanization services by owner-operators is emerging in Nigeria, its supply is still regarded as deficient (PrOpCom 2011). The private market is the largest

[1] Based on informal communications with tractor owner-operators in the Federal Capital Territory and Nasarawa state.

[2] Based on announcements on the respective state websites.

[3] One of the owner-operators interviewed traveled 600 kilometers from FCT to Oyo state to obtain a secondhand Massey Ferguson tractor, which had belonged to the Oyo state ADP, paying $1,000 for transportation, because no secondhand tractor was available in the area.

[4] The LSMS-ISA data were collected jointly by Nigeria's National Bureau of Statistics and the World Bank. The data is nationally representative and collected as part of the General Household Survey conducted by these institutions to provide household welfare measures and track poverty changes at the national and regional levels. While LSMS-ISA data were collected in two rounds, post-planting (late 2010) and post-harvesting (early 2011), the data used in this study is from the post-planting survey as most of the information regarding use of agricultural machineries is reported in this survey. The post-planting survey covers the information on farming activities between January through August 2010.

source of rented tractors, providing close to one-third (North Central and South zones) to almost half (North East and North West zones) of tractors rented in the 2010 rainy season in Nigeria (Table 2.4). We briefly describe here the key aspects of emerging private mechanization services, based on informal interactions with a few tractor owner-operators in the FCT and Nasarawa state.

Table 2.4—Sources of rented tractors in 2010 rainy season[ab] (%)

Sources	Total	North East and North West	North Central and South
Private markets	42	46	34
	[32, 53]	[33, 60]	[15, 54]
Government	28	29	27
	[19, 38]	[17, 41]	[11, 43]
Friends/neighbors	14	9	10
	[7, 22]	[0, 18]	[0, 23]
Relatives	10	15	12
	[3, 17]	[6, 25]	[0, 25]
Other	7	1	18

Source: Authors' calculations based on LSMS-ISA data (2010).

Note: [a] Share is weighted by sample weights. Numbers in brackets are 95% confidence intervals.

[b] Some farmers use more than one source and the shares do not necessarily add up to 100%. Government sources include government, political leaders, and government-financed lender, whereas private market includes mobile market, main market, local market, local merchant/grocery, private trader in local market, private trader in main market, and private company/business person.

The tractor owner-operators own one to three tractors, typically the Massey Ferguson (70 hp) or Mahindra brand. All three owner-operators we met obtained their first tractor through the government subsidy, under which tractors were typically sold at a 50 percent discount with loan payments made over a few years. The open market price of a Massey Ferguson tractor is currently around US$45,000 to $50,000,[5] so a subsidized tractor would cost $22,500 to $25,000. These owner-operators provide services to 1.5 to 5 ha/day per tractor, mostly for land preparation, plowing, and harrowing, but not planting or weeding. They often travel to neighboring states such as Niger and Kogi to provide their service, where the seasons of peak demand differ. Each tractor is typically operated by one or two operators.

Their typical business scale is as follows. The mechanization service fee is typically $67 to $200/ha, which includes payments for operators and fuel.[6] By servicing 1.5 to 5 ha/day, total revenue is in the range of $300. They operate almost every day in the peak months, without holidays, for typically five to six months mostly in the rainy season (April through September), bringing the total annual revenues to $50,000. Maintenance costs are approximately $500/month, and maintenance service is provided by mechanics in the local area. Many of their customers pay the service fees on the spot, and relatively few pay on credit. According to the owner-operators, the demand for the mechanization service is sizable, and once they have obtained and used the first tractor, they can accumulate sufficient capital in a few years to buy additional tractors from the open market at unsubsidized prices.

Although more rigorous assessments are needed, this sampling of tractor owner-operators indicates that provision of subsidized tractors to appropriate entrepreneurs could help kick-start the private mechanization service sector. The sector might be constrained due to insufficient provision of such tractors to the private sector.

[5] Throughout the paper, all references to dollars are to US dollars.

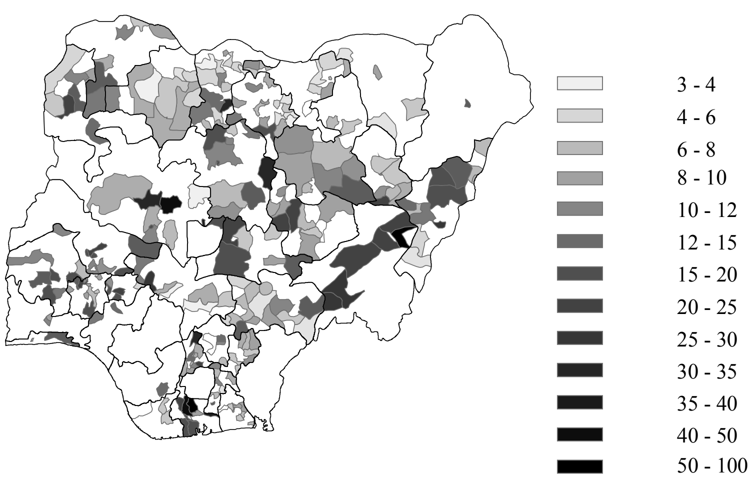
[6] Similar levels of land preparation costs are reported for maize ($175/ha; Law-Ogbomo and Ekunwe 2011) and pepper (17,000 naira/ha; Idowu-agida, Nwaguma, and Adeoye 2010).

