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Overview of the Evolution of Agricultural Mechanization in Nigeria

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Abstract

Demand for mechanization in Nigeria is growing in a fairly consistent way predicted by economic theories. The farming system has intensified and the use of animal traction has grown at a substantial rate. Demand side factors considerably explain the low adoptions of tractors in Nigeria. Where demand is sufficient for tractors, the private sector has emerged over time as a more efficient provider of hiring services (particularly farmer-to-farmer services) than the public sector. Conditions are consistent with the hypotheses that, because of generally low support for the agricultural sector in Nigeria in the past few decades, agricultural mechanization (tractor use in particular) has remained low despite the declining share of the workforce engaged in the agricultural sector. Agricultural transformation in the form of a declining agricultural labor force has happened partly through the growth in the oil industry since the 1970s. Instead of inducing further exit from farming, tractor adoptions in Nigeria might have helped those who have remained in farming to start expanding their production scale. A knowledge gap, however, still remains regarding the dominance of large tractors and the potential effects of tractor adoptions on smallholders who have yet to adopt them.

Keywords: agricultural mechanization, animal tractions, tractors, Nigeria

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1 Historical background of mechanization evolution in Nigeria

The mechanization level in Nigeria has been generally low till now. There are, nevertheless, a few relatively distinct phases in which mechanization had been at significantly different levels in scale. They are (1) pre-1973 oil shock; (2) expanded government support for large-scale farming (1973-1986); (3) reduced government support and the growth of intermediate mechanization (draft animals in the north, small-scale motorized-pumps); and (4) recent developments since 2010.[1] Table 1 summarizes the economic structure and simple indicators of mechanization in Nigeria in the past several decades. Given the diverse environment in Nigeria, this chapter often focuses on each of the six geopolitical zones (Figure 1).[2]

Table 1. Economic structure, arable land, and level of tractor and animal traction uses over time in Nigeria

Variables	1960s	1970s	1980s	1990s	2000s	2010s[d]
GDP share (%) – Service	33	40	30	24	24	53
GDP share (%) – Industry	13	27	34	43	40	25
GDP share (%) – 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[b]	10	9	7
Animal tractions			3 ~ 4[c]			25
Animal tractions (North[a])			6 ~ 10			58

Source: Share of mechanized area by tractors - Dunham (1980), Ugwuishiwu & Onwualu. (2009), Azogu (2009), and section 2 of this chapter; share of mechanized area by animal tractions - Dunham (1980), Phillips, Abalu, and Ingawa (1986), Jansen (1993), and section 2 of this chapter. GDP shares – Sackey et al. (2012) for 1960s and 1970s, World Bank (2016) for the rest; Arable land – FAO (2016).

Note: GDP = gross domestic product.

[a]North = North West and North East zone.

[b]Extrapolated by authors using the number of tractors in use and arable land from FAO (2016) and the figures for 1980s by Dunham (1980).

[c]The proportions in 2010s are applied, using the fact that animal traction use in the South has been almost nonexistent.

[d]The figures in 2010s are likely to differ from the previous years due to rebasing conducted recently.

[1] In this paper, "animal traction" is defined as the use of draft force generated by large animals and used on the plot, mainly for land preparation. In Nigeria, typically oxen, cattle, and camels are used as major draft animals.

[2] While Taraba state is part of North East (NE), we combine it with North Central (NC) given their similarity in agroecology.

(1) Pre-1973

Prior to the growth of the oil industry that started in 1973, the agricultural sector had accounted for more than 50% of Gross Domestic Product (GDP), and employed 75% of the population in Nigeria (Fogg 1965). While population density was only 30% of that today, various parts of the country had been experiencing sufficient growths of population density to trigger intensification of farming systems (Netting 1993; Turner et al. 1993). However, there had been no Ministry of Agriculture until 1966 and little coordination had existed among research institutes (Roseboom et al. 1994). There had been little focus on food crops and relatively more focus on import substitution and development of export crops such as cotton, cocoa, oil palm, and groundnuts (Olayide 1972; Abalu & D'Silva 1980; Shimada 1999). Most of these export crops had been produced by subsistence, smallholder farmers (Fogg 1965). For crops such as groundnuts, the marketing boards had the monopsony power and often suppressed the buying price, providing farmers with little economic incentive to modernize production (Whetham 1966). While crops like rice had already been introduced to a few places, such as Abakaliki area in South East (SE) in the 1940s, production had been largely done by human labor, and milling had remained traditional (Welsch 1965).

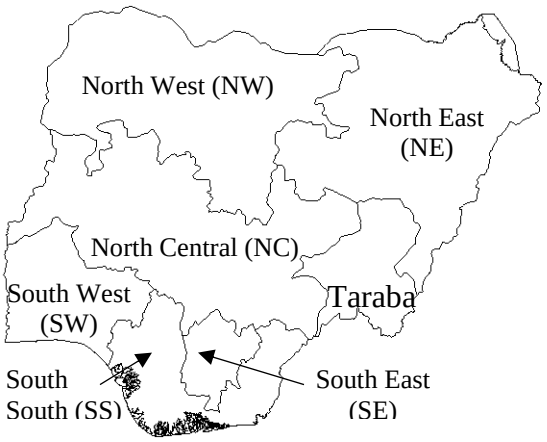


Figure 1. Geopolitical zones in Nigeria
Source: Authors.

During this period, there had still been some interest by the government in promoting agricultural mechanization. Between 1955 and 1960, a large number of power tillers (Akitu, Yanmar, Mitsubishi, Satoh, Kubota, Hako and Agria) had been imported from Japan for study at various research centers to determine their suitability to local conditions (Ademiluyi & Oladele 2008). In 1958, the first Tractor Hiring Units (THUs) were established in the former western region (now Oyo, Ondo, Ogun, and Bendel, as well as Edo and Delta States) (Akinola 1987). However, the overall level of mechanization had been quite low, even when measured in terms of the use of intermediate tools like draft animals.

(2) 1973–late 1980s: Era of expanded government support for large-scale farming

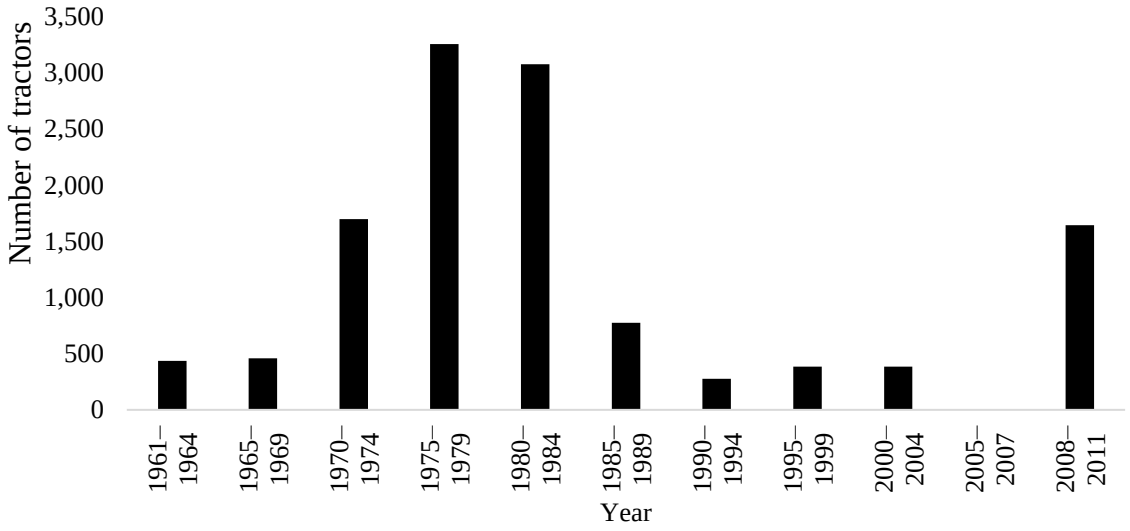
In the aftermath of the Biafran War (1967-1970) and the nationwide droughts (1972-74), food insecurity in Nigeria deepened (Shimada 1999; Mortimore 1993). At the same time, the oil shocks in 1973 increased Nigeria's foreign reserves. In addition, the demand for certain crops such as wheat and rice, which had been imported in large quantities during the food security crisis, had started rising among the larger segment of the population (Liverpool-Tasie & Takeshima 2013).

Faced with these conditions, the Nigerian government launched several agricultural policy initiatives on a substantial scale (Abalu & D'Silva 1980). They included the National Accelerated Food Production Program (1974), Agricultural Development Project (1975), Operation Feed the Nation (1976), and the establishment of the Agricultural Credit Guarantee Scheme (1977) and Nigeria Agricultural Cooperative and Rural Development Bank (1978). Many of these programs aimed at achieving self-sufficiency in major staple crops (Ezeh 1988). Construction of various large irrigation schemes started in the mid-1970s under the National

Accelerated Food Production Project (NAFPP), with River-Basin Development Authorities set up in 11 locations by 1976. Subsidies had also extended to land clearing, among other initiatives, to facilitate large-scale mechanized farming (Akpokodje et al. 2001 p33). In 1978, a Land Use Decree was enacted, partly to facilitate the large-scale farming, by taking away land from traditional chiefs and communities and giving them to the government. Lastly, the oil boom also led to increased road construction in the 1970s and the 1980s (Goldman & Smith 1995).[3]

The Nigerian government had focused on developing mechanized large-scale agricultural production (Abalu & D'Silva 1980), as wages had been reportedly rising in the mid-1970s (Okolie 1995). This was manifested in the increased number of four-wheel tractors imported. Between 1975 and 1984, 3,000 tractors had been imported into the country annually (Figure 2), which were substantially more than before and after this period, although it was still fairly small given the size of arable land in Nigeria (30 million hectares [ha]). As is described in section 3, substantial subsidies had been provided for tractor import. An increasing number of government-run Tractor Hiring Stations had been established, although with questionable efficiency, with the aim of providing mechanization services to smallholders. In addition, a few manufacturers or assemblers of tractors for certain brands were established with the aim of stimulating domestic tractor production.

