MECHANIZATION AND AGRICULTURAL TECHNOLOGY EVOLUTION, AGRICULTURAL INTENSIFICATION IN SUB-SAHARAN AFRICA: TYPOLOGY OF AGRICULTURAL MECHANIZATION IN NIGERIA

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In sub-Sahara African (SSA) countries like Nigeria, anecdotal evidence indicates that the cost of manual farming activities has been rising, with potential causes including the growing urban sector, as well as rural non-farm economies (Oseni and Winters 2009) which often raises rural farming wages (Reardon et al. 2000). While rising rural wages may help some farmers benefit through increased off-farm income earning activities, farmers getting higher returns from farming than non-farm activities may lose from higher labor costs. When high labor costs have negative effects on agricultural productivity and the welfare of smallholder farm households, effective support for mechanization may be critical.

Demand for mechanization may be determined by various factors including

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farming systems, population density or labor wages (Pingali 2007). Because of the heterogeneity in agro-ecological environment and socio-economic characteristics of farm households in SSA, farm mechanization may play diverse roles. For example, farm mechanization may be more effective in reducing labor costs rather than expanding area cultivated. In such a case, the goal for effective mechanization policies may be to raise the income of small-holder farm households through reduced production costs, rather than growing large scale farmers.

The market for mechanization services is underdeveloped in countries like Nigeria, with uneven supply across locations. Much tractor service in Nigeria is provided by government through either subsidized direct sales or public tractor hiring service (PrOpCom 2011), though private owner operators are emerging. While commercial markets exist 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 business expansion after first acquiring subsidized tractors. Due to the low operational capacity and poor maintenance of equipments among public service providers, sub-optimal distribution of subsidized tractors, and high fixed costs, current adoption of mechanization may be highly constrained by the lack of supply, leaving potential demand unmet for the majority of smallholder farmers.

We investigate two hypotheses: (i) in Nigeria, the use of mechanization, particularly tractors, may affect the characteristics of farm households in heterogeneous ways; and (ii) can potentially raise the income of small-holder semi-subsistence farmers growing traditional staple crops. We use two methods. First, using cluster analysis methods we assess how the use of mechanization is associated with farm household types and production behaviors. Second, we use a simple linear programming to simulate a farm household model to assess the potential demand for and effect of mechanized land preparation across major types of smallholder farmers in Nigeria, given their level of seasonal labor demand, liquidity constraints, and off-farm income earning opportunities.

Cluster analysis method

Various typologies of agricultural or rural households have been studied using cluster analysis method (Dorward 2006). Detailed descriptions of the method are provided in various studies (e.g. Hansen and Jaumard 1997), which we omit here. We combine hierarchical partitions with *k*-means partitions (Punj and Stewart 1983; Siou et al. 2011) because by combining two partitions methods clustering accuracy can be significantly improved. We measure homogeneity and separation of the clusters, by minimizing the standard deviations of variables within the cluster, and maximizing the standard deviations of their cluster-means across clusters. We limit the maximum number of clusters to be generated to keep the typology interpretable.

We use the Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS) 2010 data, supplemented with secondary data. The LSMS data was collected jointly by the National Bureau of Statistics (NBS) of Nigeria and the World Bank. The data well represents all types of farm households in Nigeria and is appropriate for analyzing the typology of major farm households in Nigeria. The LSMS data consists of Post-Planting (PP) Survey covering the information in January 2010 through August 2010, and Post-Harvesting (PH) Survey covering September 2010 through March 2011.