3. FARM HOUSEHOLD TYPOLOGY AND ASSOCIATIONS WITH MECHANIZATION

The interviews with private tractor owner-operators indicate that when tractor services are available, many farmers appear very willing to pay for them. Questions, however, remain about what types of farmers actually demand such services and about how mechanization affects their production behavior. Because of its vast geographical area, Nigeria has heterogeneous production environments with regard to farming systems, soil types, and water resources. In addition, socioeconomic characteristics (population density, market access, infrastructure level) vary greatly. The growing rural nonfarm economy in Nigeria (Oseni and Winters 2009) may also affect off-farm income-earning opportunities and labor costs in a heterogeneous way in rural areas. The demand for mechanization tends to be affected by such factors (Pingali 2007; Binswanger and Pingali 1988), but in addition, changes in production behavior—such as input intensity, market participation—may also be associated with mechanization. We can obtain some insights into heterogeneous demand and the role of mechanization in Nigeria is by analyzing farm household typologies and how the use of mechanization is associated with household characteristics. Here we use cluster analysis applied to a nationwide survey of farm households in Nigeria. We use the same cluster analysis method that Takeshima and Edeh (2013) describe. We therefore focus on key aspects of the method and on modifications made to Takeshima and Edeh, and omit the detailed descriptions.

A key variable used as an input for cluster analysis is the real agricultural wage. As in Takeshima and Edeh (2013), the real agricultural wage variable is the LGA median daily wage for an adult male for land clearing and preparation, standardized by the LGA median maize price. Both are obtained from the community surveys conducted in sampled LGAs as part of LSMS data. Maize price is used because that crop is almost universally grown and sold across Nigeria. Though wage data were gathered for both rural and urban sectors, for different crops, and for types of worker (gender, adulthood), no substantial variations were observed across those categories. Wages for the male adult are therefore representative. Large variations in real wages are observed across the regions (Figure 3.1).[7]

Figure 3.1—LGA median wage for land clearing and preparation for an adult male (ratio of daily wage to 1 kilogram of maize)



Source: Authors' calculations.

[7] Some communities responded with wages for multiple crops. Due to the paucity of the sample, each response is treated independently when calculating the median wage. For example, if one community gave a response for each of two crops, while another gave only one response, the median is calculated from the total of three responses. The data do not provide a specific season in which the wage is measured. Although Figure 3.1 indicates large variations in wages within some states, they are not likely due to seasonality since the community survey was conducted during the postplanting period, typically from August to October, for all locations. In addition, Figure 3.1 indicates some spatial correlations of wages within each region. Therefore, we believe the variations within each state, which are substantially high, are reliable data and not misreporting.

Unlike in Takeshima and Edeh (2013), in this analysis we also consider the distinction between two types of tractor users: (a) those using their own tractors and (b) those using only rented tractors. As will be seen, we found that the characteristics of these two types are quite different, although their distinction was not important in Takeshima and Edeh, who focused more on the identification of irrigation characteristics rather than tractor users' characteristics.

Takeshima and Edeh (2013) uses total of 2,189 observations out of 2,982 households considered farm households in LSMS data, after dropping observations due to outliers, missing information on key variables, including real farm wages and total farm sizes, as well as other data inconsistencies. As in Takeshima and Edeh, we use the same 953 farm households from the South and 1,236 from the North for cluster analysis, roughly covering 73 percent of the farm households in the sample. Cluster analysis is conducted independent of sample weights, because the application of sample weights to the aforementioned procedure has not been widely discussed in the literature. Sample weights are used, however, when calculating the proportion of farm households falling into each type.

Distinguishing between tractor types can potentially be important because their engine horsepower often differs substantially and larger tractors can often plow larger areas at a faster speed, although small two-wheel tractors are more appropriate on flooded plots. The LSMS data, however, do not describe the types of tractors used, such as two-wheel, four-wheel, and larger tractors. We leave such distinction of tractor types to future studies. In this study, we treat all tractors equally, and focus on the distinguishing characteristics of users and nonusers of tractors.

Major Types of Farm Households Using Mechanization

Tables 3.1 and 3.2 summarize the main characteristics of each farm household type as identified through the cluster analysis. Sample weights are used to calculate the proportions of households falling into each type, as well as the relevant sample statistics. We classify the households into six types in the South and six types in the North. We choose to use six types for each because that number seems to better capture the potential clusters, based on the aforementioned statistical criteria.