Figure 2. Estimated number of tractors imported into Nigeria annually (average by period)



Source: Takeshima et al. (2014).

Such relatively substantial support had lasted until the mid-1980s, when the Structural Adjustment Program (SAP) forced the government to reduce support. While the information is quite scarce regarding the extent of mechanization during this period, it is expected that the growth of tractor use had occurred to a limited extent.

(3) Late 1980s–2010: Reduced government support and the growth of intermediate mechanization

[3]As in Table 1, the contribution of agriculture to GDP still declined in the 1970s. This was because the expansion in the oil industry was much greater.

Under the SAP that started in the late 1980s, various aforementioned programs that started in the 1970s were scaled down or discontinued. The share of agricultural spending among total government spending had declined from 8% for 1981-1985 to 4% for 1986-1989 and remained low throughout the 1990s (Garba 2000).

At the same time, the SAP led to significant devaluations of Nigerian currency and raised the prices of imported goods, including tractors.[4] The nominal costs of land preparation had also increased four-fold between 1985 and 1988 (Thomas-Emeagwali and Lasisi 1988). While this devaluation had also raised the prices of imported food staples like rice and wheat and somewhat encouraged the expansion of their domestic production (Kimmage 1991), such production growths were likely to have been through more intensive uses of non-tradable inputs such as labor and land rather than tractors. These conditions did not induce the growth of domestic manufacturing of tractors either, because the SAP had broadly negative effects on the capital industries in Nigeria (Akinlo 1996).[5]

In the broad scale, the agricultural sector has remained largely stagnant during this period. Yields of major crops such as rice, maize, and sorghum have remained low without noticeable growth. Even after the transition from military regimes to democratic systems in 1999, government spending in the agricultural sector had remained 5% or less of its total spending (Mogues et al. 2012). The support for large-scale irrigation infrastructure had declined compared to the 1980s, with very few new dams being constructed since the 1990s (Takeshima et al. 2016). Fertilizer subsidies (and recently seed subsidies) have continued accounting for substantial shares of agricultural capital spending (Liverpool-Tasie & Takeshima 2013). Although support for agricultural research and development (R&D) had increased slightly during the 2000s (IFPRI 2013), overall support had remained low particularly for genetic improvements of certain crops (Takeshima & Maji 2016; Flaherty et al. 2010). Despite the growth in the primary and secondary school enrollments in Nigeria (World Bank 2016), the quality of education did not catch up, and many youths in northern Nigeria have remained illiterate despite their years of schooling (Antoninis 2014). This illiteracy level is potentially associated with relatively lower real farm wages in the North.

These factors are likely to have led to the general stagnation of tractor adoptions at low levels during this period (Table 1). While the actual area cultivated by tractors is likely to have increased because the total cultivated area increased considerably during this period, significant substitutions of machine power for human and animal power had not occurred.

There have been, however, some indications of the growing adoptions of certain intermediate mechanization technologies. Particularly, this phase has witnessed the growth of animal tractions (particularly in northern Nigeria) and to some extent the growth of mechanized irrigation through motorized irrigation pumps. The share of area cultivated by draft animals in northern Nigeria had increased from 6–10% in the 1980s to almost 60% in 2010 (Table 1). This often reflected the switch from nomadic, transhumant pastoralism and agro-pastoralism to crop-livestock integration (Okoruwa et al. 1996; Okike et al. 2004), which was earlier considered difficult in Nigeria in the 1960s (Whetham 1966). While the use of motorized pumps had not expanded to the level of use in Asia, it had expanded at least noticeably in a certain locality in

[4]For example, the nominal tractor price went up 8-fold from 50,000 Naira in 1986 to 400,000 Naira in mid-1992 (Okolie 1995 p207).

[5]The growth of industry in the 1990s shown in Table 1 was largely in food and beverages, textiles and clothing, and other consumer products, rather than capital intensive industries (Akinlo 1996; Sala-i-Martin & Subramanian 2013).

northern Nigeria in response to the overall population growth and the development of improved maize varieties which had replaced groundnuts and cotton (Goldman & Smith 1995; Smith et al. 1994). The experiences in the three rounds of National Fadama Development Projects that started in 1993 also indicated that, where irrigation is feasible, there is potentially significant demand for motorized pumps that can both reduce rainfall uncertainty (Takeshima & Yamauchi 2012) and increase crop production (Nkonya et al. 2010).

(4) Recent developments: 2010–

While there has been little indication that the level of mechanization has changed significantly in the 2010s, there have been further policy shifts during this period. As is described in section 3, the government has increasingly shifted from direct distribution of subsidized tractors to individual beneficiaries to facilitations of enterprise-based service providers. The reduced number of subsidized tractors distributed to individual beneficiaries is, however, likely to have been largely balanced by more competitive service providers, who have been obtaining tractors directly from the market and have been using them on their own farms or other farms in a more cost-efficient manner.

Recently, an increasing number of studies have shed light on mechanization adoption patterns in Nigeria, although it is unclear how their conditions differ from those in the pre-2010 period. As is described in section 2, mechanization adoption levels vary across crops, regions, and types of farm households. Furthermore, the adoption of mechanization, particularly animal tractions and tractors, appears to be induced by complementary technologies, including improved varieties that have been selected through adaptive breeding by the national agricultural research institutes. Takeshima (2017a) finds that mechanization adoption rates are higher in areas that share similar agroclimatic conditions with the areas where major plant breeding is conducted and thus have high spillover potentials.

The significant devaluation of Naira in 2016 from around 1 US$ = 199 Naira to about 320 Naira, due partly to declining oil revenues, has led to similar situation experienced in the 1980s; the prices of imported tractors increased considerably, reducing the number of tractors acquired by individual farmers or tractor associations.

2 Demand side analysis[6]

Nigeria has a diverse production environment, including in its land-to-labor ratios and farm power uses (Table 2). NC plus Taraba state is the most endowed with agricultural areas per capita (both cropped areas and pastures). The intensity of animal tractions is higher in NE (excluding Taraba) and North West (NW) than other zones, although the land-to-labor ratio is lower in NW. South zones are generally less endowed with farm land per capita, and the use of animal traction is almost nonexistent. As is shown below, these patterns are correlated with the adoptions of tractors. However, the farm power uses, particularly animal tractions, may be still relatively lower than in Asia. For example, in Japan, animal power use was often 150 hours / year / ha (30 days per farm household if they were used 5 hours / day) in the 1950s immediately

[6]The remaining sections of this chapter rely primarily on the 1st and 2nd round of the Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) for Nigeria jointly collected by the National Bureau of Statistics of Nigeria and the World Bank, as well as on various spatial variables. The 1st and 2nd round of LSMS-ISA covered the main production seasons in 2010 and 2012, respectively. The two rounds of the LSMS surveys used contain 10,000 observations in total, among which approximately 6,000 observations are farm households.

before the widespread substitutions with power tillers (Ministry of Agriculture, Forestry and Fisheries, Japan).

Table 2. Farmland endowments, farm sizes, labor and animal uses by regions

Regions	Agricultural area per capita (ha per capita)[a]		Farm size (ha)		Average manual farm power uses (days, per farm household, per year)	
	Area divided by all households	Area divided by farm households	Average	Median	Labor (family + hired)	Animal tractions
NW	0.41	0.46	0.8	0.5	227	6
NE excluding Taraba	0.68	0.74	2.0	1.2	302	9
NC + Taraba	0.73	0.86	1.5	0.8	493	1
South	0.14	0.21	1.0	0.2	380	0

Source: Authors' calculations using Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) 2010 and 2012.

Note: NC = North Central; NE = North East; NW = North West.

[a]Agricultural area per capita is calculated as the sum of cropped areas and pastures (Ramankutty et al. 2008), and population is obtained from the Nigeria 2006 Population Census (Nigeria, National Population Commission 2010).

2.1 Current machinery use / ownership by farm size

Currently 4% and 24% of farm households in Nigeria use tractors and animal tractions, respectively, covering 7% and 25% of cultivated areas (Table 3 and

Table 4). These shares are higher in the NC and NE and moderate in the South West (SW) for tractors. Animal tractions are used by more than 50% of farm households in the NW and NE, while they are almost never used in the South. The use of draft animals is largely limited in Southern Nigeria due to Trypanosomiasis carried by Tse-Tse flies that are prevalent (Alsan 2015). Southern Nigeria is also characterized by root crops and tree crops cultivated on relatively heavy soils and hilly upland, compared to northern Nigeria, where more cereal crops are cultivated on relatively lighter soils and more flat land. This may partly explain the greater use of animal traction in northern Nigeria than in Southern Nigeria.

Table 3. Percentage of farmers using tractors or animal traction in 2010 and 2012 rainy seasons in Nigeria

Region	Share (%) of farm households using tractors or animal traction				
	Tractors	Animal traction			No tractor / Animal traction
		Total	Owned animal	Rented animal only	
Total	**4**	**24**	**14**	**10**	**72**
North West	2	55	30	25	44
North East excluding Taraba	6	63	42	21	32
North Central + Taraba	10	7	4	3	84
South East	1	0	0	0	99
South South	0	0	0	0	100
South West	5	0	0	0	95

Source: Authors' calculations based on Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) 2010 and 2012.