Variables for cluster analysis are selected in order to capture the various aspects of rural farm households. For each local government area (LGA) within 37 states in Nigeria, we identify the dominant farming system, soil type, standard deviation of historical rainfall variation from 1950 through 2002 (University of East Anglia 2012), distance to major rivers (based on FAO 2000), distance to the nearest town with 20000 population (Harvest Choice 2012), and population density (person per square km) (SEDAC 2012). Dominant farming system and soil type are identified for each LGA. Following Dixon, Gulliver and Gibbon (2001), two farming system zones are distinguished: (1) the North consisting of cereal-root crop mixed system, agro-pastoral – millet / sorghum system, or pastoral system, and (2) the South consisting of root crop system, tree crop system and coastal artisanal system. Soil types are classified into alluvial soils (Fluvisols, Gleysols and Vertisols) and other types based on FAO/IIASA/ISRIC/ISSCAS/JRC (2012). Alluvial soil is generally regarded to be more fertile than other types in Nigeria (FAO 2012), allowing different farming systems to be applied. Real agricultural wage is calculated as the LGA median daily wage (USD) for land clearing / preparation for adult male, standardized by the LGA median maize price (USD). Both are obtained from the community surveys conducted in sampled LGAs as part of LSMS survey. The maize price is used because it is universally grown and sold across Nigeria. Wages are highly correlated between rural and urban sectors, and type of workers (gender, adulthood) or types of farm activities, therefore wage for male adult is representative for our purposes.

Other variables constructed from the LSMS data include household size, gender of household head, whether the head is literate and received formal education or not, per capita value of household assets not including land or livestock, annual per capita household expenditure on non-food items, and amount of other types of income such as savings interest and rental of property. Production variables constructed are total area cultivated (each of rainfed and irrigated), cost of fertilizer, seed and chemicals per hectare, total number-days of animal traction use and total number of tractor use. Other household variables considered are whether the household: owned any of the farm plots; used irrigation, animal traction, or tractors; hired harvesting labor; took out any loan or credit including non-agricultural credit from either formal or informal sources; sold harvest; or earned any income from non-farm activities one month before the interview.

These variables are selected to capture a broad range of resource constraints which define agricultural households' economic activities and play an important role in their choice of crop production methods and inputs use intensity. We also use crop dummy variables to indicate the composition of the household's crop production, in order to reflect the distinct characteristics of farming systems inherent to each major crop. These crops include: ground nuts, soybeans, or other legumes (cowpea or sesame), and key root crops (cassava or yam or cocoyam) for the North; oil palm, cocoa, or other tree crops (banana or plantain), cassava, yam or cocoyam, pumpkin and melon for the South. Maize, coarse grains (millet or sorghum), rice and key vegetables (any of pepper, onion, okro, tomato) are included for both regions. These crops are found to represent major crop combinations in Nigeria, based on a separate cluster analysis (results not shown here).

Most variables related to production behaviors are for production from January 2010 through August 2010 as PH Data does not have detailed information. Crop dummy variables as well as use of irrigation are, however, inferred both from PS and PH data. Use of irrigation is assumed whenever a household grew crops in dry season, except cassava, yam or cocoyam which can grow with little water. In the cluster analysis, all variables are standardized for the North and for the South, ensuring that their distributions have zero mean and one standard deviation.

Major types of farm household using mechanization

Table 1 lists the major characteristics of each type of farm households, indicated as either median or percentages of major variables within clusters identified. Households are clustered into six types in the South and the North, respectively. Although cluster analysis can be sensitive to outliers, our results are robust to their exclusions. Cluster medians and percentages of most variables are statistically significantly different at 5% significance level based on the joint test, except the soil types and crop sales in the North.

Most types of households grow major staple crops like maize, cassava, sorghum, yam and legumes. The exceptions are rice growers, vegetable growers in the North and cocoa growers in the South. In the South, the majority of households are small scale, low-input staple crop growers who are landless, asset poor, residing in relatively populous areas and relying mostly on crop sales for their income. The remaining farm household types are (i) relatively larger scale, landless, uneducated and poor sorghum / root crop growers; (ii) cocoa growers with slightly higher income and stronger land ownership residing relatively close to the town and major rivers; and (iii) input-intensive rice growers who are highly mechanized, with higher income and assets, operating in remote areas facing higher real wages for land preparation. In the North, most types of households are small-scale growers of sorghum, legumes, millet and maize, who are income and asset poor typically cultivating one ha of rainfed land with relatively low input intensity, relying mostly on crop sales for their income. Most of these growers are distinguished by the level of household assets, literacy, use of inputs, and their locations. Two of the other types are maize growers with slightly higher income and household asset, one of which use land extensive production with little animal traction or hired harvesting labor. The remaining type is the irrigated rice and vegetable growers who are landless, mostly located in sub-urban areas with non-farm income sources but are still relatively poor, cultivating small plots using inputs intensively.

