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THE ROLES OF AGROCLIMATIC SIMILARITY AND RETURNS ON SCALE IN THE DEMAND FOR MECHANIZATION: INSIGHTS FROM NIGERIA

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Despite economic transformations and urbanization, declining shares of the workforce employed in the agricultural sector, and gradual growth of agricultural mechanization, production costs in the agricultural sector and food prices remain high in Nigeria relative to those in some of the other developing countries. Understanding how the adoption of mechanical technologies is related to agricultural productivity is, therefore, important for countries like Nigeria.

Using farm household data from northern Nigeria as well as various spatial agroclimatic data, this study shows that the adoption of key mechanical technologies in Nigerian agriculture (animal traction, tractors, or both) has been high in areas that are more agroclimatically similar to the locations of agricultural research and development (R&D) stations, and this effect is heterogeneous, being particularly strong among relatively larger farms. Furthermore, such effects are likely to have been driven by the rise in returns-to-scale in the underlying production function caused by the adoption of these mechanical technologies. Agricultural mechanization, represented here as the switch from manual labor to animal traction and tractors, has been not only raising the average return on scale but also potentially magnifying the effects of productivity-enhancing public-sector R&D on spatial variations in agricultural productivity in countries like Nigeria.

MECHANIZATION PROGRESS IN NIGERIA

Table 1 summarizes the historical evolution of the adoption of mechanical technologies in Nigerian agriculture, especially animal traction and tractors, as well as the country's overall economic transformation and expansion of arable land over the past several decades. The adoption of mechanical technologies in agriculture has grown gradually in Nigeria, although a significant portion of it has been the growing adoption of animal traction. The increase in adoption rates of animal traction has been particularly pronounced in the North West and North East zones, where the share of area cultivated with animal traction increased from less than 10 percent in the 1980s to almost two-thirds in the period beginning in 2010 (Figure 1 shows the locations of these zones in Nigeria, as well as the current adoption rates). At the national level, the share of area with animal traction has increased from around 3 percent to about 5 percent in the 1980s and to about 32 percent in the last period depicted. Although the share of area with tractors has remained relatively stagnant since the 1980s (hovering around 10 percent), the total area cultivated with tractors is likely to have increased as well during this period, given that total arable land has increased by almost 50 percent since the 1980s (from 23 million ha to 34 million ha).

Table 1. % of area mechanized with mechanization tools

Mechanization tools	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–
GDP share (%)						
services	33	40	30	24	24	53
industry	13	27	34	43	40	25
agriculture	54	33	36	33	35	22
Arable land (million ha)	28	26	23	32	35	34
% of area mechanized						
Tractors	1[b]	5[b]	9	10	9	7
Animal traction			3–5[c]			32
Animal traction (north)			6–10			66

Source: **Takeshima H**. (2017). *The roles of agroclimatic similarity and returns to scale in demand for mechanization: Insights from Northern Nigeria.* IFPRI Discussion Paper 01692.

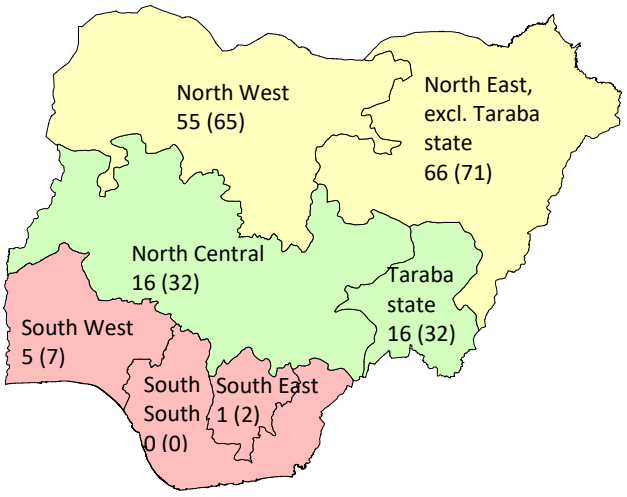

Figure 1. Region locations and adoption rates (percentages) of mechanical technologies (animal traction and tractors combined) in Nigeria (averages over 2010/2011, 2012/2013, and 2015/2016)
Source: Takeshima (2017).

