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Market Imperfections for Tractor Service Provision in Nigeria

International Perspectives and Empirical Evidence

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ABSTRACT

Agricultural mechanization often accompanies agricultural transformation. In some countries in Africa south of Sahara (SSA), such as Nigeria, the mechanization process appears slow, in spite of the declining share of the agricultural sector in the economy and employment. Knowledge gaps exist regarding this slow mechanization process, and filling this knowledge gap is important in identifying appropriate policies on agricultural mechanization in Nigeria.

In Nigeria, average horsepower and prices of tractors appear high, despite the scarcity of tractors. These patterns are different from the experiences in other parts of the world where initially tractor horsepower was often smaller (for example Asia), or farmers were better endowed with land and wealth (the Americas). In Nigeria, joint ownership of tractors is rare, and formal loans are often unavailable due to high transactions costs. IFPRI's survey in Kaduna and Nasarawa states in 2013 also suggested that the spatial mobility of tractors is generally low, and uses are highly seasonal (Takeshima et al. 2014). There do not seem to be plausible explanations for the seeming dominance of large tractor use, based on the available information of the prices and soils. Nevertheless, these patterns seem driven by private sector's own initiative rather than by governments' policies.

Indivisibility of large tractors and limited mobility of supplies may cause the imperfection in the custom hiring market. In order to distinguish the impacts of technology adoption at the extensive margin from those at the intensive margin, in the empirical analyses we tested these hypotheses focusing on the differences among marginal adopters of tractor hiring services and nonadopters of similar characteristics. The results are two-fold: (1) adoptions patterns of tractor services are partly explained by basic factor endowments, suggesting that the market for custom hiring is in some way functioning efficiently in response to economic conditions; (2) adoptions are, however, affected by supply-side factors including the presence of large farm households (and thus potential tractor owners) within the district, and (3) per capita household expenditure level differs significantly between the marginal adopters and nonadopters of similar characteristics. This difference seems to arise from the adoption per se, rather than the intensity of adoption, which is consistent with the hypothesis of the imperfection of the custom hiring market.

Keywords: tractor, market failure, double-hurdle model, generalized propensity score, Nigeria, Africa south of the Sahara

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1. BACKGROUND

Agricultural mechanization has often been an integral part of agricultural transformation around the world. It has played an important role in keeping farm production costs low by supplying cheap sources of farm power required along the production processes. The growth of agricultural mechanization in Africa South of Sahara (SSA) has been lagging behind other regions of the world. There is a broad consensus within the agricultural mechanization literature that the adoption of agricultural mechanization has been largely driven by the demand for more frequent cultivation, area expansion, and labor-saving (Pingali 2007; Herdt 1983). Despite its indivisibility, reliance on spare parts, and repair services, supply of tractors and tractor services has emerged over time, primarily led by the private sector with relatively little government interventions. While formal credit programs did not always remove the liquidity constraints, individuals would accumulate liquid wealth over time and eventually incur fixed costs to acquire tractors. Adaptive design innovations to improve the performances of tractors have been mostly provided by the private sector as well. These experiences in the United States (Manuelli and Seshadri 2014), Asia, and other regions have broadly led to the belief that agricultural mechanization will increase once the demand grows, with little supply-side constraint.

Questions still remain, however, regarding whether the situations in SSA are the same as in other regions or different due to its unique characteristics. Although land scarcity is an increasingly relevant phenomenon in SSA (Jayne, Chamberlin, and Heady 2014), Asian experiences show that mechanization grows in land scarce environment as well. In Nigeria, SSA's most populous country, the current mechanization level seems low even though the economic share of the agricultural sector has been low and declining. Interestingly, related (though in complex ways) to the ongoing debate about the low agricultural labor productivity in SSA (McMillan, Rodrik, and Verduzco-Gallo 2014; Gollin, Lagakos, and Waugh 2014), agricultural mechanization levels in Nigeria are also low given that less than half of the workforce in Nigeria is now employed in the agricultural sector. There does not seem a sign of agricultural productivity growth and cost reduction happening through other pathways either. Despite the rapidly growing demand for rice and a high tariff imposed by the Nigerian government, domestic rice production has remained stagnant, with low yield and high production costs (Gyimah-Brempong, Johnson 2014). Average horsepower of tractors (and thus average price of tractors) in Nigeria appear relatively high, given the scarcity of tractors and average farm wealth levels. As is described later, these patterns in Nigeria are more striking than they were in many other regions in the past. Joint ownership of tractors is rare due to the risk of damage, and formal loans are typically unavailable due to the high transactions costs. These conditions suggest that there are potentially significant effects of indivisibility and liquidity constraints on tractor investments and supply of tractor services. Furthermore, these patterns do not seem to be merely led by the government policies, but rather often by the private sectors' own initiatives.

Tractors, particularly of high horsepower, exhibit economies of scale. Takeshima et al. (2014) indicated that many of the tractors in Nigeria cost more than US$10,000,[1] compared to other agricultural inputs such as seeds, fertilizer, irrigation pump, or tubewells which often cost less than a few hundred dollars. Draft animals are also significantly less expensive, costing no more than several hundred dollars (Takeshima 2012). Because of such high capital costs, tractors are unique. In countries like Nigeria, tractors may be less scale-neutral technologies than in these countries in early stage.

Understanding the current patterns of agricultural mechanization in SSA is crucial in understanding whether the current agricultural mechanization level is optimal in this region from an economic standpoint, and how agricultural transformation can be facilitated there. This study provides some insight into these questions using Nigeria as an example. We provide various aspects of important evidence from two types of surveys in Nigeria as well as secondary data and literature. First, we highlight a unique aspect of agricultural mechanization in Nigeria from historical and international perspectives.

[1]All dollars in this paper refer to US dollars.

We then empirically analyze the determinants of tractor use in Nigeria, as well as the presence of some market failure.

Current equilibrium in Nigeria, that is, the dominance of large tractors, may be the result of various factors. The majority of existing tractors may be large simply because the government has historically promoted large tractors. However, another possible factor is the characteristics of demand, which are determined by the prevailing production technologies and environments in Nigeria.

This paper contributes to the various strands of literature. First, it builds on early agricultural mechanization literature by providing further evidence on the adoption patterns of tractor services from Nigeria using pseudo-panel datasets and various spatial datasets to control the heterogeneous factor endowments. It also contributes to the broader literature of agricultural and structural transformation by providing some insights into the mechanisms of tractor service adoptions, which are one of the important facilitators for moving labor out of the agricultural sector and into more productive sectors.

Methodologically, the paper contributes to the literature on transactions costs and technology adoption. Specifically, in the context of understanding the process of tractor service adoptions, this paper distinguishes the impact of technology adoptions at the extensive margin from those at the intensive margin. We separate the former impact from the latter using the generalized propensity score (GPS) model by Hirano and Imbens (2004). This paper also treats the impact at the extensive margin as an indication of the imperfection of tractor services market in Nigeria, which is also corroborated by the weakness in the impact at the intensive margin.

2. IMPERFECTIONS OF TRACTOR HIRING MARKET IN NIGERIA

International and Historical Patterns of Tractor Size Change

Types of Machines

Agricultural machinery is a capital asset that requires a relatively large initial investment. However, an important historical pattern, with current relevance to West Africa, is that the size of machinery had been relatively small at the beginning of agricultural mechanization process.

Historically, agricultural mechanization started with the adoption of two-wheel tractors (2wt) or lower horsepower four-wheel tractors (4wt), rather than the high horsepower 4wt (Table 2.1). This pattern is not only found in Asia but all around the world. In the United States in the early 1900s, average tractor horsepower was around 10–20 horsepower (hp) when the adoption of tractors began (Olmstead and Rhode 2001). In many Asian countries, not only 2wt with typically less than 15 hp became widely adopted, but 4wt have been generally in the 30-hp range.[2]

Table 2.1 Typical horsepower of tractors in selected countries over time

	Indicator		
	Period		
Country/Region	**~ 1960s**	**1970s –1980s**	**1990s–2000s**
Brazil	N/A	65–75 hp for long time [a]	
China	N/A	1978 1 million of 11 hp 800,000 of 42 hp [b]	2010 18 million < 20 hp 4 million > 20 hp)
India	N/A	15 – 50hp [c]	2000 [d] 30–40hp (55%), 20–30hp (23%), 40–50hp (14%)
Indonesia	N/A	1984 [e] 8881 – 10hp 2470 – 12hp 4WD 642 – 20hp 4WD 146 – 35hp 4WD 864 – 50hp 4WD	2000 [c] 100000 – 2WD/10hp
Nepal	N/A	35 hp [f]	N/A
Pakistan	N/A	30–60 hp (imported) [c]	N/A
Thailand	N/A	< 45hp = 300,000, > 45hp = 33,000 (1978) [c]	N/A
United States	**1910–1950** **10–20 hp [g]** **1960** **20–30 [g; h]**	1986 – while number of tractors increased by 5.1 times since 1930, total hp increased by 12.4 times [i] 100 –150? [j]	N/A
United Kingdom	35 hp in the 60s [c]	N/A	N/A
Western Europe	N/A	45hp common in 1970s [d]	N/A
Vietnam	N/A	N/A	2006[d] 266000 – <12hp 100000 – 12-35hp 24000 – 35hp