Most types are growers of major staple crops like maize, cassava, sorghum, yam, and legumes, except for rice growers, vegetable growers in the North, and cocoa growers in the South. In the South, the majority of types are small-scale, low-input growers of maize, cassava, and yam, without explicit landownership; they are asset poor, reside in relatively populous areas, and rely mostly on crop sales for their income. The remaining types are relatively larger-scale sorghum/root crop growers (who are also landless and poor) and cocoa growers with slightly higher incomes and stronger landownership (who reside relatively close to the town and major rivers) and medium-scale, mostly input-intensive rice growers who are highly mechanized, have higher incomes and more assets, and operate in remote areas facing higher real wages for land preparation.

In the North, similarly, most household types are small-scale growers of sorghum, legumes, millet, and maize, are income and asset poor, typically cultivate less than 1 ha of rainfed land with relatively low input intensity, and rely mostly on crop sales for their income. Most such growers are distinguished by their level of household assets, literacy, use of inputs, and location. Two of the other types are maize growers with slightly higher incomes and household assets, one of which engages in land-extensive production with little animal traction or hired harvesting labor. The remaining type is the mechanized growers of cereals, who are highly mechanized, have higher incomes and more assets, operate in remote areas facing higher real wages for land preparation, and use inputs like chemicals or harvesting labor relatively more intensively.

The use of mechanization seems to be associated with distinctive production characteristics. In both the North and the South, it appears that the types with more tractor users are wealthier in terms of both assets and expenditure, are located remotely in sparsely populated areas, and face higher real wages—indicating a strong association between household wealth, wages, and mechanization. That is, however, somewhat inconsistent with the conventional argument that the greater demand for mechanization is associated with higher population density and better market access (Pingali 2007;

Pingali, Bigot, and Binswanger 1987). Although an empirical investigation is beyond the scope of this paper, this pattern indicates that use of tractors is to some extent driven by the local government's intervention.

Table 3.1—Farm household types and farm mechanization in southern Nigeria[a]

	Farm household type					
Dimension	**1**	**2**	**3**	**4**	**5**	**6**
Percentage share among sample households[b]	33	8	40	7	8	5
Main crop[c]	*c*	*syc*	*cm*	*c*	*a*	*r*
Subcrop[c]	*my*	*rm*	*y*			
Real wage (daily wage to kilogram of maize)	10	13	10	13	14	18
Population density (per square kilometer)	290	106	320	500	292	79
Distance to 20,000 town (hours)	2.1	3.4	1.8	2.5	1.6	3.8
% on alluvial soil	9	0	13	98	0	4
Rainfall risk (standard deviations in millimeters)	256	155	272	266	199	142
Distance to nearest dam[e]	1.3	.64	1.4	2.2	.52	.42
Distance to river[e]	.016	.017	.016	.016	.017	.017
Household size	4	6	6	5	4	7
Age of household head	62	50	50	52	60	37
% female	47	2	11	12	17	0
% literate	3	41	93	47	59	63
Household assets excluding land (US$)	68	272	388	242	156	779
Livestock assets (US$)	0	115	20	0	0	133
Expenditure on nonfood consumption goods (US$ per capita, year)	46	44	91	74	83	130
% with nonfarm income source	30	27	65	50	80	77
% owning some plots	14	11	16	13	44	49
% taking out any credit/loan	18	35	25	24	17	36
% using irrigation	0	4	1	8	5	11
% using irrigation by diverted stream	0	0	0	0	0	11
Rainfed area (hectares)[c]	.2	1.3	.2	.3	1.0	2.3
Total area (hectares)[c]	.2	1.4	.2	.3	1.0	2.6
Fertilizer cost (US$/household)[d]	0	0	0	0	0	93
Seed cost (US$/household)[d]	0	0	0	0	0	0
Chemical cost (US$/household)[d]	0	16	0	0	13	67
% hiring harvesting labor[d]	21	39	17	9	62	63
% selling harvest[d]	70	92	70	29	99	90
% giving harvest as gift[d]	33	49	34	37	43	80
% selling or giving out harvest as gift[d]	74	95	75	45	99	92
% using rented tractors[d]	0	0	0	0	0	92
% using own tractors[d]	1	3	0	0	2	8
% using tractors[d]	1	3	0	0	2	100

Source: Authors' estimations.

Notes: a Figures in the table are median within each type, except the figures in percentage, which are adjusted for sample weights.

b Percentage shares are adjusted for sample weights.

c Crop (c = cassava, m = maize, r = rice, s = sorghum, y = yam, a = cocoa). Main crops are grown by more than 50 percent of households in each type, and subcrops are grown by more than 33 percent.

d These are for production between January 2010 and August 2010, due to data limitation.

e These distances are Euclidean distances.