Use of mechanization is associated with distinctive production characteristics. In both the North and the South, the household types with more tractor users seem to use other inputs more intensively, including fertilizer, seed / chemicals, and hired harvesting labor. This indicates the potential role of mechanization on enabling input intensive production. Some differences exist between the North and the South. In the North, mechanization-including tractorization-is associated with intensive production without much area expansion. In addition, although the shares of tractor and animal traction users vary across types, there is some use of mechanization in each type. . However, levels of mechanization vary between households in each type. Within each type, mechanization may be simply replacing labor for land preparation, although farmers end up using more labor for harvesting, instead of expanding the area. The share of tractor users has weak correlation with crop sales, and stronger positive correlation with non-farm income earners. Therefore, the impact of mechanization may be to replace household labor use on the farm, and increase instead non-farm income earning activities. The patterns in the North illustrate potential effects of mechanization on crop production and non-farm income earning activities.

In the South, due to absence of animal traction, mechanization is defined as tractor use only. Farm size of tractor users appears relatively larger than non-user types. The higher intensity of input use among tractor using farmers also seems more pronounced than in the North. Use of tractors is highly concentrated in 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, rather than labor replacement. Consequently, the effect of mechanization on other farmers is less clear in the South than in the North. The next section analyzes the potential demand for mechanization among major farm household types in the South, where use beyond rice growers is limited.

Mechanization needs for a particular type of farm households

We use a simple farm household model to assess the effect of mechanization services for land preparation on farm household's production activities. We use the example of small-medium scale traditional maize, cassava and yam producers, who also have off-farm daily wage earning opportunities. These types are prevalent across Nigeria and although they may be labor constrained, their uptake of mechanization is not common, making this type of household suitable for assessing the potential impact of mechanization services.

The key features of the model are the following: mechanization of land preparation alleviates the labor constraint during land preparation stages, affects cultivated area and labor use in subsequent months. Although farmers may have incentives to use mechanized service for land preparation and to cultivate larger areas, they must also consider increased labor requirements at later stages of production. We assume that mechanization services are only available for land preparation, and not for sowing, crop management or harvesting, which is consistent with the recent patterns in Nigeria. Modifying Alwang, Siegel and Jorgensen (1996) we solve,

$$\max_{H_{ot}, H_{kMt}, A_{kM}, L_{kMt}} V = \Sigma_k\, p_k\,(Y_k - \psi_k \cdot 12) + \Sigma_t\, w_o \cdot H_{ot} \tag{1}$$

$$- \Sigma_M\, [\Sigma_k\, A_{kM}\,(C_k \cdot D_k + w \cdot \Sigma_t\, L_{kMt} + \mu \cdot M)]$$

subject to,

$$Y_k = y_k \cdot \Sigma_M\, A_{kM} \;\; \forall\, k \tag{2}$$

$$H_{kMt} + L_{kMt} = L_{kMt}^{*} \;\; \forall\, k, M, t \tag{3}$$

$$\Sigma_k\, H_{kMt} + H_{ot} \leq H^{*}\, \forall\, M, t \tag{4}$$

$$Y_k \geq \psi_k \cdot 12 \tag{5}$$

$$\omega_{t+1} + p_k s_{kt+1} = \omega_t + p_k s_{kt} + \Pi_t - X \geq 0, \forall\, t \tag{6}$$