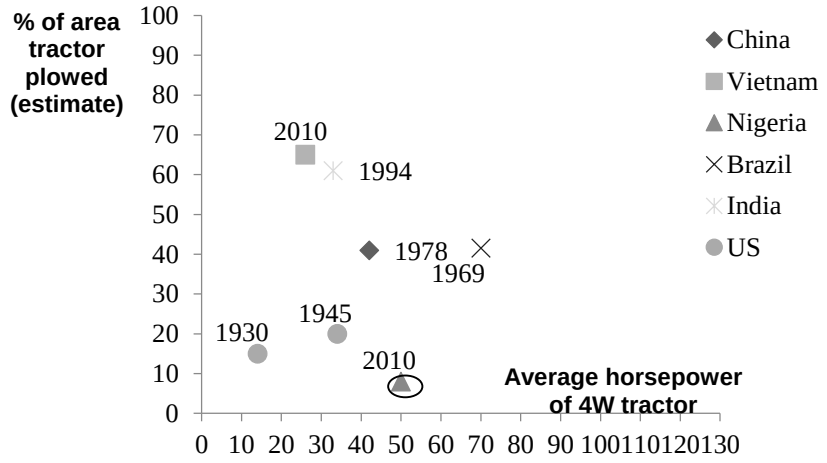
Source: [a]Kienzle, Ashburner, and Sims (2013), [b] Yang et al. (2013), [c] IRRI (1986, 164); [d] CSAM (2014); [e] = Thorbecke and van der Plujim (1993); [f] Shrestha 1978, 65; [g] Olmstead and Rhode (2001); [h] Hayami (1969); [i] USDA (1989, 3); [j] Perry, Bayaner, and Nixon (1990).

Note: hp = horsepower; 4WD = four wheel drive tractor; 2WD = two wheel drive tractor.

[2] In an extreme instances, some early tractors in Taiwan had only 2–3 hp (iron cow in Taiwan (Herdt 1983).

Currently in Nigeria and Ghana, the range is typically 50–70 hp. Tractor horsepower largely determines its optimal operational scale and the size of required fixed investment. Therefore, historically, agricultural machinery has been a relatively scale-neutral technology around the world, compared to present day Nigeria or Ghana. Tractor horsepower has been relatively high in Latin America, but as is shown below, farmers have been much wealthier than current farmers in Nigeria and Ghana. In other words, liquidity constraints have been less binding and market failure less severe elsewhere for machinery investment, compared to these two countries presently. This is also illustrated in the relationship between the average horsepower of 4wt and the level of mechanization in Nigeria and other selected countries in the past (Figure 2.1). Clearly, dominant types of tractors in Nigeria are large (high horsepower) despite the fact that the country's mechanization level is still low, which is contrasting to the past trajectory of many other countries.

Figure 2.1 Average 4W tractor horsepower and the level of mechanization (years vary)[a]



Source: Author's calculation based on Table 2..1 for average horsepower of four wheel tractors. China and Vietnam, CSAM (2014); Brazil, Stizlein (1974), India, Ugwuishiwu and Onluwal (2009, Table 2.1), United States, Olmstead and Rhode (2001).

Note: [a]Figure for Vietnam is for rice area only. Figures for the United States are the share of farmers using tractors. Figure for Brazil is for wheat only, and the average of the Rio Grande du Soil and Santa Katarina reported by Stizlein (1974, Table 7).

While it is often argued that small tractors had been invented and adopted in Asia or Europe for their smaller farm sizes (Binswanger 1987), that does not seem to fully explain the situations in West Africa. In Nigeria, size of cultivated area by farms using tractor services (including tractor owners) is less than 2 hectares (ha) (Table 2.2), which may be slightly larger than in some Asian countries but considerably smaller compared to Latin America. In the United States, the trend toward fewer but larger farms increased demand for larger horsepower tractors (Hlavacek and Reddy 1986), as larger horsepower tractors can exploit more economies of scale (Fulton, Heady, and Ayres 1978). The patterns in Nigeria and Ghana also contradict this.

Table 2.2 Area cultivated by median farm households depending on their mechanization status (ha)

Geopolitical zones	Without animal or tractors	With animal but not tractors	With tractors
North Central	0.7	0.9	1.8
North East	1.2	1.3	1.6
North West	0.4	0.6	0.5
South	0.2	0.0	1.7
Total	0.4	0.8	1.4

Source: Authors' calculations.

Relatively lower horsepower in Asia is not simply because of the dominance of 2wt that are particularly suitable for wet paddy production.[3] Four-wheeled tractors had been popular as well, particularly in South Asia, where rice–nonrice crop rotations had been common (Pingali 2007).[4] In India, where 4wt has been more dominant, 8 hp 2wt was one-third of the price of 30–40 hp 4wt. Two-wheeled tractors were relatively more expensive (Farrington 1986). In Pakistan, 2wt were not popular in the 1980s because operating costs were higher than those for 4wt (Farrington 1986).

Similarly, tractor horsepower was often as low as 10 hp in the 1920s when adoption increased, even though most farming was on dry land. Tractorization was considered a more gradual process, often substituting a few horses (out of five or six horses owned) with one tractor, while maintaining remaining stock of horses (primary examples investigated by Clarke 1991).

Use of power tillers on wet paddy has also spread in many irrigation schemes in Ghana, such as the Kpong irrigation scheme (Takeshima, Nin Pratt, and Diao 2013). Use of 2wt power tillers are therefore found in parts of West Africa.

Farm Wealth Level Relative to Tractor Prices

As discussed previously, many tractors were relatively small in Asia at the initial mechanization stage. Tractors were thus more scale-neutral technologies, where the effects of liquidity constraints in adoption were less serious and high returns could easily be translated into the adoption.

In Latin America, tractors were relatively higher-horsepower and more expensive, as their mechanization started earlier than Asia and available tractors had generally been more expensive than they are today. In 1950s, tractors with 36—45 hp in Brazil typically cost $2,800, or $25,000 in 2010 US dollars (Stitzlein 1974, Table 4). Liquidity constraints may have been serious impediments to investment. However, by 1950 when investments into tractor began rising, farm households were wealthier in Brazil than typical farm households in Nigeria or Ghana today. In addition to the largest 5 percent farm households with total production value of $42,000, close to one-third of farm households in Brazil were cultivating 16 ha of land in 1950, with annual production values equivalent to $7,000 (2010 US dollars) (Table 2.3). This is primarily because of relative land abundance in Latin America. For these 40 percent of farm households with annual production value of $7,000, investments into tractors worth $25,000 may not be entirely beyond their reach although still difficult, if returns are substantial and reasonable amount of savings can be made each year. Clearly, very few farm households in Nigeria or Ghana are in this position even today. In Brazil, by 1950 more farmers were likely to have accumulated enough savings to invest into tractors. They needed less credit or subsidy to invest into tractors, and their relative large sizes

[3] In Burma, soil preparation during the rainy season is not possible with 4wt due to their weight and the poor traction conditions of the clay soils. Accessibility to individual plots on each farm is much better than with 4wt. "Whenever there is a hardpan layer of about 125–50 mm depth, the tiller is found to be excellent in the preparation of wet soils" (IRRI 1978, 75). Use of power tillers had spread rapidly where draft animals had previously been used. Power tiller use was more strongly bullock-saving (Binswanger 1978) than labor-saving. In early 1980s, 98 percent of the land in Bangladesh was plowed by bullocks (Farrington 1986 90). This may have led to the subsequent widespread adoption of power tiller use in the country. In early 1980s, one power tiller substituted 22 pairs of draught animals in Bangladesh (Gill 1983). In Asia, 2wt have mostly been used in flooded paddy cultivation and provided a more complete total tillage substitute for draft animals than 4wt. With 4wts, substantial labor is generally required for tidying up field corners, repairing damaged bunds, and leveling (Farrington 1986). This provides some hypotheses that adoption of 2wt had been facilitated by the pre-existence of production practices where animal traction was used on wet paddy.