Although the adoption rates of animal traction have risen in Nigeria, particularly in the North West and the North East zones, its use intensity on average is still limited. Table 2 shows the animal traction use intensity (animal-days per farm household) in northern Nigeria and in other selected countries during the periods right before each of these countries experienced significant growth in tractor use as a substitute for animal traction. Table 2 suggests that the use intensity of animal traction in Nigeria has been relatively low (less than 10 animal-days per farm) compared with that of the other countries shown, including Bangladesh and Japan, where tillage was much more intensive, using larger numbers of animals for multiple rounds of tillage in early days of the agricultural transformation. These conditions suggest that there is likely to be scope for Nigeria to further intensify its use of farm power.

Table 2. Animal traction use intensity

Country/region	Reference year(s)	Animal traction intensity (animal-days per farm household per year)
Nigeria—North West	2010–2013	6
Nigeria—North East	2010–2013	9
Bangladesh	Early 1990s	90
Japan	1950s	30
Thailand	1991	15
United States	1930s	100 (including other uses of animals)

Source: Takeshima (2017).

AGROCLIMATIC SIMILARITY WITH PLANT BREEDING LOCATIONS AND TRACTOR ADOPTIONS

In Nigeria, the public sector has led plant breeding activities since the 1960s. Most improved varieties released have been tested on experimental farms that are typically located in the head-offices of Plant Breeding (PB) Institutes, as well as several outstations that belong to each PB Institute. Specifically, during the last several decades, 6 PB Institutes have accounted for about 90 percent of all improved varieties released in the country (Figure 2 illustrates the locations of these 6 PB Institutes and their outstations).

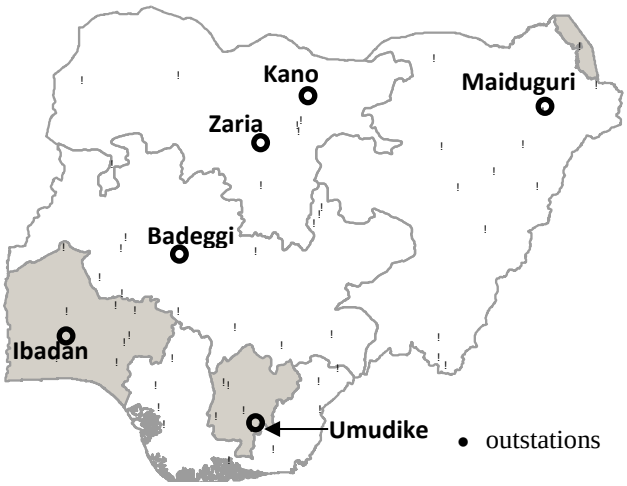

Figure 2. Locations of plant breeding in Nigeria
Source: **Takeshima H** & A Nasir. (2017). *The role of the locations of public sector varietal development activities on agricultural productivity: Evidence from northern Nigeria*. IFPRI NSSP Working Paper 42.

For the locations of each farm household in Nigeria, *Agroclimatic similarity* with these PB locations (Figure 2) can be indexed by investigating agroclimatic conditions of each location, including rainfall, temperature, soil characteristics (drainage, sodicity, salinity, texture, organic carbon contents, acidity), hydrological conditions (distance to major rivers, groundwater depth), topography (ruggedness, slope) (Takeshima 2017).

Agroclimatic Similarity, Farm Size, and Adoption of Mechanization Technologies

Table 4 shows the estimated effects of farm size, agroclimatic similarity, and their interaction on the adoption of mechanical technologies (animal traction, tractors, or both). We also show the robustness of the estimated results across various measures of agroclimatic similarity. Furthermore, we also show the results with and without the natural log transformation of farm size, as well as with and without the North Central zone as part of the sample.

Overall, the set of results in Table 4 suggests that, for a broad range of measures, both agroclimatic similarity and greater farm size, and importantly, their interactive effects, are consistently strong determinants that positively affect the adoption of mechanical technologies (animal traction, tractors, or both). It is unlikely that the strong effects of agroclimatic similarity in Table 5.1 are wrongly capturing the effects of other variables that are strongly correlated with agroclimatic similarity.

Effects of mechanization adoption on returns-to-scale

Table 3 shows the estimated effects of the adoption of mechanical technologies (animal traction, tractors, or both) on returns-to-scale, as measured through the effects on underlying production functions. Effects are shown for various measures of agroclimatic similarity for robustness-check purposes. All test specifications suggest that the input variables deemed endogenous are indeed so, and the specifications with included and excluded IVs satisfy necessary conditions for the consistency of the estimated parameters.