Table 4. Percentage of areas using tractors or animal traction in 2010 and 2012 rainy seasons in Nigeria[a]

Region	Share (%) of farm households using tractors or animal traction				
	Tractors	Animal traction			No tractor / Animal traction
		Total	Owned animal	Rented animal only	
Total	**7**	**25**	**18**	**8**	**68**
North West	1	68	46	23	31
North East excluding Taraba	5	61	44	17	36
North Central + Taraba	19	9	6	3	72
South East	1	0	0	0	99
South South	0	0	0	0	100
South West	4	0	0	0	96

Source: Authors' calculations based on Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) 2010 and 2012.

[a]Because of rounding, figures may not always add up to 100.

Nigeria is largely dominated by smallholder farmers, with the median farm size of 0.5 ha, and less than 10% of farm households cultivate 3 ha or more (Table 5). The adoption rates of tractors and animal tractions are positively correlated with the farm size, although the tractor adoption rates remain relatively low even among those cultivating 3 ha or more.

Table 5. Farm size distributions in Nigeria and corresponding mechanization level

Farm size (ha)	% of farm households[a]	% of farm households using tractors	% of farm households using animal tractions
0–0.09	16	1	8
0.1–0.49	34	2	22
0.5–0.99	21	4	39
1.0–1.49	11	4	41
1.5–2.99	11	9	43
3.0–	8	10	47

Source: Authors.

Note: ha = hectare.

[a]Because of rounding, figures may not always add up to 100.

The information is limited regarding the farm size dynamics in Nigeria and whether farm expansion is an important motivation for mechanization. While the share of the agricultural population has declined over time, the absolute agricultural population has remained high (partly due to high population growth) and the average farm size has remained small in Nigeria. Therefore, a substantial farm expansion or shift in farm size distribution has not been observed in Nigeria.

There is no information, to the authors' knowledge, on the types of all tractors used in Nigeria. However, various sources of information suggest that most tractors used in the country are four-wheel tractors, with the horsepower ranging between 50 and 75, while the uses of two-wheel tractors, or lower horsepower four-wheel tractors, are still limited (Takeshima et al. 2015; World Bank 2014).[7]

[7] There may be close to 500–1,000 functional power tillers in the country (Takeshima et al. 2014), considerably lower than the number of four-wheel tractors, which is around 30,000 (FAO 2016).

2.2 Agro-ecological conditions / cropping systems / farm household typologies

Tractor uses are particularly correlated with rice, while tractor uses on other crops are limited (Table 6). Tractors are used in as much as 30% of rice areas in Nigeria, although the margins of errors are large because of small samples. Importantly, most crops which are widely grown in Nigeria (maize, sorghum, millet, root crops) are "plough-negative" (Alesina et al. 2013). Rice is the only "plough-positive" crop widely grown in Nigeria, because the production of the other major "plough-positive" crop, wheat, is minimal due to high temperature.

Table 6. Estimated areas and area shares of tractor uses in Nigeria

Crops	Tractor cultivated area (1,000 ha)	Share (%) of cropped area with tractor use
Rice	410–790	31 [21, 41]
Maize	140–240	6 [4, 8]
Sorghum	70–190	5 [3, 7]
Millet	20–50	2 [1, 3]
Cowpea	50–90	4 [3, 5]
Ground nuts	10–60	3 [1, 5]
Cassava	50–120	3 [2, 4]
Yam	10–70	2 [1, 3]
Vegetables	0–10	1 [0, 2]

Source: Authors' calculations as the averages from LSMS waves 1 and 2.
Note: ha = hectare. Due to the small sample size, we combine two waves of LSMS surveys and took the average from two years.

2.2.1 Associations with farm household typology

Mechanization is closely related to distinct farming systems in both northern Nigeria and southern Nigeria (Takeshima et al. 2013b; Takeshima 2016) (Table 7). In the South, a higher share of tractor use is found among medium-scale, 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, a higher share of tractor use is found among mechanized cereals growers who have higher incomes and more assets, operate in remote areas facing higher real wages for land preparation, and use inputs more intensively.

Patterns of mechanization still differ somewhat between the North and the South. In the North, mechanization, including tractor use, seems to lead to intensive production without much effect on area expansion. Some tractor renters are located remotely from the market and grow relatively subsistence staple crops like maize, sorghum, millet, and legumes. Input intensity is driven rather by the use of irrigation for more commercial crops like rice and vegetables. Correlation between tractor use and either crop sales or the intensity of inputs used is somewhat weaker in the North compared to the South. 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, due to the absence of animal traction, tractor use is more defining of the level of mechanization. In addition, farm size is generally smaller than in the North, and the farm size of tractor users appears relatively larger than nonusers. The intensity of input use among tractor-using types also is 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 such as rice.

Table 7. Major characteristics of each type of farm household in Nigeria

	South						North					
Number of observations	274	275	233	61	63	29	157	79	362	148	347	29
Main-Crop[a]	*c*	*mcy*	*c*	*syc*	*a*	*r*	*ms*	*msg*	*sgl*	*m*	*sgl*	*rv*
Real wage	9	10	10	11	11	17	11	17	10	10	8	8
Population density	366	473	315	105	335	44	92	91	114	129	155	173
% literate	3	81	82	31	73	59	8	75	10	94	85	72
Household assets	91	292	283	260	333	763	184	437	174	478	257	343
Expenditure	46	85	69	42	118	112	35	53	32	53	36	57
% with nonfarm income	33	58	52	25	84	90	51	52	44	66	71	90
% owning some plots	10	12	14	8	37	48	36	41	20	25	23	3
% using irrigation	0	1	1	2	10	41	9	0	3	5	3	86
Total area	0.2	0.1	0.3	1.5	1.3	2.6	0.8	1.1	0.9	0.7	0.7	0.5
Fertilizer cost	0	0	0	0	0	93	26	5	0	60	27	67
Seed, chemical cost	0	4	0	33	34	87	14	26	4	27	11	39
% hiring harvesting labor	23	15	16	34	57	79	50	14	48	79	68	93
% with crop sales	70	80	56	95	100	90	62	75	59	68	56	62
% using animal traction	0	0	0	0	0	0	58	4	56	69	74	48
% using tractors	1	3	0	5	2	93	4	4	4	14	5	17

Source: Takeshima et al. (2013a).

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.

2.2.2 Agricultural wages

Reliable information on the trend of representative wages in Nigeria is scarce. Continued growth of the nonfarm sector and urbanization have been considered factors that had provided upward pressures on rural farm wages. The rural population growth rate has been relatively modest at 1% / year, considerably lower than the urban population growth rate of 4.4% / year (World Bank 2016). Nominal farm wages, which often stand around US$4–6 / day (Takeshima et al. 2013b) are higher than the nominal wages in Asia where the daily agricultural wages were often US$1–2 / day (in 2010 US$) before the 2000s (Barker et al. 1985; Nepal chapter) when the tractor adoptions started growing.

However, real rural wages in Nigeria, when measured based on the local purchase price of kilograms of cereals, are around 4 (in kg of local rice grain at local purchase price) in northern Nigeria, and 6 in Southern Nigeria (Table 8. Real male wages per day in Nigeria for land clearing and land preparation (in kg of local rice grain at local purchase price)

Geo-political zones	Sector	
	Urban	Rural
NW	4.0	3.5
NE excluding Taraba	4.5	4.0
NC + Taraba	6.5	3.5
SE	10.5	7.0
SS	9.0	7.0
SW	6.0	5.0

Source: Authors' calculations as median values from Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) 2010 and 2012.

Note: NC = North Central; NE = North East; NW = North West; SE = South East; SS = South South; SW = South West.

). The figures in northern Nigeria, where most tractor use is found, are still lower than those in Asia when the mechanization level had started rising (6 in rural Bangladesh in 2001 (Zhang et al. 2014), and 8 in 1995 in Nepal (Takeshima 2017b). This is because of the generally high food price in Nigeria (for example, the farmgate price of rice in Nigeria is almost double that of Thailand (Gyimah-Brempong et al. 2016)). The current real farm wages in Nigeria, on average, may still be somewhat too low to induce wider scale adoptions of tractors.

Table 8. Real male wages per day in Nigeria for land clearing and land preparation (in kg of local rice grain at local purchase price)

Geo-political zones	Sector	
	Urban	Rural
NW	4.0	3.5
NE excluding Taraba	4.5	4.0
NC + Taraba	6.5	3.5
SE	10.5	7.0
SS	9.0	7.0
SW	6.0	5.0

Source: Authors' calculations as median values from Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) 2010 and 2012.
Note: NC = North Central; NE = North East; NW = North West; SE = South East; SS = South South; SW = South West.

2.3 Determinants of tractor uses

Table 9 summarizes the key determinants of the area cultivated by tractors in Nigeria (technical details are provided in Takeshima 2015). The figures shown are marginal effects on the probability of using tractors, and the areas cultivated by tractors, measured at the mean values of each variable.