[4] In Sri Lanka, tractor ownership was more profitable than power tiller ownership (Ulluwishewa and Tsuchiya 1983). Four-wheel tractors had also been more suitable for operating rental markets over a larger geographic area, and more amenable to use as transport vehicles. Where it was easy to meet demand from a larger geographic area or plots are often located far away from farmers' residence and connected with feeder roads of poor conditions (muddy and bumpy), 4wt might have been more suitable for transporting harvest than 2wt. Four-wheel tractors had also been more popular than 2wt when large-scale sugarcane production flourished (IRRI 1978). Large tractors might have preceded a high degree of water control development such as in central Luzon or central Thailand, where their presence in sugarcane farming may have stimulated adaption to rice (IRRI 1983). Four-wheeled tractors in Central Luzon had been rapidly replaced with power tillers in the 1970s (Otsuka, Gascon, and Asano 1994). Japan switched from 2wt to 4wt after the 1970s (IRRI 1978). There, the rapid shift from walking tractors to riding tractors in 1972 (IRRI 1986) had been enabled the adoption of high-lug tires for soft soil.

might have facilitated the targeting of subsidy provision or monitoring of loan payments if credit or subsidy was provided.

Table 2.1 Farm household characteristics in Brazil, 1950

Type of farm households	% of all farm households	Cultivated area (ha)	Cultivated area per worker (ha / worker)	Production value per ha (2010 US$)	Total production value (2010 US$)
Sub-family	23	1	0.7	733	603
Family	39	4	2.5	673	2,638
Multi-family (medium)	34	16	5.5	450	7,093
Multi-family (large)	5	119	11.3	355	42,372

Source: Authors' modifications based on Barraclough and Domike (1966).
Note: ha = hectare.

Similarly, during 1920—1930 when the tractor adoptions increased from 4 to 14 percent in the United States, average land size of farms were 60 ha or more, with average harvested area of 20 ha (Table 2.4).[5]

Table 2.2 Farm sizes, cash margins, and tractors in the United States in 1920 and 1930

Year	1920	1930
Average land by farm (ha per farm)	60	64
Average size of improved land by farm (ha per farm)	32	
Average size of harvested area by farm (ha per farm)		23
% of farms with horses or mules	84	80
% of farms with tractors	National - 4	National – 14 Illinois – 33 Iowa – 31
Average cash margin of the farm (2010 US$)[a]		Illinois – 17,000 Iowa – 26,300
Tractor price (2010 US$)[a]		13,000
Average horsepower		11[b]

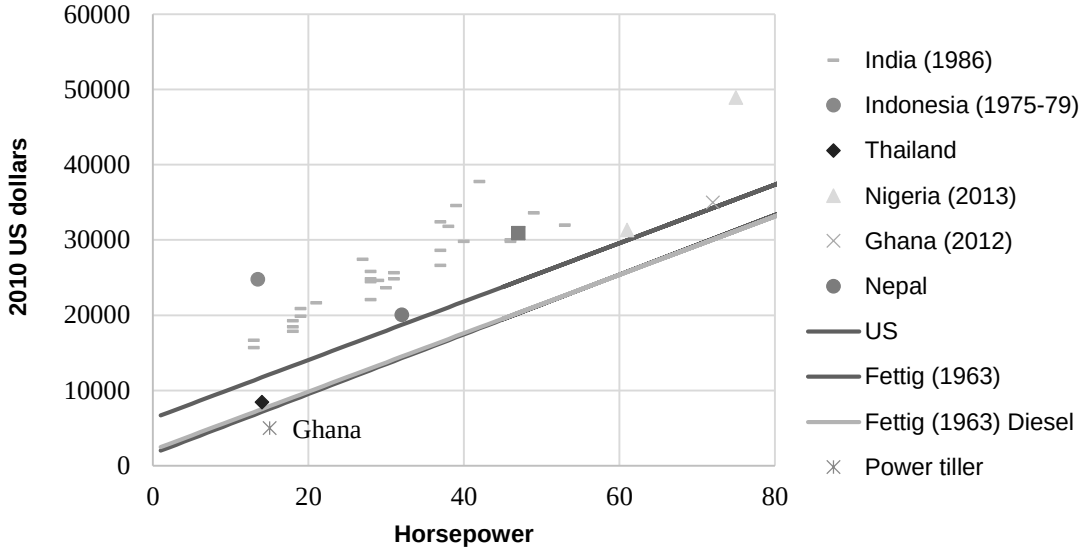
Source: Census of Agriculture (1920; 1930).
Note: ha = hectare. [a]Cash margin is from Clarke (1991, Table 3), which is synonymous to profit. Tractor price is based on Clarke (1991 p109). Both figures are converted by authors using $1 in 1930 = $13 in 2010. [b]Assessed from Olmstead and Rhode (2001, Figure 1 and Table 3).

Dominance of Large Tractors in Nigeria – General Lack of Plausible Explanations

Typically, the price of tractors and horsepower has positive but either linear to nonlinear association (Figure 2.2). In linear cases, tractor price is almost proportional to its horsepower. In nonlinear cases, the price increase per horsepower tends to diminish at higher horsepower range. If there are such nonlinear associations, then large tractors can provide greater horsepower per price. Meanwhile, horsepower speed and capacity of plowing are relatively linear. Under such conditions, large tractors tend to achieve lower cost than small tractors system. The higher profitability of large tractors is based on the production environment.

[5]The cash margin somewhat masks the indebtedness of many farmers in the late 1920s, who purchased land through mortgages during the First World War (Clarke 1991). Mortgage interest payments were approximately $200–$540 ($2,500–$7,000 in 2010 US dollars) in Iowa, Illinois, Indiana, Ohio and Missouri in 1929 (Clarke 1991), which is substantial but still a fraction of the cash margin.

Figure 2.2 Horsepower and tractor prices



Source: World Bank (2012), WDI (2014), IRRI (1986); Takeshima et al. (2014), Roumasset and Thapa (1983), IRRI (1986), Hayami and Ruttan (1970); Fettig (1963).

Note: Ghana data is from World Bank (2012 Box 4.1). Assumed Purchasing Power Parity (PPP) conversion rate of 0.8 in 2012 (WDI 2014). Power tiller price in Ghana was from Takeshima et al. (2013). India data is from IRRI (1986), PPP conversion rate = 0.5, US$ 1 in 1986 is US$ 1.99 in 2010. Since the figure may include implements, we multiplied the price by two-thirds to obtain assumed tractor only prices. Nigeria data is from Takeshima et al. (2014), PPP conversion rate of 0.6 in 2013, and US$ in 2013 is US$ 0.94 in 2010. Nepal data is from Roumasset and Thapa (1983), conversion rate assumed to be 1 rupee = $0.0683 in 1982 (http://fxtop.com/en/historical-exchange-rates.php), PPP conversion rate = 0.4, US$1 in 1982 = US$2.26 in 2010. Lines for the United States are from Takeshima et al. (2014), Fettig (1963) for diesel and non-diesel tractors, using conversion rate of $1 in 1962 = $7.22 in 2010. Hayami and Ruttan (1970, 1137) provide similar figures for tractors from 1915–1960.

However, the reverse is also possible. From the manufacturing standpoint, there are sufficiently large numbers of smaller tractors (both two-wheel and four-wheel) produced in Asia (particularly China and India), which can be easily imported into Nigeria if there is demand. Many of the large tractors produced for Africa seem to be produced separately from domestic markets in Europe or India, indicating that manufacturing of these large tractors cannot be easily added to existing tractor manufacturing systems. This suggests that the manufacturing costs of large tractors currently imported into countries like Nigeria may be sufficiently higher given the horsepower, relative to small tractors. In Kpong area in Ghana, where 40–50 power tillers are used, commercial (unsubsidized) price of Indian 15 hp power tillers is approximately $4,000 ($5,000 at PPP), which is below the straight lines from Fettig (1963) in Figure 2.2. In addition, from a shipping perspective, large tractors can be bulky even when disassembled, and only limited quantities can be put into one container, which can raise the shipment costs per tractor. This is less of a concern for smaller horsepower tractors that also tend to be smaller in size. In terms of operation, two small tractors can be used in two separate plots at the same time, while one large tractor cannot. These factors indicate that the dominance of large tractors in Nigeria cannot be explained by the price.