$$s_{kt} = s_{k,t-1} - \psi_k + Y_k \geq 0, \forall\, k, t \tag{7}$$

$$H_{ot}, H_{kMt}, A_{kM}, L_{kMt} \geq 0 \;\; \forall\, k, M, t \tag{8}$$

The household starts the year in January with some stock of cash and crops from previous harvest, which are depleted or replenished every month. The household maximizes annual net income V from the production of crops $k \in$ {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 income. V is determined by the farmgate price (USD per ton), harvest (ton), and monthly subsistence requirements for the household (ton) of crop k (p_k, Y_k, and ψ_k), daily wage for off-farm activities (w_o, USD) 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, chemicals for each k (C_k, USD) incurred through the D_k months of production periods, area planted for k under each M (A_{kM}, hectare), hired labor used for production of k under each regime M in month t (L_{kMt}, person-days) at wage w (USD per day), and the cost of mechanization service for land preparation (μ, USD/ha). Maize, cassava, yam become harvestable in August, December and August, respectively (Ngeleza et al. 2011). This objective is maximized subject to constraints (2) through (8). Constraint (2) relates the output to area and yield (y_k, ton / ha). Constraint (3) states that required monthly labor per ha under each regime M for production (L_{kMt}^*, person-days) must be supplied by either household labor or hired labor. Constraint (4) states that monthly household labor endowment is fixed at H^* (person-days), which is allocated to either production ($\Sigma_k H_{kMt}$) 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. With safetyfirst rule (5), the household produces subsistence amount of food for themselves rather than purchasing. 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 ($p_k s_{kt}$) and net income in month t (Π_t). Net income in month t is composed of any off-farm income, any sales of crops if they take place net production costs (input purchase, labor payment, payment for mechanization service), and reduction in crop stock in month t, to pay for monthly subsistence household expenditure (food and non-food items, clothes, school fees, health fees etc) (X), all in USD. Crop balance constraint (7) states that the household consumes each crop k from the stock with initial stock level at t (s_{kt}, ton), and stock should not be depleted. Finally, (8) states the non-negativity of endogenous variables.

The values of exogenous parameters are set as follows based on the relevant literature in Nigeria and converted into 2010 prices using inflation rates, LSMS dataset and other secondary statistics ($k \in$ {maize, cassava, yam}): p_k = (250, 50, 150); y_k = (2, 15, 10); C_k = (4, 5, 60); ψ_k = (0.015, 0.075, 0.075); s_{k0} = (0.15, 1, 1); D_k = (6, 8, 11); (w, w_0) = (4, 6); H^* = 50 (25 man-days per month as in Alwang, Siegel and Jorgensen (1996)) times two working-age adults); X = 200; and ω_0 = 500. The values for L_{kMt}^* are taken from the similar labor requirements in Guinea-Savannah region in Ghana estimated by Ngeleza et al. (2011). We analyze three scenarios based on the cost of mechanization service for land preparation; (1) μ = 100, (2) μ = 200, and (3) no mechanization service available, and see how such differences affect the household's net income, area cultivated, use of mechanization services and labor use. We solve the above problem using GAMS.

The main results are presented in table 2. Demand for mechanized land preparation service exists when it is made available at μ = 200 which is higher than the current fees in areas where there are currently such services. This weakly supports our hypothesis that the potential demand for mechanized land preparation service is quite high, even among small-scale staple crop growers. The net income effect is relatively small, changing from $2,523 to $2,525, where farmers simply replace manual labor with machinery for preparation of yam plots, allocating 30 more man-days (or $120 more) for non-farm income earning activities. The preparation of yam plots is the first to be mechanized because labor replacement is greatest for yam, compared to other crops.

When mechanized land preparation becomes even cheaper at μ = 100, which is closer to the current service, the farmer concentrates on relatively more profitable yam production by increasing cultivated area from 0.59 to 0.98 ha, while reducing the area cultivated for less profitable crops from 0.88 ha to 0.06 ha. As a result, the total cultivated area is reduced from 1.57 ha to 1.13 ha. Such reduction in cultivated area enables re-allocation of household labor from farming to non-farm activities, raising total net income to $2591 from $2525.

Though the model here is specifically for small-scale farmers growing maize, cassava and yam in the Guinea-Savannah zone, and also it does not consider the aspect of necessary improvement in infrastructure and service network, there are important implications. Many small-scale farmers in Nigeria may have relatively high willingness to pay for mechanized land preparation service. Realizing this potential demand for mechanization could raise household income without necessarily expanding the scale of production.