The findings suggest that adoption of mechanical technologies (animal traction, tractors, or both) significantly raises the return-to-scale in agricultural production at the farm household level. The estimated returns-to-scale is generally in the range of 0.5 among non-adopters, whereas it is on the order of 1.0 among the adopters. Although estimated returns-to-scale is not necessarily representative of each type of farm household, the differences in return-to-scale between these two groups are internally consistent estimators.

The same interpretations apply to the estimated coefficients (output elasticities) of each input. Although their differences are less precisely estimated, results generally suggest that the increase in returns-to-scale from the adoption of mechanical technologies largely accrues to increased output elasticities of land (generally 0.6 among

Table 4. Determinants of adopting mechanical technologies, panel fixed effects, linear probability model (elasticities)

Measure of agroclimatic similarity	Desig-nation	North West and North East (excl. Taraba State)		Northern Nigeria	
		Farm size	Ln (farm size)	Farm size	Ln (farm size)
Primary specifications (a)	*D*	.159**	.225**	.075**	.142**
	F	.097*	.139**	.085*	.132**
	D × *F*	.078*	.087*	.071*	.090**
Robustness check (b) using the maximum similarity among all breeding institutes	*F*	.044†	.099**	.043†	.086**
	D × *F*	.027	.047*	.030†	.045**
Robustness check (c) using the average similarity weighted by the number of developed varieties released	*F*	.093**	.144**	.055†	.113**
	D × *F*	.072*	.091**	.046	.072**
Robustness check (d) using all outstations of breeding institutes	*F*	.112*	.164**	.010	.084*
	D × *F*	.092*	.111**	.002	.044

Source: Author's estimations based on LSMS (various years).
Note: Statistical significance: † 10 percent, * 5 percent, ** 1 percent.
D = agroclimatic similarity; *F* = farm size (size of farm purchased outright or distributed by the village)

Table 3. Effects of adoption of mechanical technologies on production functions and returns on scale

Variable/category	Agroclimatic similarity index							
	(a)		(b)		(c)		(d)	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Production function coefficients								
Land	.649**	.019	.599**	.177	.657**	.004	.642**	-.034
Labor	.327	.055	.359	.067	.317	.053	.324	.062
Livestock	.000	.025	.008	.018	.001	.025	.001	.026
Agricultural equipment	.067	.123**	.042	.118**	.067	.124**	.067	.124**
Other expenditures for purchased inputs	.160**	.245**	.182**	.281**	.165**	.245**	.161**	.248**
Agroclimatic similarity	.150*	.292**	.173*	.090	.001**	.002**	.152*	.299**
Returns-to-scale	1.203**	.469*	1.157**	.662	1.208**	.451*	1.195**	.426*
No. of observations	1,662	1,718	1,662	1,718	1,662	1,718	1,662	1,718
p-value								
H_0: Input variables exogenous	.000	.000	.000	.000	.000	.000	.000	.000
H_0: Model is not overidentified	.317	.378.	.394	.131	.332	.427	.328	.379
H_0: Model suffers from weak identification	.002	.082	.002	.005	.003	.080	.002	.073
H_0: Variables are jointly insignificant	.000	.000	.000	.000	.000	.000	.000	.000

Source: Authors' estimations based on LSMS (various years).
Note: Statistical significance: † 10 percent, * 5 percent, ** 1 percent.

adopters as opposed to near 0 among nonadopters). These findings are consistent with the hypothesis that the positive interaction effects of agroclimatic similarity with farm size on adoption (Table 4) are partly driven by the effects on returns-to-scale shown in Table 3.

CONCLUSIONS

There has been a knowledge gap regarding how agricultural mechanization in countries like Nigeria has both been induced by and affected agricultural productivity. In particular, despite the important role the public sector has historically played in raising overall productivity and improving technologies through R&D in plant breeding, little knowledge existed in Nigeria about how this role might have affected the adoption of mechanical technologies. Furthermore, despite the general agreement that agricultural mechanization is associated with a greater returns-to-scale in agriculture, little has been known about whether the former causes the latter, rather than the other way around, limiting our understanding of how returns-to-scale evolves during the agricultural transformation process.