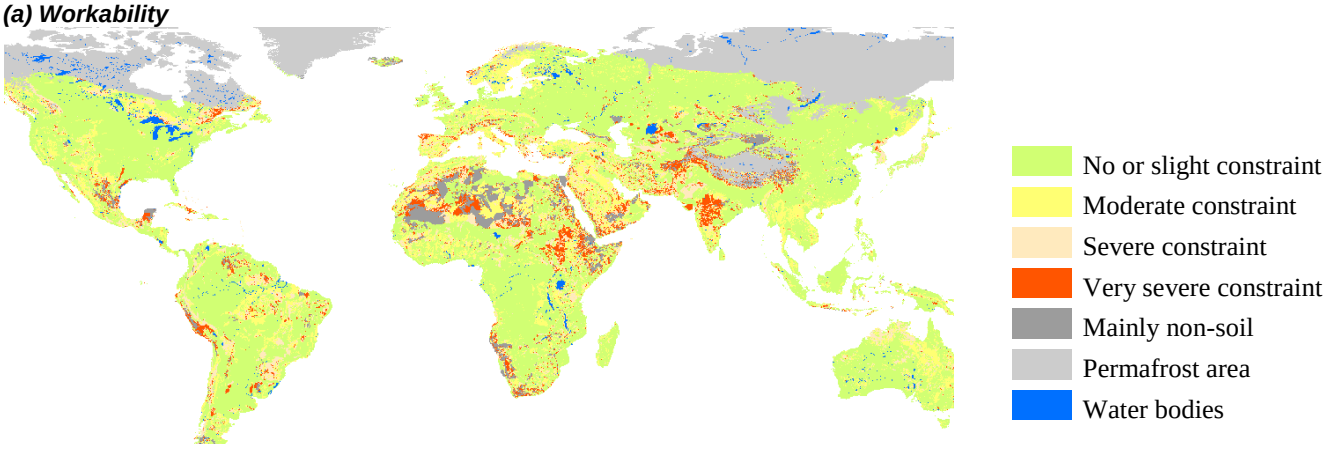
Soils: Largely Anecdotal, not Investigated Thoroughly

Large tractors with high horsepower are often preferred on heavier soils with more difficult plowing conditions. Takeshima et al. (2014) suggest that soil bulk density can vary within Nigeria, and may affect the selections of tractor horsepower. For plowing upland fields, power tillers and small 4wt with less than 30 hp are typically not competitive with larger 4wt because the lighter weight of the smaller machines

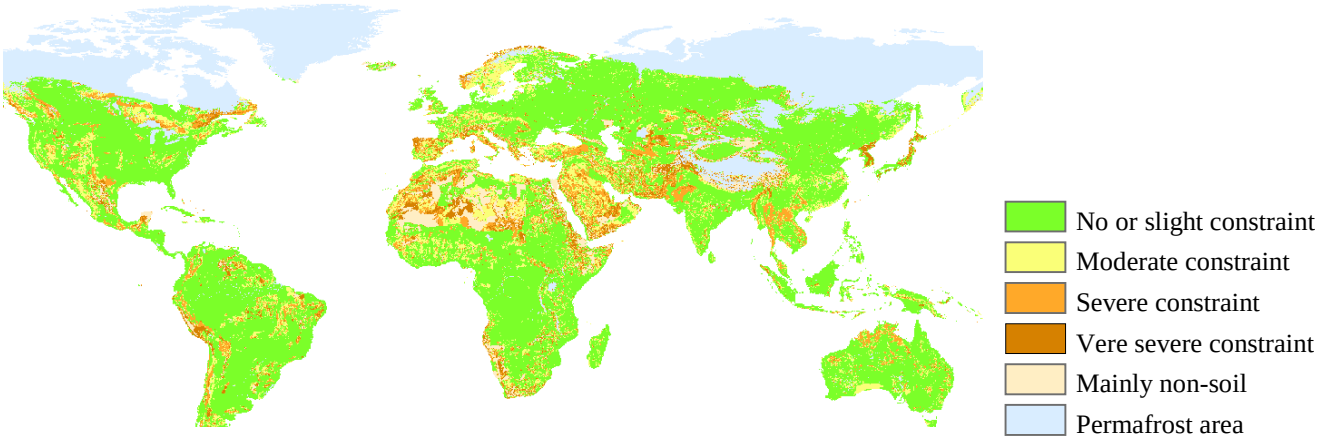
lead to slippage problems (Binswanger 1987). It is sometimes argued that larger tractors with higher horsepower are preferred in Nigeria because of its heavier soils. There is, however, little evidence that soils in Nigeria are heavier than other parts of the world (for example Asia). Figure 2.3 illustrates the workability and rooting conditions of soils, which are both partly affected by the ease of tillage (Fischer et al. 2008). According to Figure 2.3, soils in West Africa do not appear any heavier, nor face greater constraints in workability or rooting conditions compared to the soil of Asian countries such as India.

Figure 2.3 Workability and rooting conditions of soils

(a) Workability



(b) Rooting conditions



Source: Fischer et al. (2008).

Unclear Policy Effects

One may argue that the dominance of large tractors in Nigeria is due to the government's policies of promoting them. However, in underdeveloped areas such as rural Nigeria and SSA, it is widely believed that the public sector has low capacity for regulatory enforcement, due to generally diminishing roles of national institutions in areas further from the capital cities (Michalopoulos and Papaioannou 2014). It is generally unclear how successfully the government can influence the type of tractors used in the country.

In Nigeria, similar promotion of larger irrigation equipment, such as sprinklers or drip irrigation, has been unsuccessful in the past, while private investments into small-scale irrigation pumps have been relatively more common in certain areas (Takeshima et al. 2010). In Nigeria's rice milling sector, attempts to promote large mills have generally failed, while small traditional mills continue to persist. Large mills often require effective rice import tariff systems, which is often not the case (Johnson 2014).

Another example is threshing machines. Locally fabricated threshing machines are commonly found in major rice-producing regions, although there is technically no direct efforts from the government in promoting these small threshing machines. In spite of governmental promotion of large tractors, if the private sector finds small tractors to be more profitable, the government may find it difficult to encourage the use of large tractors and prevent the uses of smaller ones. In some Asian countries, small scale mechanization spreads despite governments' attempts in promoting large-scale mechanization (Biggs and Justice 2013).

The other possibility is that large tractors dominate the tractor market because they were originally brought in by the government, partly for political patronage of certain constituents, and they can eventually dominate the market through resale. However, if these tractors are to be valuable for political purposes, they have to have economic values as well—recipients can re-sell them in the market or use them effectively on their plots. If smaller tractors are more popular, the governments can patronize more potential voters by purchasing larger quantities of smaller tractors at the same costs. They may not do so because small tractors may have lower values for recipients. While subsidized tractors can be resold at prices below competitive market prices, if the demand is large enough. However, side-selling prices are likely to be close to competitive prices because subsidized tractors are rationed. If the demand is low, side-selling prices may be low as well, but then the issue of indivisibility is less serious.

The discussions above suggest that there are no clear explanations for why there are only large, high horsepower tractors in countries such as Nigeria, despite the large presence of smallholder farmers. This paper does not attempt to examine these reasons. But if these are the equilibria reached due to combinations of various economic factors, it is likely to persist.

3. AGRICULTURAL LABOR MARKET IN NIGERIA

Rising farm wage is considered one of the driving forces of agricultural mechanization. Rising farm wages increase the relative cost of labor to land or capital, and induces farmers with high land endowments to substitute labor with machinery, while inducing farmers with low land endowments to exit agriculture. This process is a core cause of agricultural transformation.

Recent studies suggest that rising agricultural wages and farm labor costs are increasingly perceived as costly inputs in Nigeria (Takeshima, Nin-Pratt, and Diao 2013). The recent Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS-ISA) data for Nigeria, which were collected by the World Bank and Nigeria's National Bureau of Statistics, provides a nationally representative snapshot of farm labor use that is relevant for agricultural mechanization, particularly at the land preparation stage. While the LSMS-ISA data may not be as detailed as that of other surveys focusing more on labor aspects, it is useful in identifying farm household characteristics and labor use. Here we briefly illustrate those characteristics using various descriptive statistics from the data.

Human Capital

The human capital levels in Nigeria, measured by level of education, have risen over the past several decades. The well-known Barro and Lee (2013) indicators are not available for Nigeria. However, the author's calculations based on the LSMS data discussed below suggest that the average number of years of formal education among the population ages 15 or older is approximately 6 years,[6] which is similar to some South Asian countries such as India, Pakistan, and Bangladesh. The trend of increased enrollment of children in primary or secondary schools has remained steady, following similar neighboring countries such as Ghana (World Bank 2014).

Education levels vary across gender and sector (urban versus rural) (Table 3.1). The average of 4.6 years in rural areas is approximately half of the 8.6 years reported in urban area. While the gap is smaller, the average among females is 1.4 years lower than males.

Table 3.1 Estimated average years of formal education in Nigeria (aged 15 or older), disaggregated by gender and sector

Variable	Male	Female	Total
Rural	5.4	3.8	4.6
Urban	9.2	8.0	8.6
Total	6.9	5.5	6.2

Source: Author's calculations based on National Bureau of Statistics and World Bank (2010; 2012).
Note: Based on secular education, excluding Koranic education.

Education levels also vary across regions. Table 3.2 summarizes the estimated working age of the population in each geopolitical zone, disaggregated by level of education. The northwest and northeast regions host the largest number of population without any formal education, while the South zones typically have larger populations with at least some level of secondary education.