Table 3.2—Farm household types and farm mechanization in northern Nigeria[a]

	Farm household type					
Dimension	**1**	**2**	**3**	**4**	**5**	**6**
Percentage share among sample households[b]	28	3	42	16	3	8
Main crop[c]	*sgl*	*m*	*sgl*	*ms*	*m*	*m*
Subcrop[c]		*gv*			*gsr*	*s*
Real wage (daily wage to kilogram of maize)	8	9	8	13	19	15
Population density (per square kilometer)	148	181	157	119	78	129
Distance to 20,000 town (minutes)	2.4	1.9	2.4	3.0	3.0	3.0
% on alluvial soil	4	95	2	1	6	1
Rainfall risk (standard deviations in millimeters)	142	119	142	161	143	160
Distance to nearest dam[e]	.54	1.8	.41	.45	1.1	.45
Distance to river[e]	.017	.014	.017	.017	.016	.017
Household size	6	6	6	7	8	7
Age of household head	50	35	40	50	40	40
% female	1	0	0	2	3	4
% literate	6	91	92	7	67	93
Household assets excluding land (US$)	134	575	295	189	875	500
Livestock assets (US$)	527	0	462	437	323	36
Expenditure on nonfood consumption goods (US$ per capita, year)	33	57	38	35	97	73
% with nonfarm income source	50	63	64	46	79	80
% owning some plots	19	7	23	36	46	33
% taking out any credit/loan	25	40	44	38	52	41
% using irrigation	5	22	4	10	0	13
% using irrigation by diverted stream	1	0	1	2	0	10
Rainfed area (hectares)[d]	0.7	0.4	0.6	0.7	0.8	0.6
Total area (hectares)[d]	0.8	0.4	0.6	0.7	0.8	0.6
Fertilizer cost (US$/household)[d]	0	30	31	40	20	53
Seed cost (US$/household)[d]	0	5	0	0	0	0
Chemical cost (US$/household)[d]	0	25	0	0	40	13
% hiring harvesting labor[d]	44	74	72	60	71	47
% selling harvest[d]	56	60	58	61	55	74
% giving harvest as gift[d]	64	44	64	69	69	56
% selling or giving out harvest as gift[d]	81	69	84	90	81	87
% using own animal traction[d]	29	41	46	40	16	6
% using animal traction (including rented)[d]	47	67	71	69	38	17
% using rented tractors[d]	1	12	0	0	97	0
% using own tractors[d]	1	14	2	2	3	3
% using tractors[d]	2	26	2	2	100	3
% using animal traction or tractors[d]	48	86	72	71	100	20

Source: Authors' estimations.

Notes: [a] Figures in the table are median within each type, except the figures in percentage, which are adjusted for sample weights.

[b] Percentage shares are adjusted for sample weights.

[c] Crop (m = maize, r = rice, s = sorghum, l = millet, g = legumes, v = vegetables). Main crops are grown by more than 50 percent of households in each type, and subcrops are grown by more than 33 percent.

[d] These are for production between January 2010 and August 2010, due to data limitation.

[e] These distances are Euclidean distances.

Patterns of mechanization differ somewhat between the North and the South. In the North, comparing the types that display different shares of tractor or animal traction use, mechanization including tractorization seems to lead to intensive production without much effect on area expansion. The wealthiest households (type 5) use tractors widely but do not seem to own them, whereas some tractor owners are found among the other types. Moreover, the tractor renters seem to be located remotely from the market and to grow relatively subsistence staple crops like maize, sorghum, millet, and legumes. Input intensity is driven rather by the use of irrigation of more commercial crops like rice and vegetables. Tractor use has relatively little correlation with crop sales or with intensity of inputs used. In northern Nigeria, it seems tractors are used mostly to replace labor rather than for intensification, and animal traction may be playing the role of intermediate substitute for tractors.

In the South, patterns are somewhat different. First, due to the absence of animal traction, tractor use is more defining of the level of mechanization. In addition, farm size in the South is generally smaller, and the farm size of tractor users appears relatively larger than nonusers. The intensity of input use among tractor-using types also seems more pronounced than in the North. Use of tractors is highly concentrated among the (irrigated) rice growers. In the South, the use of mechanization seems limited to area expansion for input-intensive production of certain crops like rice. Consequently, the effect of mechanization on other farmers is less clear in the South than it is in the North, and the next section analyzes the potential demand for mechanization among major farm household types in the South.

4. MECHANIZATION NEEDS FOR PARTICULAR TYPES OF FARM HOUSEHOLDS

Mechanized land preparation is currently used by only a few, although diverse, farm household types, and not by the majority of farmers, particularly in southern Nigeria. If the market for mechanization services is constrained from the supply side, potential demand for mechanization cannot be fully observed. Rising labor costs observed anecdotally around Nigeria indicate that it is important to investigate the level of potential demand for mechanization services at the costs observed in areas where such a service actually exists. We conduct a simple simulation to assess the effect of mechanization services for land preparation on a farm household's production activities. We use the example of small-to-medium-scale traditional maize, cassava, and yam producers, who also have off-farm daily wage-earning opportunities. Such types are prevalent widely across Nigeria, and although they are labor constrained, their uptake of mechanization is not common and they are suitable for assessing the potential impact of a mechanization service.