Table 9. Determinants of the area cultivated by tractors (pseudo-panel double hurdle model; marginal effects evaluated at the mean of observations)

	Double hurdle model	
Dependent variable	**Probability of using tractor**	**Area cultivated by tractors (ha)**
Model	**Probit**	**Truncated regression**
Ln (cultivable land per capita)	.007***	-.011
Average area (ha) of owned or distributed land per plot	-.000	.153***
Number of owned or distributed plots	.002	.012
Household size	.001	.024
# of working-age household members (no education, M)	-.004*	-.078
Primary education, M	.002	.018
Secondary education or above, M	-.001	.021
Koranic education, M	-.003	-.162
Any other education, M	-.019	.398*
# of working-age household members (no education, F)	-.002	-.041
Primary education, F	.001	-.088
Secondary education or above, F	.003**	-.099**
Koranic education, F	.002	.009
Any other education, F	-.006	-.350
Ln (real district average farm wage)	.014	-.129
Ln (real asset value)	.003***	.023
Own draft animals (yes = 1, no = 0)	.002	-.246
Ln (real values of draft animal)	-.000	.072*
Real price of one kilogram of fertilizer (average of Urea and NPK)	.0007	-.007**
Soil with high workability (1 = workable, 0 = otherwise)	.014***	.770**
Bulk density of the soil (tons per m^3 of soil)	.041	-1.115
Clay contents of the soil (clay content (<2 micrometer) in %)	-.001**	-.022*
Distance to the nearest town with population of 20,000 (hours)	.001	-.094*

Euclidean distance to the nearest dam (geographical minute)	-.006*	-.333**
Euclidean distance to the nearest river (geographical minute)	-.183	-3.832
Ln (sample maximum owned and distributed land within district, hectare)	.003**	
Time dummy (year 2012 = 1)	Included	Included
Sector dummy (rural = 1, urban = 0)	Included	Included
Correlated random effects components	Included	Included
Zonal dummies	Included	Included
Constant	Included	Included
σ		4.292***
Number of observations	5241	223

Source: Takeshima (2015b).
Note: Significance: *** 1 percent, ** 5 percent, * 10 percent.
M = male, F = female; Ln =natural log; ha = hectare; NPK = Nitrogen, Phosphate, and potassium.

Results are generally intuitive. Doubling of agricultural land per capita raises the likelihood of tractor adoptions by 0.7 percentage points. A greater land endowment relative to labor induces the use of tractors. A greater number of non-educated male working-age household members reduces the likelihood of tractor service adoption. Conversely, a greater number of working-age female members with at least a secondary education raises the adoption of tractor services. These results are consistent with the hypothesis that human capital formation induces the substitution of machinery for land-preparation labor. Once human capital is controlled, farm labor wages in the area do not seem to affect tractor adoption, possibly indicating that it is the labor costs of household members that may induce substitution with tractors.

Doubling real asset values raises the adoption possibility by 0.2 percentage points, possibly because of the reduced risk aversions toward tractor services. Tractor service adoption is higher on more workable soil and soil with less clay content, possibly because of lower plowing cost. Adoption is also higher in areas closer to the nearest dam, possibly because of better access to formal irrigation facilities where intensive production, including mechanized plowing, can have high returns.

Upon the adoption of tractor services, the areas cultivated by tractors depend largely on the average plot sizes and soil workability. A positive effect of the higher bulk density of soil may reflect the use of higher horsepower tractors (as indicated in Takeshima et al. 2014) that are more appropriate for cultivating larger areas. The number of highly-educated, female, working-age household members has negative effects on tractor use intensity, though it has positive effects on tractor adoption. This reflects the general orientation of such households to be engaged in farming to a lesser extent. However, the number of male, working-age household members with any other types of education has a positive effect, indicating somewhat complicated effects of human capital.

Greater draft animal assets positively affect tractor use intensity. Greater draft animal assets indicate possibly greater demand for it, which can be substituted by tractors. An increase in real fertilizer price reduces the extent of tractor adoption, potentially indicating that tractor and fertilizer may be gross complements (possibly because of the synergy between deeper tillage and soil nutrient absorption). Soil workability, lower clay contents, and proximity to dams also induce greater tractor use intensity.

Importantly, doubling the size of largest owned and distributed land within the local government area (LGA) in the sample raises the possibility of tractor service adoption by 0.2 percentage points. This indicates that the supply of tractor service is somewhat constrained by the scarcity of large farm households that are likely to have an incentive to invest in tractors and serve nearby farmers.

2.4 Demand for wider-scale adoptions of tractors in Nigeria

Since tractor use growth in Nigeria has been stagnating for a few decades, it is generally difficult to identify its primary drivers. However, certain factors are associated with greater smallholder mechanization demand.

The demand for mechanization in land preparation has grown to a sufficient level in various pockets within Nigeria, potentially warranting the development of a hiring market for smallholders as customers. The demand for tractor adoptions are higher in NC, NE, and SW, than other zones, higher in rice areas than in areas for other crops, and higher in areas where land is relatively more abundant than labor.

In northern Nigeria, relatively widespread uses of animal tractions suggest that a farming system that involves fairly intensive plowing has evolved. In such an environment, greater farm endowment relative to labor seems an important determinant of tractor adoptions.

The use of animal traction may be another indicator of the use of farm power that is substitutable with tractors. This is also consistent with the correlation between more widespread animal traction uses and tractor adoptions in the North, particularly NE. However, the overall animal traction uses intensity may be still lower compared to the uses intensity in Asia. The average real wages are also still somewhat low. These factors may partly limit wider-scale adoptions of tractors.

The prevalence of plough-negative crops (maize, millet, root crops) and the near absence of plough-positive crops like wheat may limit the overall demand for tractor-tillage in Nigeria. While in the long-run, these crops are also likely to be mechanized, the cropping system may still limit the wider diffusions of tractor uses in the short-to-medium term.

The demand for mechanized harvesting may be still generally low, partly due to low overall yields and harvests and low production intensity with limited use of dry season irrigation. The patterns in which tractor-tillage is observed to some extent (albeit in low intensity), and mechanized harvesting is still largely absent in Nigeria, is consistent with the past sequential patterns in which mechanization of land preparation precedes the mechanization of harvesting.

3 Supply side analysis

3.1 Machinery purchase/import policies, financing policies

The Nigerian government has long intervened into domestic tractor markets, including subsidized tractor distributions. Until recently, subsidized tractor distributions had been similar to the nation's fertilizer subsidy program, in that both federal and state governments procure tractors and distribute them with subsidies. Subsidy rates have varied over time. Subsidies of 50–75% had been common up to the early 1980s (Scherr 1989; World Bank 1985 p.37). Sometimes, the subsidies were provided to the cooperatives or group farms. For example, the launching of a machinery ownership scheme in 1980 by the federal government provided half of the purchase cost of farm machinery to be owned and used by farming cooperatives or group farms (Manyong et al. 2005, p41). In the 2000s, the subsidy rates had been slightly lower. For example, under the Obasanjo administration, the subsidy was typically 25% (Ladeinde et al. 2009). States often added subsidies, which vary from year to year. For example, the rates in Kaduna state were 40 percent subsidy (25 percent by the federal government and 15 percent by the state government) in 2010 (PrOpCom 2011, 3), but rose to 60 percent (the state-government contribution increased to 35 percent) in 2013.[8] Takeshima et al. (2014) also provides detailed descriptions of current

[8] Personal communication with the Kaduna State Ministry of Agriculture.

state-level tractor distribution systems in Kaduna state in Nigeria, which seems to continue in various states, while the federal government discontinued the subsidized distribution of tractors in 2012.[9]

Government loans have also been made available, providing indirect subsidies in the form of interest rate subsidies. Details of government loan arrangements were not revealed to the authors and are expected to vary across states and over time. Informal interactions with the beneficiaries of subsidized tractors indicate that a recent common arrangement is an interest-free loan with a three-year payback period. Costs are, however, also often incurred due to delays in loan approval or by various transaction costs paid either by beneficiaries for subsidy applications or by the government for monitoring repayment (Takeshima et al. 2014).

The quantities distributed with subsidies had also been determined ad hoc, often depending on the budget availability, and varied from year to year. The number of subsidized tractors distributed in the country was likely the highest from the late 1970s to the early 1980s. From 1975 to 1983, 22,000 (mostly imported) tractors were sold at subsidized prices to parastatal agencies, such as the River Basin Development Agencies, and to large-scale private companies (Jabbar 1995), as well as cooperative societies, group farmers, and retired tractor operators to run THUs (Akinbamowo 2011). The federal government's expenditure on the tractorization program increased from 11 million Naira (about US$16 million, or US$85 million in 2010 dollars) during the first five-year plan (1970–1974) to54 million Naira in 1975–1979 (about US$86 million, or US$319 million in 2010 dollars), and 240 million Naira during the third plan in 1980–1985 (about US$341 million, or US$775 million in 2010 dollars; Jabbar 1995, 101). In the 2000s, the amount distributed by the federal government was often around 1,000 and tractors were not distributed every year (Bello 2005).

3.2 Trade / Import policies (tariff, direct restriction, and other interventions) / Parts

In the early 1970s, import policies regarding tractors and agricultural equipment were generally liberalized (Manyong et al. 2005). During the 1970s, the import duty on raw materials used to manufacture pipe, electronics, metal fabrications, and kitchen utensils was abolished (Egwaikhide 1999). While trade policies became generally more restrictive in the early 1980s, the majority of importation of agricultural tractors was largely government-led between the late 1970s to the early 1980s and was less dependent on trade policies.

After the SAP, private-sector tractor importation was unregulated, except for the imposition of tariffs. However, tractor importation had still been mostly led by the government, and the private sector's importations of four-wheel or two-wheel tractors had remained small. This is likely to be the case in the 2010s, when the government imports approximately 900 tractors a year, while the private sector imports around 100 (World Bank 2014).