[6] Each education level is defined as the following; primary education = P1, P2, P3, P4, P5, P6; secondary education = JS1, JS2, JS3, SS1, SS2, SS3; post-secondary education = teacher training, vocational/technical, NCE, Poly/Prof, 1st Degree, Higher Degree. Approximate years of education is calculated by assigning the years to each category in the following way; (1) no education = 0, (2) received some primary education = 3, (3) completed primary education = 6, (4) received some secondary education = 9, (5) completed secondary education = 12, (6) post-secondary education = 6. We did not include in calculation the Koranic education and other education as their conversions to secular education is unclear.

Table 3.2 Total number of working age population in Nigeria (15–60 years old) based on education status (million)

Geo-political zones	(1) No education	(2) Received some primary education	(3) Among (2), completed primary education	(4) Received some secondary education	(5) Among (4), completed secondary education	(6) Post-secondary education	(7) Koranic education	(8) Other
Male								
North-central	2.3 ± 0.2	1.0 ± 0.1	0.7 ± 0.1	2.7 ± 0.3	1.4 ± 0.2	0.9 ± 0.1	0.1 ± 0.0	0.0 ± 0.0
Northeast	3.7 ± 0.3	0.7 ± 0.1	0.6 ± 0.1	2.0 ± 0.2	1.1 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.0 ± 0.0
Northwest	6.0 ± 0.4	1.5 ± 0.2	1.1 ± 0.1	2.6 ± 0.2	1.3 ± 0.2	0.7 ± 0.1	1.7 ± 0.2	0.0 ± 0.0
Southeast	0.5 ± 0.1	1.3 ± 0.1	1.0 ± 0.1	2.6 ± 0.2	1.5 ± 0.2	0.7 ± 0.1		0.0 ± 0.0
South	0.5 ± 0.1	1.5 ± 0.2	1.1 ± 0.1	4.3 ± 0.3	2.7 ± 0.3	1.4 ± 0.2		0.0 ± 0.0
Southwest	1.5 ± 0.2	1.6 ± 0.2	1.4 ± 0.2	5.6 ± 0.4	3.8 ± 0.4	1.7 ± 0.2	0.0 ± 0.0	0.1 ± 0.1
Total	14.5 ± 0.7	7.7 ± 0.4	6.0 ± 0.3	19.7 ± 0.7	11.9 ± 0.6	6.0 ± 0.4	2.2 ± 0.2	0.2 ± 0.1
Female								
North-central	4.1 ± 0.3	1.2 ± 0.1	0.9 ± 0.1	1.9 ± 0.2	1.1 ± 0.2	0.6 ± 0.1	0.1 ± 0.0	0.0 ± 0.0
Northeast	5.0 ± 0.3	0.8 ± 0.1	0.6 ± 0.1	1.2 ± 0.1	0.6 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	0.0 ± 0.0
Northwest	7.9 ± 0.4	1.1 ± 0.2	0.9 ± 0.1	1.1 ± 0.2	0.5 ± 0.1	0.2 ± 0.1	2.2 ± 0.2	0.0 ± 0.0
Southeast	1.6 ± 0.1	1.7 ± 0.1	1.2 ± 0.1	3.0 ± 0.2	1.8 ± 0.2	0.8 ± 0.1		0.0 ± 0.0
South-Southwest	1.2 ± 0.1	2.0 ± 0.2	1.5 ± 0.2	4.1 ± 0.3	2.5 ± 0.2	1.2 ± 0.2		0.0 ± 0.0
Total	3.0 ± 0.3	2.1 ± 0.2	1.8 ± 0.2	5.4 ± 0.4	3.7 ± 0.4	2.0 ± 0.3	0.0 ± 0.0	0.1 ± 0.1
	22.8 ± 0.8	8.9 ± 0.4	6.8 ± 0.4	16.6 ± 0.6	10.2 ± 0.6	5.0 ± 0.4	2.7 ± 0.3	0.3 ± 0.1
Rural M	12.5	5.1	3.8	10.2	5.6	2.3	2.0	0.0
Rural F	18.5	5.5	4.0	7.5	3.9	1.3	2.4	0.1

Source: Authors' calculations based on Nigeria, NBS and World Bank (2010; 2012).
Note: Numbers with "±" are margins of errors. M = male, F = female.

Hired Labor Use for Planting Activities

The use of hired farm laborers is common in Nigeria. In 2010 and 2012, about 64 percent of farm households hired workers during planting season for their farming activities (such as land preparation, planting, and weeding) (Table 3.3). These are households which had hired workers anytime during the four months prior to the post-planting surveys which were conducted during August through October of 2010 and 2012. Because the start of planting season varies across regions, these may not be the perfect measures of their use of labor for land preparation, planting or weeding. However, they provide good indicators of how commonly hired workers are used for these farming activities. Typically, farm households (including those not hiring workers) pay a total of $40 for hired workers. Interestingly, households using tractors are more likely to hire workers (78 percent), and pay more for their labor ($112 per household).

Table 3.3 Use of hired labor for planting season

	% hiring labor in the past 4 months				Median payments – all households (including nonhirers) (US$)		
Geopolitical zones	All	Without animal nor tractors	With animal but not tractors	With tractors	Without animal nor tractors	With animal but not no tractors	With tractors
North-central	68	70	15	80	75	0	160
Northeast	55	40	66	72	0	40	63
Northwest	70	66	75	71	27	40	60
South[a]	61	61		88	40		188
Total	64	62	70	78	40	38	112

Source: Authors' calculations based on LSMS 2010 and 2012.
Note: [a]South = Southeast, South-south and Southwest combined. Includes, land preparation, ridging, planting, weeding, and fertilizer application.

Table 3.4 provides the approximated labor uses (total man-hours) by a typical farm household in each geo-political zone. Generally speaking, a typical farm household spends about 500—1,000 man-hours in the 4 months prior to the interview for land preparation, ridging, planting, weeding, and fertilizer applications. For farm households using only manual labor, the hired labors provide 14 percent (= 81/577) of total labor use for these activities. These shares are generally similar for households using draft animals, but slightly higher for households using tractors (31 percent = 228/740). The northeast zone typically uses the largest labor force, approximately1,000 man-hours, for these activities—which is considerably higher than those in other regions. This may reflect the heavier reliance of farming on manual labor in the northeast region, although its causes are not clear.

Table 3.4 Planting activities by household labors in the past 4 months: Total hours (land preparation, ridging, planting, weeding, fertilizing) (zonal mean)

	Family member			Hired labor (assuming 1 day = 8 hours)			Total		
Geopolitical zone	Without animal or tractors	With animal but not tractors	With tractors	Without animal or tractors	With animal but not tractors	With tractors	Without animal or tractors	With animal but not tractors	With tractors
North-central	672	1152	384	151		323	823	1152	707
Northeast	1,008	747	960	0	112	176	1,008	859	1,136
Northwest	420	448	175	81	120	180	501	568	355
South[a]	450		648	68	0	320	518		968
Total	496	560	512	81	77	228	577	637	740

Source: Authors' calculations based on LSMS 2010 and 2012.

Note: Although the questionnaire asked the information for the "past rainy season", some farmers responded with figures for up to 52 weeks. In order to derive family labor use for the 4 months, we censored those values to 16 weeks.

Information about the types of households supplying this labor is not available in the data. However, some inferences can be drawn from the job descriptions of household members. Table 3.5 summarizes the share of households with working-age members (aged 15–60) who worked primarily in agricultural activities for payments (salary and wages) in the past 12 months. The average number of such household members are included as well. While the agricultural activities here are likely to include not only planting season activities, but also harvesting activities, they also provide useful insights as to how hired laborers in the agricultural sector are supplied.

Table 3.5 Hiring out of agricultural labor in the past 12 months – based on post-planting survey

	% of households hiring out agricultural workers			Average number of hired out agricultural workers[a]		
Geopolitical zones	Total	Total among farm households	Total among nonfarm households	Total	Total among farm households	Total among nonfarm households
	43 ± 1	76 ± 1	8 ± 1	0.6	1.1	0.1
North Central	56 ± 3	87 ± 3	6 ± 2	0.8	1.2	0.1
North East	59 ± 3	70 ± 3	20 ± 5	0.8	1.0	0.2
North West	61 ± 3	73 ± 3	26 ± 4	0.8	1.0	0.3
South	32 ± 2	77 ± 2	6 ± 1	0.5	1.1	0.1

Source: Author's calculations based on National Bureau of Statistics and World Bank (2010; 2012).

Note: [a]They include those who received payments from work, as well as those not receiving payments due to the following reasons: "Just started work and waiting for first payment"; "Traineeship"; "Paying off debt"; "Payment upon completion of work"; "Owed by employer".