The key feature of the model is the following: the mechanization of land preparation affects the labor constraint during land preparation stages, which could also affect the cultivated area, as well as labor use in subsequent months (through the change in cultivated area). Thus, although farmers may have incentives to use mechanized services for land preparation and to cultivate a larger area, they must also consider increased labor requirements for sowing, crop management, and harvesting at the later stages. We consider that mechanization services may be available only for land preparation, and not for sowing, crop management, or harvesting, which is realistic given the recent mechanization patterns in Nigeria. Modifying Alwang, Siegel, and Jorgensen (1996), we solve the following constrained optimization problem:

$$\max_{H_{ot}, H_{rMt}, A_{rM}, L_{rMt}} V = \Sigma_r p_r (Y_r - \psi_r \cdot 12) + \Sigma_t w_o \cdot H_{ot}$$

$$- \Sigma_M [\Sigma_r A_{rM} (C_r \cdot D_r + w \cdot \Sigma_t L_{rMt} + \mu \cdot M)] \quad (1)$$

subject to

$$Y_r = y_r \cdot \Sigma_M A_{rM} \; \forall \; r \quad (2)$$

$$H_{rMt} + L_{rMt} = L_{rMt}^{*} \; \forall \; r, M, t \quad \text{(labor requirement per hectare for each crop, month, under regime } M\text{)} \quad (3)$$

$$\Sigma_r H_{rMt} + H_{ot} \leq H^{*} \; \forall \; M, t \text{(household labor constraint)} \quad (4)$$

$$Y_r \geq \psi_r \cdot 12 \quad (5)$$

$$\omega_{t+1} + p_r s_{rt+1} = \omega_t + p_r s_{rt} + \Pi_t - X \geq 0, \forall \; t \quad (6)$$

$$s_{rt} = s_{r,t-1} - \psi_r + Y_r \geq 0, \forall \; r, t \quad (7)$$

$$\omega_{12} \geq \omega_0, s_{r12} \geq s_{r0} \quad (8)$$

$$H_{ot}, H_{rMt}, A_{rM}, L_{rMt} \geq 0 \;\; \forall\, r, M, t, \qquad (9)$$

where a farmer's objective is to maximize annual net income V from the production of crops $r \in$ {maize, cassava, yam} carried out through months $t \in${1 = January, 2 = February, ..., 12 = December}, deciding the area under each mechanization status M for land preparation {manual = 0, mechanized = 1} and off-farm wage-earning activities. V is determined by the farmgate price (US$ per ton)[8], harvest (ton), and monthly subsistence requirements for the household (ton) of crop r (p_r, Y_r, and ψ_r), daily wage for hiring out for off-farm activities (w_o, US$) and household labor hired out for off-farm activities (H_{ot}, person-days), and production costs determined by monthly cost per hectare of inputs other than labor such as fertilizer, seeds, and chemicals for each r (C_r, US$) incurred through the D_r months of production periods, area planted for r under each M (A_{rM}, hectare), hired labor used for production of k under each regime M in month t (L_{rMt}, person-days) at wage w (US$ per day), and the cost of mechanization service for land preparation (μ, US$/ha), which is zero if manual. The harvest Y_r becomes available at a particular month for each r. Maize, cassava, and yam become harvestable in August, December, and August, respectively (Ngeleza et al. 2011).

The objective function (1) is maximized subject to constraints (2) through (9). Constraint (2) relates the output to area and yield (y_r, ton/ ha). Constraint (3) states that the required monthly labor per hectare under each regime M for production (L_{rMt}^*, person-days) must be supplied by either household labor or hired labor. Constraint (4) states that the monthly household labor endowment is fixed at H^* (person-days), which is allocated to either production ($\Sigma_r H_{rMt}$) or off-farm activities.

We also assign various constraints as in Alwang, Siegel, and Jorgensen (1996) to consistently reflect the reality for these farm households in SSA countries. Constraint (5) sets the safety-first rule, in which households produce a subsistence amount of food by themselves rather than purchasing. A household starts the year in January with some stock of cash and crops from the previous harvest, which are depleted or replenished every month. The liquidity constraint (6) specifies that the household must have sufficient liquid wealth at the beginning of month t (ω_t) including the sales value of crop stock ($p_r s_{rt}$) and net income in month t (Π_t) which is any off-farm income and sales of crops if they take place net of production costs (input purchases, labor payment, mechanization service) incurred and reduction in crop stock in month t, to pay for monthly subsistence household expenditure X (food and nonfood items, clothes, school fees, health fees, and so on, all in US$). The crop balance constraint (7) states that the household consumes each crop r from the stock with the initial stock level at t (s_{rt}, ton), and stock should not be depleted or must be replenished whenever harvest becomes available in particular month t. The sustainability constraint (8) states that the liquid asset and crop stock levels at the end of the year (t = 12) should not be lower than the levels at the beginning of the year (t = 0), so that the solution of the optimization problem is economically sustainable across years. Finally, (9) states the nonnegativity of endogenous variables.