Conclusions

Agricultural mechanization is considered one of the essential factors for growing agriculture and reducing poverty among farm households. Identifying appropriate support for mechanization is crucial in many SSA countries with potentially heterogeneous demand for mechanization. The information has been lacking regarding the types of farmers who have been using mechanization, and what the level of potential demand is among non-adopters. We provide useful evidence with important implications from the case of Nigeria. First, tractor use is associated with input intensive crop production. Second, tractor use in the North is more associated with increased non-farm income earning activities, rather than expansion of cultivated area. Tractor use in the North seems to be increasing, albeit slowly, across various farm household types; while in the South, it is highly concentrated among large scale rice producers. Third, while mechanization services are not available for many small-holder farmers in Nigeria-mostly because of the shortage of machineries and private service providers, farmers may be willing to pay for the mechanized land preparation services if they are available at the prices currently offered in some locations.

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, but rather reducing the cost of land preparations. At the same time, lack of supply of mechanization may still be highly constraining for many small-holder farm households in Nigeria which grow traditional staple crops in semi-subsistence manner. Identifying the effective support for increased supply of private mechanization services is therefore likely to be critical, and such growth in supply may not be automatically induced from rising demand for it. Despite the government's goal to develop large scale commercial farmers through mechanization, a significant share of benefits from mechanization may potentially arise from increased productivity of small-holder farmers in Nigeria. Mechanization policy for many SSA countries such as Nigeria must therefore be designed taking into account its roles for small-holder farmers.

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Table 1. Major Characteristics of Each Type of Farm Households

	South						North					
Number of observations	277	81	380	79	71	41	167	42	156	391	336	30
Main-Crop[a]	*c*	*mcy*	*c*	*syc*	*a*	*rcm*	*ms*	*mg*	*ms*	*sgl*	*sgl*	*rmv*
Real wage	10	10	10	11	11	17	11	24	11	8	10	8
Population density	366	658	365	105	382	46	102	95	125	149	114	173
% Literate	0	85	84	42	69	56	8	31	97	87	5	97
Household assets	88	310	308	249	253	671	198	204	510	295	149	271
Expenditure	49	109	78	41	108	111	36	34	57	38	30	43
% with non-farm income	32	65	54	29	82	80	51	26	67	69	47	73
% owning some plots	9	10	14	10	34	39	37	21	33	23	19	3
% using irrigation	0	0	1	2	8	29	10	0	1	4	4	63
Total area	0.2	0.1	0.2	1.3	1.3	2.6	0.7	1.0	0.7	0.7	0.9	0.4
Fertilizer cost	0	0	0	0	0	60	30	0	56	27	0	55
Seed, chemical cost	0	9	2	19	33	100	15	22	26	12	3	57
% hiring harvesting labor	23	9	16	30	55	59	53	5	71	64	48	90
% with crop sales	74	81	74	91	97	93	89	88	84	85	80	93
% using animal traction	0	0	0	0	0	0	63	12	62	68	55	47
% using tractors	0	0	0	0	1	100	5	10	15	4	3	20

Source: Authors.

Note: [a]Main crops are grown by more than 50% of households in each type; *c* = cassava, *m* = maize, *r* = rice, *s* = sorghum, *l* = millet, *y* = yam, *g* = legumes, *v* = vegetables, *a* = cocoa.

Table 2. Cost of Mechanization Service μ (USD / Ha), Income and Labor Use

	μ = 100	μ = 200	No service available
Annual net income ($)	2591	2525	2523
Income – crop sales ($)	1336	1373	1373
Labor earning (hiring out) ($)	2004	1700	1579
Labor cost (hired labor) ($)	0	0	0
Mechanization cost ($)	98	119	0
Other production cost ($)	652	429	429
Family labor cost ($)	396	700	820
Total cultivated area (ha)	1.13	1.57	1.57
Maize area (ha)	0.09	0.09	0.09
% mechanized land preparation	0	0	
Revenue ($)	0	0	0
Cassava area (ha)	0.06	0.88	0.88
% mechanized land preparation	0	0	
Revenue ($)	0	618	618
Yam area (ha)	0.98	0.59	0.59
% mechanized land preparation	100	100	
Revenue ($)	1336	755	755

Source: Authors.