In total, 43 percent of households hired out at least one agricultural worker in the past 12 months. In the northeast, northwest, and north-central regions, the share is close to 60 percent, which is significantly higher than the 30 percent reported in the south. Farm households are more likely to hire out agricultural workers (76 percent at the national level) than nonfarm households (8 percent). These patterns are similar across regions. Although some nonfarm households in the northeast and northwest hire out agricultural workers (20 percent and 26 percent respectively), these shares are low. On average, households hire out 0.6 agricultural workers. This average includes households with 0 hired agricultural workers. In particular, farm households hire out 1.1 agricultural workers. Labor exchange among farm households is common, potentially indicating substantial farm power needs and the eventual demand for agricultural mechanization.

Importantly, the differences across farm households and nonfarm households are not due to the differences in their general hiring out activities of laborers. This is illustrated in Table 3.6, which show figures similar to those in Table 3.5, but includes all types of activities for which labor was hired out. When both agriculture and nonagricultural activities are considered, both farm and nonfarm households tend to hire out workers (both groups reported 83 percent). The average number of hired out workers are also similar (1.5 versus 1.4). When all activities (not only agricultural activities) are considered, we notice that farm households are mostly replacing hiring out work in nonagricultural activities with that in agricultural activities.

Table 3.6 Hiring out of labor (both agriculture and nonagriculture) in the past 12 months: Based on post-planting survey

	% of households with such household members			Average number of such household members		
Geopolitical zones	Total	Total among farm households	Total among nonfarm households	Total	Total among farm households	Total among nonfarm households
	83 ± 1	83 ± 1	83 ± 2	1.5	1.5	1.4
North-central	87 ± 2	90 ± 2	82 ± 3	1.6	1.7	1.5
Northeast	76 ± 3	76 ± 3	80 ± 5	1.5	1.5	1.4
Northwest	80 ± 2	79 ± 2	85 ± 4	1.5	1.6	1.4
South	81 ± 1	85 ± 2	80 ± 2	1.4	1.5	1.4

Source: Author's estimations based on National Bureau of Statistics and World Bank (2010; 2012).

Note: They include those who received payments from work, as well as those not receiving payments due to the following reasons: Just started work and waiting for first payment; Traineeship; Paying off debt; Payment upon completion of work; Owed by employer.

Overall, education levels in Nigeria have been gradually rising, which can affect the supply of agricultural labor. However, rural education levels are still lower than urban education levels. The effect of human capital development on the agricultural labor supply is not monotonic and must be investigated further. Hiring-in of agricultural labor is relatively common in Nigeria, suggesting that demands for intensification and future mechanization are growing.

4. IMPERFECTIONS OF TRACTOR HIRING MARKET: EMPIRICAL EVIDENCE

Two aspects are important in assessing the extent of market imperfections; (1) whether actual tractor uses follow standard economic theory; (2) whether marginal adoption of tractor significantly affect key outcome variables (such as household expenditure). If (1) holds, it indicates that at least some aspects of tractor hiring market functions in response to economic forces. In other words, significant effects of supply-side factors on tractor demand can indicate that a market structure that is more likely to lead to market imperfections exists, due to supply-side constraints. Condition (2) indicates that tractor adoption involves significant regime switching for the households, which is consistent with the hypothesis that the tractor hiring market is imperfect. We describe these aspects and corresponding empirical evidence in more detail in this section.

Determinants of Tractor Uses and Its Intensities

We first assessed if tractor uses follow standard economic theory. In particular, given the literature on the demand for mechanization and discussions on the potential supply-side constraints in the previous sections. It is in one way characterized as the variant of hurdle model where there is a hurdle in accessing tractor hiring market, but both the process of getting such access to tractor hiring market and the intensity of tractor service use are generally affected by the factors identified key determinants of mechanization adoption in the literature. Following the transactions costs literature (for example, Takeshima and Winter-Nelson 2012) this process is framed as,

$$\begin{aligned} d^0 &= f(Z, Y) \\ d^1 &= f(X, Y) \quad \text{if } d^0 = 1 \\ T &= f(X, Y) \text{ if } d^1 = 1 \end{aligned} \tag{1}$$

where $I^0 = 1$ if the farm household has access to the tractor hiring market (= 0 otherwise), $I^1 = 1$ if the farm household actually hires in tractor service (= 0 otherwise), and T is the hiring in intensity. Z represents the specific factors affecting the access of a farm household to the tractor hiring service market, X represents the factors that affect the supply and demand of tractor services within such market (such as agroecological conditions, households' farm sizes, farm wages, access to general output and input markets other than tractor hiring service), and Y represents factors that affect both processes.

Our data pose an empirical challenge in estimating these equations; I^0 is not observed. We only observe I^1 which is nested within I^0. Under the assumption that the factors affect I^0 and I^1 in the same way (same signs and significance), the second step of I^0 and I^1 can be approximated by a reduced form probit in which the dependent variable $I^* = I^0 \cdot I^1$ is regressed on Z, Y, and X. The third stage can be estimated using truncated regression. A statistically significant coefficient for Z in the reduced form probit is then a weak indication of its statistically significant effect in I^0. Estimation of reduced form probit and truncated regression is equivalent to Cragg's (1971) double-hurdle model.

Some methods have been proposed in the literature to partly overcome this problem, such as partial observability probit (Poirier 1980; Abowd and Farber 1982). Their results may be, however, susceptible to the specifications of each stage. We therefore use reduced form probit, and check its robustness through a fairly simple specification of partial observability probit. The results of partial observability probit are shown in the Appendix.

Data

Our data are from the 1st and 2nd round of the LSMS-ISA for Nigeria (NBS and World Bank 2010, 2012) and various spatial variables. Since these rounds are pseudo-panel and many determinants of agricultural mechanization are likely to be time-invariant (such as factor endowments) between the two survey rounds, we use pooled cross-section specification to estimate (1). We, however, also apply the idea of correlated random-effects (CRE) model as in Chamberlain (1984) and its pseudo-panel extension (Takeshima and Nkonya 2014) to control for some of the potentially unobserved cohort specific effects. Specifically, we use local government area (LGA) as such cohorts. We assume that district sample averages of certain time-variant variables across two rounds of LSMS surveys are correlated with the unobserved district specific effects. This modified pooled cross-section specification is different from standard CRE models. We assume that time-invariant variables such as factor endowments are identified separately from the unobserved cohort fixed effects once they are approximated by the time average of time-variant variables mentioned above. Inclusions of these cohort variables reduce the potential bias in the pooled cross-section method.

The two rounds of the LSMS surveys used contain 10,000 observations in total. We focus our analyses on approximately 6,000 farm households that reported planting at least one plot in the post-planting survey. Not all of these farm households, however, reported the plot sizes, including the GPS-based measurements. Because the total farm sizes, individual plot sizes, and measurements of the tractor use intensity (meaning the area cultivated by tractors) are important determinants of tractor uses, we excluded these observations as well. After further dropping missing observations and outliers, a total of 5,241 observations were used for the analyses.

Descriptive statistics of variables used in the analyses are presented in Table 4.1. When both rounds of the LSMS surveys were combined, approximately 4 percent of the sample households reported tractor use.

Other sets of variables are identified based on the literature on farming system evolutions and agricultural mechanization. Endowments of cultivable land are assumed to be the sum of areas that are already cropped and areas that can be converted into farmland, such as pasture. Pasture is relatively easily converted into farmland compared to forest (Binswanger 1987). Endowments of cultivable land and pasture are calculated for each enumeration areas using their coordinates. Cropped areas and pastures are estimates based on the geographic information system (Ramankutty et al. 2008). This figure was divided by the population of the corresponding LGA based on the Nigeria 2006 Population Census (Nigeria, National Population Commission 2010), to obtain cultivable land area per capita.

Soil data are from two sources. First, a soil workability dummy was constructed using the soil workability scores developed by Fischer et al. (2008). It is a score assigned to soils in each of 30 arc-second grids across the globe based on how soil management is constrained by the soil texture, effective soil depth or volume and soil phases. It is scaled as the following: 1 = no or slight constraints; 2 = moderate constraints; 3 = severe constraints; 4 = very severe constraints. In our analysis, we further aggregated these scores into two categories; 1 (workable) if no or slight constraints exist, and 0 otherwise. The majority of soil types in the LSMS sample belong to the first category. In order to reflect the local heterogeneity of soil, we further add two soil quality indicators, soil bulk density, and clay contents. Both are available from ISRIC (2013) at 1km by 1km resolution.

Distance to water resources, which affect the cost of irrigation, are proxied by the Euclidean distances to the nearest dams and rivers, each of which is based FAO (2012) and FAO (2000). Distance to the nearest town with a population of 20,000 or more are obtained from Harvest Choice (2012).