The values of exogenous parameters are summarized in Table 4.1. As is discussed later in the sensitivity analyses, key results are generally robust to some variations in these parameter values. Crop prices p_r are assessed from various sources. Maize price is the sample mean in the South region from LSMS data. Cassava and yam farmgate prices are set based on figures reported in various studies, including Bamire and Amujoyegbe (2005) and Chikoye et al. (2007), because of the insufficient observations reporting price per standardized weights (kilograms or tons) in LSMS data. Crop yields y_r are also set based on various sources, including FAO (2012b), Bamire and Amujoyegbe (2005), and Chikoye et al. (2007). Reported cassava and yam yields vary widely across sources, although cassava yields are generally higher than yam yields. We therefore set 15 tons/ha for cassava and 10 tons/ha for yam.

[8] "Ton" refers to metric tons throughout the paper.

Table 4.1 Values of some parameters

Parameters	Maize	Cassava	Yam
Crop farmgate prices (p_r; US$ per ton)	250	50	150
Crop yield (y_r)	2	15	10
Subsistence consumption (ψ_r)	0.015	0.075	0.075
Initial stock (*ton*)(s_{r0})	0.18	0.9	0.9
Months of production period (D_r)	6	8	11
Monthly production cost excluding labor/ mechanization (C_r, US$/hectare)	4	5	60
On-farm hiring-in wages (w) (US$/man-day)		6	
Off-farm hiring-out wages (w_0) (US$/man-day)		4	
H^* (man-days/month)		50 = 25 man-days × 2 adult members	
Monthly household expenditure (X, US$/month)		200	
Initial liquid wealth (ω_0, US$)		500	
Cost of mechanized land preparation (μ, US$/hectare)		μ = 100, 200, or no service available	

Source: Authors' compilations from various sources.

Months of production period D_r are inferred from the land preparation and harvesting timing for the Guinea savannah region in Ghana reported by Ngeleza et al. (2011). On-farm hiring-in wage (w) is the LSMS sample median of land preparation wages for an adult male in the South. Off-farm hiring-out wage (w_0) is selected slightly lower than the on-farm hiring-out wage due to the lack of information. Monthly labor availability for the household (H^*) is set at 50 man-days. For this, we assume days per person is set at 25 days per month, relaxing the assumption of 20 days per month in Alwang, Siegel, and Jorgensen (1996), as a more conservative assumption of labor constraints. We assume two working-age adults per household based on the sample mean from the LSMS data in the Southern region.

Levels of beginning-of-the-year crop stock (s_{r0}) as well as subsistence consumption (ψ_r) are set in the following ways: based on FAO (2012b), the average annual per capita consumptions of maize, cassava, and yam for the whole country between 2005 and 2009 are 25.7, 112.5, and 84.4 kg. We assume that the model household here has four adult-equivalent household members in terms of food consumption (by assuming two dependent household members are equivalent to one adult equivalent).[9] We also assume cassava and yam consumptions are twice as high in the South than the national average. Storage loss is 10 percent for each crop every month, as in Alwang, Siegel, and Jorgensen (1996). We also take into consideration the trend of growing maize consumption between 2006 and 2009, where maize consumption had increased by 30 percent. With these sets of information, we set the monthly subsistence consumption of maize, cassava, and yam at 0.015, 0.075, and 0.075 tons, respectively. We also assume that the household has a beginning stock of these crops worth 12 months of subsistence consumption, so that the initial stock becomes 0.18, 0.9, and 0.9 tons, respectively.

The initial liquid wealth other than stored crops (ω_0) is estimated roughly as the aggregate value of household assets excluding land and livestock assets in Table 3.1. Monthly household expenditure is assumed to be $200. This is based on the per capita annual nonfood expenditure and household size in Table 3.1.

Monthly production costs for each crop are also generally difficult to assess. LSMS data suggest that the typical maize and cassava plots in Nigeria receive no seed, chemicals, or fertilizer, leading to virtually no production costs other than labor. On the other hand, if we assume production costs to be such that the total profit is zero given the yield and farmgate price, as well as labor costs as presented above, the monthly production costs for maize and cassava can be $7 and $11/ha. Due to the absence of representative figures, we take the average, namely $4/ha and $5/ha for maize and cassava, respectively. On the other hand, the cost of yam production is typically much higher than that of maize or cassava. Yam production cost is often driven by the high cost of planting materials (yam sett) (Bamire and Amujoyegbe 2005). Due to the lack of reliable cost information, we set the yam production cost so that

[9] Based on LSMS data, the typical household has two working-age members and four dependents.

the profitability is similar to that of maize and cassava, which may hold if farmers are rational and are producing maize and cassava aside from yam. Lastly, monthly labor requirements for maize, cassava, and yam production (L_{rMt}^{*}) for central Nigeria (Table 4.2) are assessed from the similar labor requirements in the Guinea savannah region in Ghana (Ngeleza et al. 2011).

We analyze three scenarios based on the cost of mechanization service for land preparation (μ)—(1) μ = 100, (2) μ = 200, and (3) no mechanization service available—and see how such differences affect household's net income, area cultivated, use of mechanization services, and labor use. We solve the above problem using The General Algebraic Modeling System (GAMS).