Import tariffs have been generally imposed on tractors and spare parts in Nigeria. Import duties (customs duties) have accounted for the bulk of import tariffs on agricultural tractors. Even after the introduction of value-added tax (VAT) in 1994, agricultural equipment, including tractors and spare parts, have often been exempt from VAT. Only recently, VAT has become imposed on certain types of agricultural tractors (5% for fully-built tractors imported, while 0% VAT for complete-knocked down (CKD), and semi-knocked down (SKD) tractors imported, as of October 2016).[10]

[9] Personal communication with Federal Ministry of Agriculture & Rural Development (FMARD) officials.
[10] https://www.customs.gov.ng/hscode/resulthscode.php?TYPE=DESC&HSCODE=tractors&MODE=ALL.

Import duties on component parts of commercial vehicles and tractors were reduced from 25 to 5 percent by 1989 (Busari & Udeaja 2007). Import duties for spare parts have remained largely at 5%, which is the rate applied today (World Bank 2014). Import duties for tractors have fluctuated but often remained below 25%. Before 2005, import duties had often been zero percent for agricultural machinery (Manyong et al. 2005). More recently, some import duties have been imposed, which often differed between CKD, SKD and fully-built tractors (World Bank 2014). Sometimes, all types of agricultural tractors were exempted from import duties, including the latest tariff structure as of October 2016.[11]

3.2.1 Concessional loans

While concessional loans are often used as part of the South-South cooperation in several countries in Africa south of the Sahara including Nigeria, the use of concessional loans for tractor imports seems to have been less common in Nigeria. This may be partly because in Nigeria, state governments (of Nigeria's 37 states) often import tractors, and the imports by the federal government generally accounted for a small share of total imports. It is, however, not surprising if there are ongoing discussions between the state governments in Nigeria and foreign governments, which may later lead to the development of bilateral agreements.

Small tractors are generally less common in Nigeria, and importations of smaller Chinese tractors seem to have been minimal. This may be partly because China's concessional loans are not applied to tractor importations in Nigeria. In contrast, the shares of Indian four-wheel tractors seem to have been growing in Nigeria, including Mahindra and Sonalika brands, India's two major manufacturers. AGCO's Massey-Ferguson tractors are another new brand of tractor that is relatively commonly marketed. Both Mahindra and Sonalika had set up tractor assembly lines in Nigeria in the late 2000s, to expand sales in both the Nigerian market and the rest of the West African region. Such growths seem to have been driven by the general growths of various private Indian companies' entries into Nigeria since its transition into a democratic regime in 1999 (Osondu-Oti 2015), rather than simply due to the Indian government's general interests in strengthening ties with Nigeria. As Nigeria is the largest source of oil imported into India to meet its growing energy demand, this demand often motivates the uses of concessional loans.

3.3 Licensing and registration

3.3.1 Licensing

The Nigerian government has also implemented various licensing policies. Specifically, it has imposed licensing requirements for operating, importing, and distributing tractors and registration requirements for owning tractors.

For tractor operation, the government had revised the law in the mid-1980s, requiring tractor operators to be above 18 years old, and to pass a trade test, often equivalent to a technical college certificate. With this law, the ownership of a standard driver's license had become no longer sufficient to operate a tractor (Iboaya 1987). As of 2014, tractor operators must hold a Class F driver's license, a professional license for "Agricultural machines and tractors" (Olumide et al. 2014). However, recent studies suggest that not all of the operators in the country are formally licensed with a trade test certificate (Ogunlade & Abdulkareem 2008).

[11]Information obtained from https://www.customs.gov.ng/hscode/resulthscode.php?TYPE=DESC&HSCODE=tractors&MODE=ALL (October 24, 2016)

Similarly, importing and distributing tractors require licenses. In Nigeria, most importers and distributors of new tractors are authorized as sole agents by the foreign companies which are all licensed; some of the major ones include Springfield Agro Ltd. selling Mahindra tractors, Tak tractors selling Indian Sonalika tractors, and Dizengoff selling AGCO's Massey Ferguson brands. The information of distributors of second-hand tractors is limited and what percentage of them is licensed is not yet known.

3.3.2 Registration of tractors

In Nigeria, rights to mining, agricultural, and construction equipment may be registered, under the same process that applies to motor vehicles, with the Federal Road Safety Commission (FRSC) office and the relevant state motor vehicle registration office (UNIDROIT 2015). Despite the directions of the federal government in 1993 to establish Motor Vehicle Administration Departments in all states (which followed the Economic Community of West African States [ECOWAS] Sub-region treaty in 1990), only a few states have so far complied. Most of the licensing and registration of vehicles, including agricultural tractors, are done by the FRSC (Ogeleyinbo 2015). Again, however, a recent study suggests that there are a significant number of tractors (mostly second-hand) that are not registered with this formal procedure (Takeshima et al. 2015).

3.4 Policies (including subsidy) on fuels / Diesels

Tractors in Nigeria typically run on diesel. The formal sector prices of general petroleum products in Nigeria have been lower than in many other countries, thanks partly to the large oil reserves that make Nigeria one of the largest exporters in the world. However, the real market prices of petroleum products had often deviated considerably, particularly between 1986 and 2009, with the peak in 1992 and 1994, in which there were actually frequent shortages at the pump stations (Okogu 1995; Ezeani 2014). Some studies suggest that the prices could have been lower if the oil industry had been governed more efficiently.

In Nigeria, oil exploration started in 1901, oil was first discovered in commercial quantity in 1956, and produced in 1958 (Ogunsola 1990). While the largest source of overall energy in Nigeria has been hydro-energy, whose production started in 1969 (Ogunsola 1990), consumptions of petroleum have continued rising.

Until 1973 fuel prices had been fully market-determined. In 1973, uniform pricing policy was introduced, and the government took over the downstream refinery sector (Adenikinju & Falobi 2006). Adding to the already-existing first oil refinery in Port Harcourt, which had been a joint venture between the government and Shell and British Petroleum, two more refineries had been built by the government in Warri & Kaduna in 1980 and another one in Port Harcourt in 1989 (Adenikinju & Falobi 2006). The number of refineries in Nigeria has remained at four up to 2016 (Eregha & Mesagan 2016). Since 2000, under the oil-sector reform, the government has attempted to sell the refineries to the private sector. Also, 20 private refiners were granted licenses to start private refineries. However, the utilizations have remained only 20-30% of the total capacity of 445,000 barrels per day. Despite four oil refineries having capacities to achieve oil-self-sufficiency in Nigeria, 70% of fuel consumption is met by imports (Rentschler 2016).

The heavy reliance on petroleum imports had initially been induced by the policies under the military regimes in the 1990s, which prioritized importation instead of repairing the refineries (Adenikinju & Falobi 2006). Throughout the 1990s, the government had controlled the importation of petroleum products. Only in the 2000s did the government start involving the

private sector in imports. However, before 2006, all fuels including petrol, diesel, and kerosene had been effectively subsidized in various forms (Ezeani 2014). Diesel has been unregulated since 2007, but kerosene and gasoline are still subsidized (Rentschler 2016). Fuel subsidies in Nigeria accounted for about 0–5% of GDP recently, albeit with varying estimates (Plante 2014; Rentschler 2016). Up until now, the lack of transparency and continued government involvement in the supply, distribution, and pricing are generally considered to have reduced the benefits of subsidies on fuel prices.

3.5 Industrial policy on machinery manufacturing

While Nigeria had attempted in the past to manufacture tractors domestically, it has largely failed. In the 1970s, two tractor assembly plants and the National Center for Agricultural Mechanization (NCAM) were established with the aim of releasing 5,000 tractors per year (Jabbar, 1995). Specifically, Nigeria Truck Manufacturers (NTM), assemblers of Fiat tractors as well as Fiat trucks, and Steyr Nigeria Ltd., assemblers of Steyr tractors and Steyr trucks, had been both established in the 70s. Similarly, Peugeot Automobile Nigeria Limited (PAN) and Volkswagen of Nigeria Limited (VWON) were established in Kaduna and Lagos to assemble passenger cars from imported CKD parts and components, through joint ventures between the Nigerian government and these companies (Adubifa 1993 p43). However, both NTM and Steyr Nigeria Ltd. had folded up within ten years of their establishment, and PAN and VWON had also closed within a short length of the period of operations. Even while in operation, many of these companies complemented their sales with imported implements and equipment. Besides, government policy that production incorporate a minimum of 30 percent of local content was never adhered to, because of often low-quality of locally produced raw materials like steels (Adubifa 1993; Oni 2011).

Attempts to raise the local manufacturing capacity have also been made. Mechanization units have been set up within the Agricultural Development Projects, state, and federal government. These institutions and NCAM have been assigned a mandate to coordinate the local R&D conducted by 140 institutions, including universities, polytechnic institutes, research institutes, industrial development centers, incubation centers, and colleges of agriculture, and provide training of machine operators / mechanics / blacksmith / artisans (Rural Artisan Training Support Unit, Ilorin) (Ajibola and Zalla 2007). However, the extent of such activities, as well as the impacts, are relatively unknown.