Table 4.1 Descriptive statistics of variables among farm households used in the analyses[a]

Variables	Mean	Median	Standard deviation
Use tractors (1 = yes; 0 = no)	**.04**	**.00**	**.19**
Cultivable land per capita (ha)	.51	.36	.58
Average area (ha) of owned or distributed land per plot	.74	.33	4.06
Number of owned or distributed plots	1.34	1.20	.76
Household size	6.16	6.00	3.20
# of working age household members (no education, M)	.29	.15	.35
Primary education, M	.28	.25	.19
Secondary education or above, M	.68	.65	.49
Koranic education, M	.09	.00	.22
Any other education, M	.00	.00	.01
# of working age household members (no education, F)	.62	.50	.52
Primary education, F	.30	.25	.24
Secondary education or above, F	.49	.43	.44
Koranic education, F	.11	.00	.26
Any other education, F	.00	.00	.01
Real district average farm wage	6.04	5.00	2.04
Real asset value excluding land	857.93	292.73	3080.83
Own draft animals (yes = 1, no = 0)	.12	.00	.33
Real values of draft animal	355.71	.00	2031.72
Real price of one kg of fertilizer (average of Urea and NPK)	1.09	.86	1.83
Soil with high workability (1 = workable, 0 = otherwise)	.62	1.00	.49
Bulk density of the soil (tons per m^3 of soil)	1.33	1.30	0.10
Clay contents of the soil (clay content (<2 μm) in %)	17.55	17.00	5.40
Distance to the nearest town with population of 20,000 (hours)	2.72	2.40	1.57
Euclidean distance to the nearest dam (geographical minute)	.97	.79	.70
Euclidean distance to the nearest river (geographical minute)	.02	.02	.01
Sample maximum owned/distributed land within district (ha)	4.83	1.95	16.49
Real per capita expenditure per year (excluding food)	212.00	78.67	3745.94

Source: Author based on LSMS (2011, 2013).
Note: [a]Real values are measured in average values of equivalent amount (kilogram) of rice and white gari. M = Male, F = Female.

All other variables are calculated from the NBS and World Bank (2010, 2012). Farmland holdings are the sums of farmland obtained through outright purchase or distributed by the community chief. Since high fixed costs are associated with land purchase, and land distribution is determined by factors beyond the control of the farmer, these farmland holdings are likely to be exogenous. Variables indicating the monetary values of the farmland are converted into real values, deflated by the average of the district median prices of local rice and *gari* (made from cassava), which are two of the major staple crop and food in Nigeria.

Nonfood household expenditure variable is used as outcome variables in the next section. The expenditure variable is a calculated figure, aggregated over all items reported in the expenditure modules of LSMS, each converted into a 12-month equivalent amount. More specifically, we combine short-term expenditures (7 days and 30 days) from post-planting survey and long-term expenditures (6 months and 12 months) from post-harvesting survey. This is because our interest is on the expenditure immediately following the planting season when tractors are typically used. Using short-term expenditures from post-planting survey instead of post-harvesting survey ensures that these expenditures more clearly reflect the cost savings realized from using tractors instead of labor in the planting season. Using long-term

expenditures from post-harvesting survey instead of post-planting survey ensures that the majority of reference periods are after the planting season, so that long-term expenditure *after* the use of tractors are captured. Real expenditure values are obtained by deflating through the above-price index.

One of the unique variables used in the analysis is the sample maximum within the LGA of owned- or community-distributed farmland. This variable is expected to proxy the likelihood of the presence within the district of households with large farms. Tractor owners are typically found among these households. The large farm often provides the incentive to invest into tractors that are complementary to land. These households are also more likely to be wealthier and their liquidity is less constrained against the tractor investments —particularly if expensive high horsepower tractors are the type that are suitable in their production environments. The presence of large farm households within the district is likely to affect the supply of tractor service within the district, but not the demand for it. Therefore, the significance of this variable on tractor service adoption may indicate certain constraints in the supply of tractor services.[7]

Results of pseudo-panel double hurdle model are presented in Table 4.2. 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. We omit the results for district time averages of time-variant variables mentioned above, which were included to partly control for the unobserved district fixed effects—the coefficients on those variables have no relevant meanings. Some variables were log-transformed in order to improve the goodness of fit of the model. Some log-transformed variables were converted as $x = x + 0.01$, so that observations with $x = 0$ can be included. Similar methods have been employed by other studies (Michalopoulos and Papaioannou 2014). Results are robust to different values of the similar magnitudes. Standard errors are adjusted for potential serial correlation within the enumeration areas.[8]

Results are generally intuitive. Doubling of cultivable land per capita raises the likelihood of tractor service adoption by 0.7 percentage points. A greater land endowment relative to labor induces the use of tractors which is a complement to the former and a substitute to the latter. Nigeria has become relatively land scarce in an international context, which is also indicated in Table 3.1 where cultivable land per capita is about 0.5 ha among our sample. In such circumstances, overall demand for intensive land preparation is high, and tractors serve as substitutes for labor depending on the level of labor scarcity. The number of male, working-age household members without education reduces the likelihood of tractor service adoption, possibly because they are willing to be engaged in manual land preparation. Conversely, a greater number of working-age female members with at least secondary education raise the adoption of tractor services. These are consistent with the hypothesis that human capital formation induces the substitution of labor with machinery. Once human capital is controlled, farm labor wages in the area does not seem to affect tractor adoption, indicating that it is the labor costs of household members that induces 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. An increase in real fertilizer price raises the possibility of tractor service adoption, possibly because fertilizer and tractors may be broadly substituted. The former is complementary to labor, while the latter is complementary to land. 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.

[7] Ideally, the information of the number of tractor owners within the district should be used to assess the level of access to tractor hiring service. To the author's knowledge, such information is not available in our data or from the Nigeria, National Bureau of Statistics. Nevertheless, presence of large scale farmers in the sample in the district indicate that (based on the probability sampling theory), the number of such large-scale farmers in the district must be substantial, which also raise the likelihood that sufficient number of tractor owners exist in the district and provide hiring services.

[8] Although programs such as STATA allow this adjustment, there seems to be no clear consensus regarding whether it is appropriate to adjust standard errors against heteroskedasticity or serial correlation in the case of probit or truncated models. However, in our case, unadjusted standard errors are generally smaller and coefficients are more significant. The results in Table therefore provide generally conservative estimates of the statistical significance of coefficients.

Table 4.2 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 μm) 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: Author.

Note: *** 1 percent, ** 5 percent, * 10 percent. [a]Significance is based on standard errors adjusted for EA cluster effects. M = male, F = female; Ln =natural log; NPK = Nitrogen, Phosphate, and potassium.

Upon the adoption of tractor services, the areas cultivated by tractors depend largely on the average plot sizes of owned or distributed farm 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. However, this point must be investigated further in future studies. 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 the somewhat complicated effects of human capital. A positive effect of draft animal assets may suggest that draft animals are not substitutes for tractors because of their considerable differences in the power (when compared to Nigeria's high horsepower tractors. However, they are complementary in allowing the

subsequent production practices, such as second plowing, transporting of agricultural inputs or harvests, on the large farm that has been prepared by tractors. 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 LGA in the sample raises the possibility of tractor service adoption by 0.2 percentage points in the probit model, which is statistically significant. As discussed in the previous section, 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 into tractors and serve nearby farmers.

These results suggest that, although tractor adoption in Nigeria is low, it is generally driven by or functioning according to economic factors. This is important because the results imply that policies to encourage the use of tractors will require supplementary policies that affect underlying economic structure, human capital formation, and farm wages.

However, these results also suggest that the adoption of tractor services by farmers is also constrained by some supply-side factors, particularly the presence of owners of large farmland within the district, which can affect the availability of tractor services within the district. The latter effect is consistent with the observations discussed in earlier sections about the large average tractor size in Nigeria, their sparcity and limited mobility, and the potential consequence of tractor service market failure. We investigate the indications of such market failures further in the next section.

Market Failures in Tractor Service Provisions

Directly testing the presence of market failure is often difficult as it requires detailed understanding of the market structure. Here, we focus on identifying a condition at the household level, which is likely to be one of the consequences of the market failure. We first illustrate such a condition conceptually. We then empirically test this condition empirically.

Technology Adoption under Market Failure – a Simple Conceptual Illustration

We illustrate a household's decisionmaking mechanism on technology adoption when there is a market failure in the supply of this technology. This is in one way described by a mixed-regime model in which a household faces fixed transactions costs in switching from a no adoption state to an adoption state (Takeshima and Nkonya 2014). A household maximizes the profit

$$\max_{\mathrm{I_r},\mathrm{L_r},\mathrm{M_r}} \Pi = I_0 \cdot [F_0(L_0; z) - p_L L_0] + I_1 \cdot [F_1(L_1, M_1; z) - p_L L_0 - p_M M_1 - \eta]$$

subject to

$$I_0 + I_1 = 1$$

$$L_r, M_r \geq 0 \quad \forall\, r.$$

where the profit Π depends on the output F_r, cost of labor (= labor use L_r times its unit price p_L), and the cost of mechanization services ($p_M M_1$). For simplicity, we assume labor and machines are the only inputs. A farmer faces two regimes $r \in (0,1)$. Regime 0 is constrained where no tractor service is available, while regime 1 is unconstrained and tractor service is available. A farmer starts from regime 0 ($I_0 = 1$), and decides whether to move to regime 1. There is, however, transactions costs η associated with switching to regime 1. This cost is due to the various constraints, including limited mobility of tractors discussed in earlier sections.