Table 4.2 Person-days per hectare

	Land preparation						Sowing, crop maintenance, and harvesting (combined)		
	Labor and tractors			Labor only					
Month	Maize	Cassava	Yam	Maize	Cassava	Yam	Maize	Cassava	Yam
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	25	0	0	25	0	0	0	0	0
April	1.9	0	0	25	0	0	0	0	9.4
May	0	32.2	0	0	44.4	0	15.6	0	0
June	0	0	0	0	0	0	6.3	6.3	14.1
July	0	0	0	0	0	0	10.9	12.5	14.1
August	0	0	0	0	0	0	9.4	12.5	21.9
September	0	0	0	0	0	0	0	12.5	0
October	0	0	6	0	0	56.9	0	0	0
November	0	0	0	0	0	0	0	0	0
December	0	0	18.8	0	0	18.8	0	43.8	0

Source: Modified from the original data for the Guinea savannah zone used in Ngeleza et al. (2011).

Notes: Assume 1 day = 8 hours. 1 hectare = 2.5 acres. Figures are rounded to one decimal point.

Results

The main results are presented in Table 4.3. Key interpretations are the following: Demand for mechanized land preparation service exists when it is made available at μ = 200 through various supports including improvement in infrastructure and the service network, which is higher than the mechanization service fees in the area where such services currently exist. This weakly supports our hypothesis that the demand for mechanized land preparation service is potentially quite high even among small-scale staple crop growers. The net income effect is relatively small, changing from $2,517 to $2,519, where farmers simply replace manual labor with machinery for preparation of the yam plot, allocating 29 more man-days (or $116 more) for nonfarm income-earning activities. The plot for yam is mechanized first because of the greatest reduction in labor use for yam compared with other crops (Table 4.2).

Table 4.3—Results under different scenarios based on the cost of mechanization service

Key outcomes	Cheap mechanized land-clearing service μ = 100	Expensive mechanized land-clearing service μ = 200	No mechanization available
V (objective value)—net income	2,581	2,519	2,517
Income—crop sales (US$)	1,303	1,340	1,340
Labor earning (hiring out) (US$)	2,011	1,703	1,587
Labor cost (hired labor) (US$)	-	-	-
Mechanization cost (US$)	96	113	-
Other production cost (US$)	637	411	411
Family labor cost (opportunity cost) (US$)	389	697	813
Total cultivated area (hectares)	1.11	1.55	1.55
Mechanized area (hectares)	0.96	0.57	0.00
Maize area (hectares)	0.09	0.09	0.09
% mechanized land preparation	0	0	0
Revenue (US$)	0	0	0
Cassava area (hectares)	0.06	0.90	0.90
% mechanized land preparation	0	0	0
Revenue (US$)	0	627	627
Yam area (hectares)	0.96	0.57	0.57
% mechanized land preparation	100	100	0
Revenue (US$)	1,303	713	713

Source: Authors' estimations.

When the mechanized land preparation becomes even cheaper at μ = 100, which is closer to the fee in the area where there is currently such service, the farmer starts concentrating on relatively more profitable yam production, increasing its cultivated area from 0.57 to 0.96 ha, while reducing the less profitable cassava area from 0.90 ha to 0.06 ha. As a result, total cultivated area reduces from 1.55 ha to 1.11 ha. Such a reduction in cultivated area enables allocation of labor from farming to nonfarm activities, raising total net income to $2,581 from $2,519.

We also assessed the robustness of such patterns through sensitivity analyses. An interesting aspect of sensitivity is the effect of off-farm hiring-out wages and liquidity constraints, as well as farmgate crop prices. The information for off-farm wages and farmgate prices is often difficult to obtain, and liquidity constraints can significantly affect the effective demand for modern production technologies. Tables 4.4 and 4.5 summarize the results of the sensitivity analyses on how net income, cultivated area, and mechanized area depend on hiring-out wages, initial liquid wealth (excluding crop stock), or crop prices. In Table 4.4 we assess the case where the household expenditure, initial liquid wealth and off-farm wage are $150 and $200 / month, $200, $300, $400 and $500, and $3, and $4 /day, respectively. In Table 4.5, we assess the cases where crop prices are 5 percent lower or higher than the initial assumptions in Table 4.1. Solutions are feasible as long as the off-farm wage and liquid wealth are above certain levels. Some solutions are infeasible, indicating that those households would further adjust their expenditures. Key patterns of cultivated area and mechanized area are robust. Even with lower off-farm wages and initial liquid wealth, demand for mechanized land preparation exists at $100/ha, and increased use of land preparation would not lead to expansion of cultivated area, and would often lead to contraction. Such patterns are also robust against slight changes in crop prices. Though not shown, results are also generally robust to slight changes in other parameters.

Although the model here is specifically for small-scale farmers growing maize, cassava, and yam in the Guinea Savannah Zone, we identify two important implications. Contrary to the strategy favored by some Nigerian state governments of promoting the growth of large-scale producers through mechanization, many small-scale farmers may have a relatively high willingness to pay for mechanized land preparation services, and mechanization will help many small-scale farmers raise income but not expand their production scale.