3.6 Machine ownership and market institutions of mechanization service provisions

Currently, tractors in Nigeria are sold by both the large importers mentioned above, and small and medium retailers. Several importers in Nigeria tend to meet the demand by institutional clients, such as state governments, for their tractor distribution programs, sugarcane estates, international groups, and Zimbabwean farmers in Kwara state (Ajibola and Zalla 2007; authors' fieldwork in 2014). These importers import either the finished product or equipment in CKD format, the latter of which is sold to distributors who assemble the machines. Some importers have specific clients and send technicians to provide services under contract (Ajibola and Zalla 2007). In addition, a number of tractor retailers, ranging from medium-scale retailers selling about 100 tractors per year to small-scale retailers selling 10–30 tractors per year (new, refurbished, or combined), also operate in Nigeria. Small-scale retailers focus more on repair and maintenance; sales of tractors are often supplementary for them. These small retailers transact

mostly with individual farmers. In Zaria, the second largest city in Kaduna state, there are several small-scale retailers of this type. Small-scale retailers are likely to be the major sources of secondhand tractors for individual buyers. While some state governments still directly supply new tractors, these private-sector agents currently largely serve the tractor hiring service (THS) providers in Nigeria.

In Nigeria, there have been both THS providers run by the public sectors and those run by the private sectors. However, the public-sector THS has gradually been overtaken by the private sector. The LSMS-ISA survey indicates that a majority of THSs are provided by the private sector, as well as friends / neighbors or relatives (Table 10).

Table 10. Sources of tractor services in 2010 rainy seasons (%)

Sources	Share (%)[a]
Private markets	42
Government	28
Friends / Neighbors	14
Relatives	10
Others	7

Source: Author's calculations based on Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA).
The percentages are calculated using the sample-weights.
[a]Because of rounding, figures may not add up to 100.

3.6.1 Public-sector tractor hiring service

In Nigeria, some of the first public-sector THUs were established in 1958 in the former western region (now Oyo, Ondo, Ogun, and Bendel States) (Makanjuola et al. 1990). The first National Development Plan (1962-1968) expanded THUs (Asoegwu and Asoegwu 2007). In the early 1970s, state governments were mostly in charge of the operation of government THUs (Manyong et al. 2005). Land clearing was also subsidized. Earlier THUs did not always provide services for farms. For example, at Akure tractor station in southwestern Nigeria, 86 percent of the total work done in 1970 consisted of mowing school and police compounds (Kolawole 1972). Mechanics who could repair tractors were often few (Kolawole 1972). Public sector THUs had been expanded gradually after the 1970s. In 1983, over 3,000 four-wheel and 300 single-axle tractors were in operation in over 250 THUs distributed all over the country (Akinola 1987). In most cases, the Government THUs had been subsidized by 25-50% (Manyong et al. 2005), apart from the government's purchase of tractors and paying of wages and salaries (Akinbamowo 2011 p2).

By the mid-1980s, the government THUs had been largely considered inefficient (Akinbamowo 2011); delays were frequent, forcing many farmers to travel distances of about 60 kilometers (km) or more about ten to fifteen times to visit the hire stations before being served (Akinola 1987, p. 66). By the mid-1980s, it was recommended that all government THUs should be phased out within two years to be replaced by privately owned THUs (Akinbamowo 2011). For example, in Ondo State, THUs were commercialized by transferring 102 tractors and assorted equipment to the Ondo State Investment Holdings (1989-1992) and later the Agricultural Inputs Supply Company (AISC) (1992-1999) (Akinbamowo 2011). Other government THUs were also gradually transferred to the private sector.

Recently, the federal government of Nigeria shifted its focus from direct distributions of subsidized tractors to the promotion of private-sector tractor-hiring services. Currently, the Nigerian government is pursuing a mechanization implementation program (MIP), which

focuses on establishing private sector–managed tractor-hiring enterprises called the Agricultural Equipment Hiring Enterprises (AEHE). MIP also provides subsidies for small-scale farmers (those cultivating between 0.5 ha and 4 ha) who use tractor services. As of 2016, about 80 AEHEs have been set up within key industrial clusters, each with five tractors plus implements, five two-wheel tractors, and a few other harvesters or threshers, operated by the private sector, including farmers, cooperatives, or investors (Takeshima et al. 2014).[12]

3.6.2 Private-sector tractor hiring service: Farmer-to-farmer service provisions

By the mid-1980s, private-sector THUs had been growing (Akinola 1987). While various types of tractor ownership and service provision have been promoted, including cooperative, joint ownership, or enterprise ownership, as briefly mentioned above, the most common type is the individual ownership of tractors by farmers, who provide farmer-to-farmer THUs.

While nationally representative figures are, to the author's knowledge, unavailable, a case study of 111 tractor owners in two Nigerian states (Kaduna and Nasarawa) (Takeshima et al. 2014) provides useful insights into key characteristics of the tractor owners. The case study compares two types of tractor owners: (a) government-sourced (GS) tractor owners who were selected and obtained tractors from the government; and (b) market-sourced (MS) tractor owners who obtained tractors from the market.

Brands, source of tractors, and financing

Tractors owned by sampled tractor owners vary in terms of brands, including Fiat, Ford, Massey Ferguson, Mahindra, New Holland, Steyr, and Tak tractors. Common brands and financing of tractors differ considerably between the MS owners and GS owners. Typically, MS owners have obtained second-hand tractors which were mainly Steyr, Fiat, and Ford brands, while GS owners have obtained new tractors (New Holland, Massey Ferguson), although Massey Ferguson and Mahindra are owned extensively by both MS and GS owners. Relatively few tractors are registered, despite the requirements mentioned above. This was particularly so among MS owners. For MS owners, 80% of tractor acquisition costs were financed by personal savings and informal loans. For GS owners, about 34% of the costs were financed by government loans, although 40% of the costs were still financed by private savings and informal loans.

Key characteristics of service provisions

Significant shares of tractor use are dedicated for own farms.

Table 11 summarizes the typical areas cultivated by each tractor per year, through hiring out and own-farm use. Typically, own-farm use accounts for 25–30% of total areas served by tractors. Tractor owners often value tractor uses for own-farm use more than hiring out; in terms of perceived values, own-farm use accounts for 33–50% of total values extracted from tractor use (Takeshima et al. 2014). Such higher perceived values of own-farm use may reflect higher marginal returns than the competitive market prices they can charge for hiring out.

[12] Personal communications with the FMARD staff.

Table 11. Area cultivated annually per tractor (hectare per year, tractor)

Category	Government-sourced tractor owners		Market-sourced tractor owners	
	Mean	Median	Mean	Median
Total farming	103	70	169*	133*
Hired out farming	74	30	128	88
Own farming[a]	29	16	41	23

Source: Takeshima et al. (2014).
Note: * = 10 percent statistical significance.
[a]Counted multiple times if multiple operations (plowing, harrowing, ridge making) are applied to the same plots.

Tractors are used for a few activities. Table 12 summarizes how many ha of different farming activities and how many hours of different nonfarm activities tractors are used for. Typically, harrowing, plowing/tilling, and ridge-making account for a majority of farming use. For each of them, own-farm use accounts for about a quarter of total farming use of tractors. For nonfarm activities, transporting farm products or nonfarm goods account for the majority of tractor use. Own-farm uses account for about 40% of total tractor use for nonfarm activities.

Table 12. Average annual tractor uses by farming activities (all tractors combined)

Type of activities	Hiring		Own farm		Total	
	Mean	Median	Mean	Median	Mean	Median
Farming (hectares)						
Land clearing	1	0	0	0	1	0
Harrowing	74	33	21	11	94	60
Plowing / Tilling	49	11	16	8	64	45
Ridge making	30	0	12	0	42	0
Rotovating	2	0	1	0	3	0
Planting / Weeding	2	0	1	0	3	0
Harvesting	1	0	0	0	1	0
Total farming[a]	156	74	51	25	208	124
Nonfarm activities (hours)						
Milling / Threshing / Processing	2	0	7	0	9	0
Transporting farm products	103	0	75	18	178	98
Transporting nonfarm goods	44	0	22	0	67	0
Local transportation	6	0	1	0	7	0
Fetching water	8	0	3	0	10	0
Firewood transport	13	0	5	0	17	0
Total[a]	177	10	112	30	290	179

Source: Takeshima et al. (2015).
[a]Figures may not add up to total due to rounding errors.

MS owners in the sample cultivate greater areas per tractor per year (Table 13). On average, MS owners operated 169 ha at the mean and 133 ha at the median. These are statistically significantly higher than the mean and median among GS owners—103 and 70 ha, respectively.

Table 13. Profitability differences between types of tractor owner-operators (US$1000)

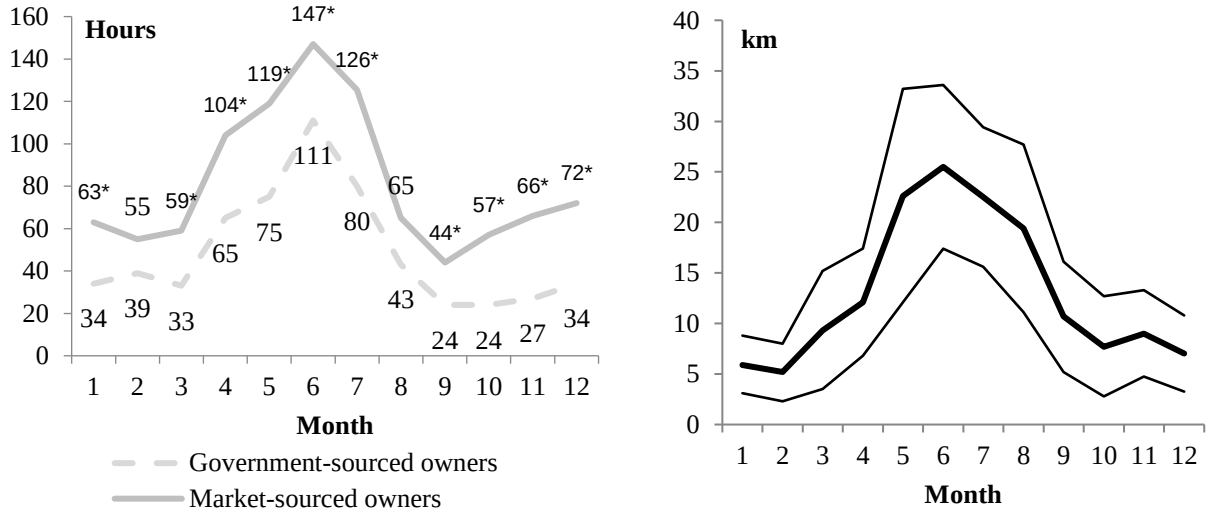
Category	Government-sourced tractor owners		Market-sourced tractor owners	
	Mean	Median	Mean	Median
Total gross benefits per year	**8**	**5**	**13***	**11***
Monetary values of own-farm use	2	1	4	3
Farming activities	2	1	3	1
Nonfarm activities	0	0	1	0
Gross earnings from hiring out	6	4	9	6
Farming activities	5	3	7	5
Non-farm activities	1	0	2	1
Payment for operators and fuel	**3**	**1**	**5**	**3**
Operators	1	0	2	1
Fuels	2	1	3	2
Maintenance and repair	1	1	1	1

Source: Takeshima et al. (2014).
Note: * = 10 percent statistical significance.