This paper partly fills this knowledge gap, using farm household data from Nigeria as well as various spatial agroclimatic data. The results suggest that the adoption of key agricultural mechanization technologies in Nigeria (animal traction, tractors, or both) has been higher in areas with higher agroclimatic similarity with agricultural R&D stations, and this effect is heterogeneous, being particularly strong among relatively larger farms. Furthermore, these effects are likely to have been driven by the fact that the adoption of these mechanical technologies has been directly causing a rise in returns-to-scale in the underlying production function. Agricultural mechanization, represented here as the switch from manual labor to animal traction and tractors, has been not only raising the average returns-to-scale but also potentially magnifying the effects of productivity-enhancing public-sector R&D on spatial variations in agricultural productivity in countries like Nigeria.

In Nigeria, both intensification-driven demand and scale effects–induced demand are jointly important determinants of the adoption of mechanical technologies. Even intermediate mechanization technologies such as animal traction have important scale effects, suggesting that the agricultural sector in Nigeria has undergone significant changes in the comparative advantages among farms with different scales. In Nigeria, overall agricultural production technologies, including varietal technologies that critically affect the returns on farm power use and are often generated through public-sector agricultural R&D, are still inferior and have been holding back further mechanization growth at the intensive margins, including the substitution of tractors for animal traction at a wider scale.

Policy recommendations

The results in this report have important policy recommendations. Achieving inclusive transformation of agriculture remains crucial in countries like Nigeria, where the agricultural sector faces dual-challenges of rising labor costs and persistent smallholder dominance (despite the emergence of larger farmers in certain pockets). Such transformation is expected to require increased use of agricultural machinery like tractors by smallholders. If not, farmers will either simply leave the agricultural sector, raising the reliance on food import (which is typically associated with higher food price) and loss of foreign exchange, or remain in agriculture that is less productive.

Many constraints still need to be removed, including technological, institutional factors. For institutional factors, the government should continue promoting custom-hiring service rather than tractor ownership as the medium for smallholders' access to machines.

For technological constraints, the government should recognize the complementarity between high-yielding varieties and mechanization for smallholders. Specifically, the government needs to support the diffusion of high-yielding varieties. One way to do so may be to expand the plant-breeding locations, especially in areas that are distinct from existing plant-breeding locations in terms of agroclimatic conditions. Doing so will particularly raise demand for tractors among smallholders located in areas that share similar agroclimatic conditions with those new plant-breeding locations, for which current yield potential is low, and demand is insignificant. Complementarity with yield-enhancing biological technologies is also manifested in lower adoption of animal traction at intensive margins.

It is also particularly important for large countries like Nigeria, to better understand the agroecological diversity across the country, through R&D to develop more precise soil map, for example. The findings in this report suggest that, the potential demand for mechanization among smallholders can vary considerably across locations, but understanding the exact spatial variations of such demand requires more significant investments in data-collection, climate monitoring, hydrological research, and soil sampling, among others. While the data used in this report capture some of such variations, much more needs to be done to improve the accuracy.

For mechanization growth in Nigeria, it is important to coordinate the investments into high-yielding technologies, with measures to stimulate land market (either rental or sales), as well as land clearing. This is because the effects of high-yielding technologies on machine adoptions seem magnified if the farm is larger. Strengthening land tenure system, which provides greater security to some farm owners to rent out land to other farms, stimulates the land rental market. This helps those who want to expand operations using mechanical technologies, while also compensating landowners through rental revenues. Land clearing, including de-stumping, is also an important process of expanding farm area that mechanical technologies, especially tractors, can be more readily applied to. The finding of this report suggests that targeting these efforts in areas with higher yield potentials (given the agroclimatic conditions, and their similarity with existing plant-breeding locations) is likely to have the greatest effect in making mechanization feasible, which is also important for service providers to emerge, overcoming various market failures (due to indivisibility, limited mobility, and upfront investment requirements associated with machines).

Lastly, while not directly addressed here, general policy-recommendations discussed in the literature are also relevant, and likely to be complementary to the demand-side factors discussed in this report. These include the support to improve knowledge on machine operations, R&D on machine designs, reducing import restrictions (tariffs on imported machines and parts), and strengthening rural finance to increase credit-provisions for machine purchase.

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