Table 4.4—Sensitivity analysis

Initial liquidity (excluding crop stock)	Mechanization fee (US$/hectare)	Off-farm wage 3: Net income (US$)	3: Area (hectare)	3: Mech. area (hectare)	Off-farm wage 4: Net income (US$)	4: Area (hectare)	4: Mech. area (hectare)
Expenditure = US$200/month							
300	100				2,440	0.76	0.61
	200				2,418	1.27	0.16
	–				2,417	1.27	0
400	100				2,511	0.93	0.78
	200				2,470	1.43	0.35
	–				2,468	1.43	0
500	100	–	–	–	2,581	1.11	0.96
	200	–	–	–	2,519	1.55	0.57
	–	–	–	–	2,517	1.55	0
Expenditure = US$150/month							
200	100	–	–	–	2,617	1.20	1.05
	200	–	–	–	2,543	1.61	0.68
	–	–	–	–	2,541	1.61	0
300	100	2,060	1.46	0.27	2,687	1.37	1.22
	200	2,046	1.46	0	2,593	1.74	0.90
	–	2,046	1.46	0	2,588	1.76	0
400	100	2,141	1.65	0.46	2,758	1.55	1.40
	200	2,117	1.65	0	2,642	1.86	1.12
	–	2,117	1.65	0	2,622	2.11	0
500	100	2,222	1.83	0.65	2,829	1.72	1.57
	200	2,188	1.83	0	2,691	1.99	1.34
	–	2,188	1.83	0	2,651	2.36	0

Source: Authors' estimations.

Note: Mech. = mechanization.

Table 4.5—Sensitivity analysis with respect to marginal changes in crop prices

Mechanization fee (US$/hectare)	Crop price –5%: Net income (US$)	–5%: Area (hectare)	–5%: Mech. area (hectare)	Crop price +5%: Net income (US$)	+5%: Area (hectare)	+5%: Mech. area (hectare)
100	2,514	1.10	0.95	2,650	1.12	0.97
200	2,450	1.55	0.56	2,589	1.56	0.58
–	2,448	1.55	0	2,586	1.56	0

Source: Authors' estimations.

Note: Mech. = mechanization.

5. CONCLUSIONS

Agricultural mechanization is considered one of the essential factors for promoting agriculture and reducing poverty among farm households. Identifying appropriate supports for mechanization is crucial in many SSA countries with potentially heterogeneous demand for mechanization. However, information has been lacking regarding what types of farmers have been using mechanization and what the level of potential demand among nonadopters is, given the labor costs, seasonality, and dynamics of mechanization use and agricultural labor demand, as well as liquidity constraints, which are important features of many farm households in SSA countries.

We provide useful evidence with important implications using the case of Nigeria. First, current tractor use is associated with input-intensive crop production. Second, tractor use in the North seems more associated with increased nonfarm income-earning activities than with area expansion and seems to be emerging, albeit slowly, across various farm household types, whereas in the South it is highly concentrated among large-scale rice producers. Third, although mechanization services are not available to many smallholder farmers in Nigeria mostly because of the shortage of machines and private service providers, they may be willing to pay for such services if they are available at the prices offered in the other locations where such services are available.

Tractorization, wherever adopted, might have potentially helped diverse types of farm households in Nigeria in their respective needs, not necessarily expanding area cultivated and increasing output sales, as commonly expected, but reducing the cost of land preparation. At the same time, the lack of supply of mechanization may still be highly constraining for the majority of smallholder farm households in Nigeria growing traditional staple crops in a semisubsistence manner. Identifying effective means of support for the increased supply of private mechanization services is therefore likely to be critical; such growth in supply may not be induced automatically by rising demand for it. In addition, although the goal of government is generally to promote mechanization for the purpose of growing large-scale commercial farmers, a significant share of the benefits from mechanization may potentially arise from the increased productivity of Nigeria's smallholder farmers. Policies regarding mechanization for many SSA countries, including Nigeria, must therefore be designed taking into account the role of mechanization for smallholder farmers.

APPENDIX: CLUSTER ANALYSIS METHOD

We combine the hierarchical method and K-mean method 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 solution as starting points for the subsequent K-mean method. In the K-mean method, we use Gower's (1971) dissimilarity measure, which is appropriate for our data where the variables j contain both binary and continuous data.

We conduct a statistical test to see if the number of clusters we select is better than any small number of clusters in the following way. 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), the between-cluster variance for j is defined as

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

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.

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

where n_i is the number of observations within cluster i, and s_{ij}^2 is the sample variance of variable j within cluster i.

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) present the natural log transformation of the ratio for each j. We calculate the statistic

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

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. In both the South and the North, clustering into six types is better than clustering into a smaller number of types.

Table A.1—Cluster analysis statistics (σ_k) for different numbers of clusters[a]

Region	Number of clusters				
	2	3	4	5	6
South	-89.4	-72.5	-66.3	-63.4	-52.3
North	-159.4	-121.3	-109.4	-84.9	-76.3

Source: Authors'.

Notes: [a] Numbers are different from Takeshima and Edeh (2013) because we add a variable that distinguishes farmers who use their own tractors from those who use only rented tractors.

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