The extent of service provision is fairly seasonal, but MS owners are more active than GS owners throughout the year (Figure 3(a)). The asterisks in the figure indicate statistically significant differences between the two groups (at 10 percent statistical significance). In June, MS tractor owners operated close to 150 hours per tractor on average, while operating only 44 hours in September. The off-season hours operated by MS owners are still often greater than those operated by GS owners.

Figure 3(b) illustrates the extent of travel by the service providers from home districts, measured in Euclidean distance, in each month. For example, on average, tractor owners stayed 6 km away from their home districts in January. This could mean either they spent the whole month in a district that is 6 km from their home district, or they spent half the month in their home district (0 km away) and the rest of the month in a district that is 12 km away (so that the within-month average is 6 km), regardless of the directions. This is a crude, yet useful, indicator of how the extent of their travels varies across seasons. The extent of travel is generally low. On average, tractor owners stay only 10–15 km away from their home districts throughout the year. Distribution is also highly skewed, however, and the average is driven by a fraction of owners who spent time far away from their home districts. The operations are therefore generally confined to interviewees' home districts and to neighboring adjacent districts, except for a few service providers who travel relatively long distances. Even during the peak season, service providers other than these long-distance travelers, typically operate within a 25–30-km radius of their home districts. Typically, 75 percent of hiring services are provided within the LGA, and half of all hiring services are provided within the village. Moreover, a substantial share of operations is conducted on own farms. Therefore, tractor owners typically conduct more than 80 percent of the operations within their own LGAs. MS owners are relatively more efficient than GS owners since, when they do travel, they tend to travel to areas with soils that are suitable for the horsepower of the tractors they own (Takeshima et al. 2015).

Figure 3. (a) seasonality of tractor uses (hours per month by tractor owners)[a]; (b) average distance between home districts and where hiring-services are provided (based on 111 samples of tractor owners in Nasarawa and Kaduna combined)[b]



Source: Takeshima et al. (2014).
Note: km = kilometer.
[a]Asterisks indicate the statistically significant difference from the figures for the government-sourced owners.
[b]The narrower lines indicate a 90 percent confidence interval of the average in each month.

Profitability

Table 13 summarizes the revenues and costs of tractor uses, by both GS owners and MS owners. MS owners earn annual revenues of US$13,000 at the mean and US$11,000 at the median (including the self-evaluated values of own-farm uses), which are statistically significantly higher than those of GS owners (US$5,000 at the median and US$8,000 at the mean). For both types of owners, earnings from farming-related uses account for 80–90 percent of total earnings. Earnings from hiring services account for 70 percent of total earnings. MS owners therefore use tractors to a greater extent than do GS owners for both own-use and hiring, as well as for farm and nonfarm activities. Differences of fuel and operator payments are smaller and statistically insignificant between MS owners and GS owners, as compared with the differences in the gross benefits. MS owners pay statistically significantly less for fuels, and sometimes for operators per unit of farming and nonfarm operations, than GS owners do (Takeshima et al. 2014). The maintenance and repairing costs are not statistically significantly different between MS and GS owners.

In addition, in Nasarawa, a significant share (23 percent) of sampled MS owners travel in a group. These group travelers earn more from hiring services than those who travel alone (Takeshima et al. 2014), indicating that forming a group is motivated by potentially greater returns.

Overall, there are private sector THS providers in Nigeria, who remain largely in the informal sector but have invested in tractors through personal savings and informal loans and provide more extensive services than those who are supported by the government. They do so despite the considerable seasonality in demand and generally limited mobility of tractors.

4 Role of mechanization in agricultural transformation

This section provides empirical evidence of various effects of the adoptions of tractors on agricultural productivity, intensifications, and farm household welfares, using the LSMS-ISA 2010 and 2012 and narratives based on the past studies. These effects are estimated using the propensity score matching (PSM) method (detailed technical issues are provided in Appendix A). The estimates should be interpreted as the effects experienced by actual tractor adopters and cannot be generalized to the effects for non-adopters.[13] Because most adopters are relatively larger farms (although many are still smallholders), the findings cannot be generalized as potential effects for smaller farms who have yet to adopt tractors. Due to the low level of tractor use growth, it is generally difficult to assess the role of mechanization in agricultural transformation. This is particularly so for mechanized harvesting. There are, however, some observed effects of mechanization on key economic behaviors and outcomes, which offer insights into how mechanization is related to the agricultural transformation that is unique in Nigeria.

(1) Substitution of animal tractions

The clearest effect of tractor adoptions found is the substitution of animal tractions (Table 14). Generally, on average, adopting tractors leads to 2.1 day reductions in the use of animal tractions (both owned and rented animals combined), and a 1 day reduction in the use of animal tractions by own draft animals. In addition, adopting tractors reduce the probability of using animal tractions by 20% points. This effect is statistically significant at 5% and also robust against the violation of unconfoundedness assumption in the PSM. These effects hold for both at the national level and within North West / North East zones where the use of animal tractions is particularly high.

Table 14. Effects of tractor adoptions on animal traction uses

	Use of animal traction (days)	Use of own animal traction (days)	Use of rented animal traction (days)	Whether using animal traction (yes = 1)	Whether using own animal traction (yes = 1)
Whole sample	-1.91** (.86) [2.73]	-1.36** (.67) [2.98]	-.55 (.45)	-.20*** (.05) [2.11]	-.11** (.04) [1.50]
NW and NE	-2.20** (1.08) [1.76]	-1.28† (.87)	-.93† (.62)	-.22*** (.07) [1.87]	-.11* (.06) [1.27]

Source: Authors.
Note: *** 1% ** 5% * 10% †15% statistical significance. NE = North East; NW = North West.
Numbers in parentheses indicate the standard errors. Numbers in brackets indicate the Rosenbaum bound figures of the robustness of results.

(2) Significant effects on chemical fertilizer use and area cultivated

Tractor adoptions are also found to significantly increase both the area cultivated, by 0.4 ha on average, and the likelihood of the use of chemical fertilizer, by 13.7 percentage points (Table 15). Tractor use therefore seems to induce greater use of land and chemical fertilizer. Although not shown, the effects on cropping systems are found to be generally insignificant, indicating that such intensifications of land and chemical fertilizer uses generally occur

[13] This is because we rely on average treatment effects "on the treated" (adopters), whose consistency requires fewer assumptions than average treatment effects for the entire population.

preserving the current cropping systems.

Tractor uses are also found to have slightly significant effects on household income (with less statistical significance). Specifically, it raises real household income during the post-planting period by 14.8 percent and to a lesser extent in the post-harvesting period. Overall, tractor adoptions seem to increase real household income by 13 percent. Although these effects are relatively less precise due to the small sample size, they still indicate the general directions of tractor adoptions' impacts.

Table 15. Effects of tractor adoptions on chemical fertilizer use and crop revenues and household income

Area cultivated	Use chemical fertilizer (yes = 1)	Real household income (post-planting period)	Real household income (post-harvesting period)	Real household income (PP and PH combined)
.410*** (.144)	.137** (.060)	.148† (.097)	.136 (.098)	.128† (.080)
[1.23]	[1.37]	[1.30]	[1.15]	[1.22]

Source: Authors.
Note: *** 1% ** 5% * 10% †15% statistical significance.
Numbers in parentheses indicate the standard errors. Numbers in brackets indicate the Rosenbaum bound figures of the robustness of results.

(3) Relatively insignificant effects on labor use

In contrast to the substitutions of animal traction use, land and chemical fertilizer use, and real household income, the effects of tractor adoptions on labor uses are generally insignificant (Table 16). In addition, the effects are also insignificant on hired labor for harvesting. The effects on labor are insignificant for both post-planting season, and post-harvesting season, male, female, and child workers. The impacts on off-farm labor uses, nonfarm salary, and the likelihood of having nonfarm income are also insignificant. Tractor adoptions therefore may not be inducing significant transitions from farming to off-farm activities.

Table 16. Effects of tractor adoptions on household labor uses and off-farm incomes

Farm labor use from post-planting survey (person-days, 12-month equivalent)			Farm labor use from post-harvesting survey (person-days, 12-month equivalent)			Hired labor use for harvesting (person-day)	
Adult males	Adult females	Children	Adult males	Adult females	Children	Males	Females
10.037	4.457	17.844	23.417	-18.035	-1.844	3.655	-.367
(12.123)	(12.134)	(22.019)	(22.549)	(28.922)	(30.792)	(4.029)	(2.227)

Off-farm labor use from post-planting survey (person-days, 12-month equivalent)			Off-farm labor use from post-harvesting survey (person-days, 12-month equivalent)			Nonfarm salary (equivalent to kg of cereals)	Probability of having nonfarm income (%)
Adult males	Adult females	Children	Adult males	Adult females	Children		
-3.474	-3.813	-18.845	12.151	2.480	4.298	-795.100	7.2
(13.967)	(17.485)	(13.579)	(24.987)	(30.923)	(25.879)	(1009.661)	(5.8)

Source: Authors.
Note: Numbers in parentheses indicate the standard errors.

Overall, currently, the effect of mechanization on agricultural transformation in Nigeria is somewhat unique. Tractor adoptions seem to be helping smallholders survive and become more

productive, rather than inducing their exit from farming. This is partly consistent with the economic structures in Nigeria. The share of the labor force in the agricultural sector in Nigeria is already somewhat low given the level of mechanization; about 50% of the workforce has left farming even though the tractor adoption rate is only 8% (Takeshima 2015b). Those who are still in farming may be those who are less induced to exit farming due to various characteristics and household specific constraints. Tractor adoption is rather used to help them become more productive.

In Nigeria, exit from farming has occurred without mechanization, possibly because of low agricultural support (R&D, etc.) and labor absorption in the nonfarm sector (oil sector, financial industry, etc.). Tractors seem primarily substituting the animal tractions, rather than the labor. Mechanization itself does not induce a further significant exit from farming or shift of labor into the nonfarm sector. However, tractor use helps those who have remained in farming to narrow their income gaps with those of nonfarm households, by partly increasing area cultivated and use of inputs such as chemical fertilizer.

4.1 Tractor uses and soil compaction

The effects of mechanization on soil compaction are known to be some of the key environmental consequences of applying greater weight on the plot. Whether these effects are particularly greater in Nigeria or not is still under investigation in the literature.

The heavy tractor weights are still one of the primary causes of soil compaction. In Nigeria, as was mentioned above, a majority of tractors imported are above 60 horsepower, with weights of over 3.5 metric tons, which exceeds the limit set for soils resistant to compaction (Ahaneku & Asonibare 2014). Such a high average weight of tractors in Nigeria may be potentially damaging to the soils. Some soils are easily compacted; they include those that predominate in the fine sand and silt fractions in the Sahel, commonly found in northern Nigeria (Lal 1985). Similarly, for sandy loam soils in northern Nigeria, the dry bulk density of soils changed due to tractor traffic before sowing does not get recovered during the production season (Mamman & Ohu 1997; Dauda & Samari, 2002).

However, high horsepower tractors do not necessarily cause more soil compactions than small tractors. This is because often soil compaction is aggravated by the greater number of passes, while reducing the number of passes by using units that carry out several operations also generally reduces the soil degradation (Hamza & Anderson 2005). Sometimes stronger tractors are also needed to break up the compacted soils (Lal 1995). Sometimes yields respond in inverted-U shape to traction intensity (responding positively to the initial few tractor-passes, and negatively afterward) (Lal 1995). Similarly, animal traction can have a possibly significant effect on soil compaction (Soane & van Ouwerkerk 1994). Depending on its severity, switching from animal traction to tractors may not substantially aggravate soil compaction. While the effect of soil compactions on Alfisols (Lixisols, Luvisols, and Nitosols) have been relatively commonly studied (Lal 1995), the effect on Fluvisols is generally understudied, even though Fluvisols is one of the major soils in Nigeria on which tractors are used (

Table 17). In addition, many earlier studies focus on crops other than rice (Lal 1995), for which tractors are mostly used in Nigeria.

Table 17. Soil types and tractor uses in Nigeria

Soil types	Share of tractor-using households, by soil types (%)	Share of areas cultivated by tractors, by soil types (%)
Fluvisols	26	34
Lixisols	5	29
Luvisols	19	14
Nitisols	2	9
Arenosols	4	6
Leptosols	7	5
Plinthosols	5	2
Others	32	1

Source: Authors' calculations based on Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) data (2010/11 and 2012/13 combined) and FAO et al. (2012).

5 Conclusions

The adoption patterns suggest that demand for mechanization in Nigeria is growing in a fairly consistent way predicted by economic theory. Substantial growths of the adoption of animal traction use indicate that the demand for increased farm power use is rising in Nigeria, consistent with the increase in overall population density. At the intensive margin, however, adoptions of animal tractions may still be low. Real farm wages may still be low in northern Nigeria. These factors are consistent with the low overall demand for tractor use in Nigeria. Where tractors are adopted, the adoptions seem induced by greater overall farm land endowment per population in the area, the larger size of own farms, and cropping systems centered around plough-positive crops like rice. When there is sufficient demand for tractors, the private sector has emerged over time as the source of more efficient service providers (particularly farmer-to-farmer service providers) than the public sector as far as meeting greater demand and overcoming seasonality of demand and limited mobility. These conditions suggest that demand factors considerably explain the low adoptions of tractors in Nigeria. Conditions are consistent with the hypotheses that, because of generally low support for the agricultural sector in the past few decades in Nigeria, the growth in the non-agricultural sector increased the reliance on food importation, rather than domestic production intensity, and agricultural mechanization (tractor use in particular) has remained low despite the declining share of the workforce engaged in the agricultural sector.

Where tractors have been adopted, the adoptions have generally helped smallholders to remain in farming, rather than to induce their exit from farming. Tractor adoptions have not directly induced agricultural transformation in Nigeria. Agricultural transformation in the form of a declining agricultural labor force has happened partly through the growth in the oil industry since the 1970s. Tractor adoptions might have rather helped those who have remained in farming, due to remoteness (and relative farmland abundance), to start expanding their scale of farming.

Lastly, there are still knowledge gaps, which need to be addressed in future studies. There

are still signs of market imperfections (Takeshima 2015b). Accessibility of a custom-hiring service may remain a constraint, possibly due to the dominance of expensive, high horsepower tractors in Nigeria. It is unclear why small tractors are so few, relative to large tractors. Furthermore, agricultural productivity growth and tractor use growth have been stagnant in Nigeria. Because of this, the linkages between agricultural productivity growth and tractor use growth remain largely unknown. Future studies will have to continue investigating how the increase in labor costs affects smallholder farmers, how tractor use growth may help smaller farmers who are yet to adopt tractors, and how wider-scale mechanization growths continue to affect the economic transformation in Nigeria.

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Appendix A: Balancing properties of the propensity score matching analysis

As was seen in section 2, the extent and depth of the adoptions of tractors vary considerably across geopolitical zones within Nigeria. Comparing adopters and non-adopters of tractors in very different environments often biases the estimates of tractor adoptions. We therefore focus on specific regions with relatively favorable environments for intensifying tractor adoptions. Specifically, we focus on farm households in LGAs which have at least one tractor adopter and non-adopter and are included in the samples in LSMS-ISA 2010 and 2012. Furthermore, we excluded farm households cultivating more than 5 ha of land, which account for approximately 5% of samples, to improve the matching quality. The application of PSM shows that selected samples and estimated propensity scores satisfy requirements for sufficient balancing properties (Table 18). Table 19 shows the set of variables used and their effects on propensity scores. Note that, because we focus on specific subsamples for our analyses in PSM, the set of variables are somewhat different from those in Table 9.

Table 18. Balancing properties of propensity score matching

	Values
Rubin's B	0.35
Rubin's R	0.88
% of variables with statistically significant differences (at 10%) in means	0
Sample	
Control	537
Treated	168
Treated – on support	147
Total	705

Source: Authors.

Note: In a well-balanced sample, Rubin's B should be less than 0.4, Rubin's R should be between 0.5 and 2 (Cochran & Rubin 1973; Rubin 2001), and few variables should have statistically significant differences in means between adopter and non-adopter samples.

Table 19. First stage regression of propensity score matching method

Variables	Coefficient
EA share (%) of vegetable producers	-.002
EA share (%) of sorghum producers	-.001
EA share (%) of maize producers	-.0002
EA share (%) of rice producers	.003***
EA share (%) of cassava producers	.0004
Annual precipitation (mm)	-.0004*
Terrain roughness	.004
Soil workability	-.142
Drought index (0 = severe, 100 = no drought)	-.0003
Household size	.003
Gender of household head (female = 1)	.229**
Age of household head	-.002
Share of non-educated working-age household members	-.092**
Own farm land	.087*
Area of own farm land (ha)	-.011
Real value of household assets (natural log)	.041***
Own draft animals	-.019
Distance to the nearest town with population 20,000	.040**
Real price of chemical fertilizer	.057
Number of farm plots	.020
Agricultural land per capita	.026

Euclidean distance to the nearest state governor-origin LGAs	.115**
Real agricultural wages	-.044**
Soil bulk density	-.130
Soil clay contents	-.016***
Size of the largest farm area within EA (natural log)	-.020
Geopolitical zones dummy	Included
Year dummy	Included
Urban / Rural sector dummy	Included
Sample size	705
Pseudo-R^2	.224

Source: Authors.
Note: Asterisks indicate the statistical significance: *** 1% ** 5% * 10%.
EA = enumeration area; ha = hectare; LGAs = local government areas; mm = millimeters.

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