If $\eta = 0$, decisions on *I* is irrelevant and the model reduces to

$$\max_{\mathrm{I_r},\mathrm{C_r},\mathrm{X_r}} \Pi = F(L, M; z) - p_L L - p_M M.$$

Here, a marginal increase in the use of M (caused by a decrease in P_M) has no effect on profit. We illustrate this case where the agent is indifferent in using no M and using marginal quantity of M. This happens when $\partial F / \partial M = p_M$, $\partial F / \partial L = p_L$, and

$$\frac{\partial \Pi}{\partial M}\Big|_{\frac{\partial F}{\partial M}=p_M} = \frac{\partial F}{\partial M} - p_M = 0$$

In other words, a marginal increase of M from $M = 0$ should have no effect on the outcome variables.[9]

When $\eta > 0$, there is an approximate gain in Π associated with regime switching,

$$-\int_{L^*}^{L_0}\left(\frac{\partial F(L, M_0)}{\partial L} - p_L\right)dL + \int_{M_0}^{M^*}\left(\frac{\partial F(L^*, M)}{\partial M} - p_M\right)dM \tag{2}$$

where L^* and M^* are global optimal solutions under both regimes. (2) is related to the so-called *wedge* arising due to the misallocation of resources such as labor across sectors. If $\eta > 0$ but the constraint in regime 0 is nonbinding, $L_0 = L^*$, and $M_0 = M^*$, and the term is zero. Based on the linear integral theory, the first term represents the loss due to using less labor (as a result of substitution with the use of M) measured at the initial condition $M = M_0 = 0$. However, the whole term is non-negative because the second term, which represents the benefits from tractor use, is positive and offsets the loss (first term).

If labor is highly substitutable to machinery, these effects are somewhat mitigated, but still considerable. To illustrate this, we provide examples of this effect through a simple simulation based on constant elasticity of substitution (CES) production function,

$$\Pi = A[aM^{\rho} + (1-a)L^{\rho}]^{\beta/\rho} - p_M M - p_L L \tag{3}$$

where M is the mechanical power and L is the labor power. a is the share parameter, $\rho = 1/(1-\varepsilon)$ in which ε is the elasticity of substitution between M and L. β is the scale parameter, where $\beta < 1$, $\beta = 1$ and $\beta > 1$ indicates decreasing, constant, and increasing returns to scale, respectively. For simplicity, we assume $A = 4$, $a = 0.33$, and $p_L/p_M = 2$. These values are selected solely to illustrate how the implications of above discussions on the market failure depend on production structure, and thus need to be empirically tested. Using the standard profit maximization conditions of Π and applying the first order conditions, Table 4.3 summarizes gains from removing barriers to tractor use, under various levels of labor-tractor substitutability and scale factors. If β is large enough for technology to have fairly constant returns, and substitutability with labor is low, the wedge due to tractor service market failure is larger. For example, while the wedge is only 3 percent when $\beta = 0.6$ (so that returns to scale are fairly diminishing) and $\varepsilon = 20$ (labor can largely substitute tractor use), it is 100 percent if $\beta = 0.8$ and $\varepsilon = 3.3$. While we do not estimate the CES function per se, simulation results suggest that the effect of tractor service market failure can lead to edges of varying size.

Table 4.3 Effects of removing barrier to tractor use: Illustrative exercise (percent change in profit)

Elasticity of substitution between labor and machinery services (ε)	$\beta = 0.9$	$\beta = 0.8$	$\beta = 0.7$	$\beta = 0.6$
$\rho = 0.95$ ($\varepsilon = 20$)	21	9	5	3
$\rho = 0.9$ ($\varepsilon = 10$)	50	20	11	7
$\rho = 0.8$ ($\varepsilon = 5$)	149	50	27	16
$\rho = 0.7$ ($\varepsilon = 3.3$)	374	100	50	30

Source: Author.

[9]This point is important for the impact of agricultural technology adoption in general. Whether it is modern seeds or fertilizer, their marginal adoptions should have no effect on profits in the perfect market.

Propensity Score Matching Among Marginal Adopters

The conceptual framework in the previous section suggests that one can detect the indication of the failure of the tractor service market. Specifically, if significant changes in key outcome variables are explained by a marginal adoption of a tractor, they can indicate the failure of the market. Here, the focus on marginal adoption is important. This is because outcome variables are affected by both at the extensive margin (tractor use or no tractor use), and intensive margin (intensity of tractor use). For the intensive adopter, the change in outcome variables through adoption may be due to the intensive use. For example, while the outcome variables of a farmer using tractors for 50 ha of land may be significantly different from nonadopters, such difference is likely to arise from the cost reduction in land preparation accumulated over 50 ha of land, which cannot be separated from the changes purely due to the adoption of tractors. However, if the changes in outcome variables are identified from farmers using tractors for only a half hectare (thus adopting it marginally), the effects may be more likely to be due to the adoption per se.

The effect of tractor service adoptions on the various outcome variables can be in one way estimated through propensity score matching methods (PSM) (Rosenbaum and Rubin 1983), which is widely used in other technology adoption studies and impact evaluations of various targeted intervention programs.

Because we only observe d^1 and not d^0, the application of PSM here should be interpreted in the following way. There are three groups: (1) marginal tractor users; (2) those with access to tractor services but not using tractors; and (3) those without access to tractor services. In PSM, we essentially compare the differences in the outcome variable (household expenditures) between (1) and (2) + (3). Under the discussions in conceptual framework in the previous section, (2) should have the same outcome as (1), while (3) has lower outcome than (2). Therefore, a significant difference in outcome variable between (1) and (2) + (3), which we estimate, is a sufficient condition for the significant difference between (1) + (2) and (3), which is the hypothesis of our interest.

As was mentioned above, the PSM here only focuses on marginal adopters of tractor services. We define *marginal adopters* as those using tractors for only small areas of land. Limiting the analyses to marginal adopters, however, also limits the size of the treatment group. We decided to use 0.4–0.45 ha as thresholds. In Nigeria, these are fairly small among tractor users who often cultivate 5 ha or more.[10] Thus, much of the impact of their adoptions, if it exist, is likely to be from the adoption on extensive margin than on intensive margin, which is what we need to estimate. Using lower thresholds can limit the size of samples in the treatment group used in the analyses to less than 20–30 observations, which can considerably limit the power of the test. These limitations are partly overcome in the next section where we apply the methods for continuous treatment, rather than binary treatment.

We use radius matching with varying caliper size, suggested by Dehejia and Wahba (2002), and kernel matching. Due to the small sample size of the treatment group (marginal adopters of tractors), results vary to some extent across different matching methods. Though the nearest-neighbor method is another matching algorithm popularly used, we do not use this method because the estimates tend to be inefficient (Caliendo and Kopeinig 2008). This may be inappropriate for the small sample size of the treatment group used in this study. We use the caliper of 0.005, 0.01, and 0.05, as the estimated propensity score are generally in the range of 0–0.1.

The PSM method is vulnerable to the violation of ignorability assumption (or "selection of observables" as sometimes phrased), which can be particularly serious in cross-section methods. However, we include the correlated random effects exploiting the pseudo-panel nature of the datasets, in order to partly control for district-level unobserved fixed effects. Such adjustments are expected to partly mitigate the limitation of PSM due to the ignorability assumption.

Estimated average treatment effects are summarized in Table 4.4. The effects are often statistically significant. Based on radius matching, using tractor services on 0.4 ha of plots lead to almost

[10]Based on the informal conversation with local experts.

a 40 percent increase in per capita household expenditure, compared to nonadopting households with similar characteristics. At the median of the sample, this is equivalent to approximately $22 per capita per year, or $135 per year at the household level. Using the threshold of 0.45 ha also leads to statistically significant effects of nearly 35 percent in various specifications. These significant effects that are present, despite the marginal adoption of tractors services, are consistent with the conditions illustrated in the conceptual framework that can arise as a result of the failure in the tractor service market. In the absence of the market failure (so that farmers face no barrier in paying for the desired amount of tractor service), marginal adoptions of such services should not have significant impacts on household expenditures.

Table 4.4 Results of propensity score matching method among marginal adopters

Matching methods	Threshold (area cultivated by tractors)	
	0.4 ha	0.45 ha
Kernel matching	.250	.334
Radius matching with caliper = 0.005	.359*	.344*
Radius matching with caliper = 0.01	.308	.333*
Radius matching with caliper = 0.05	.247	.324*

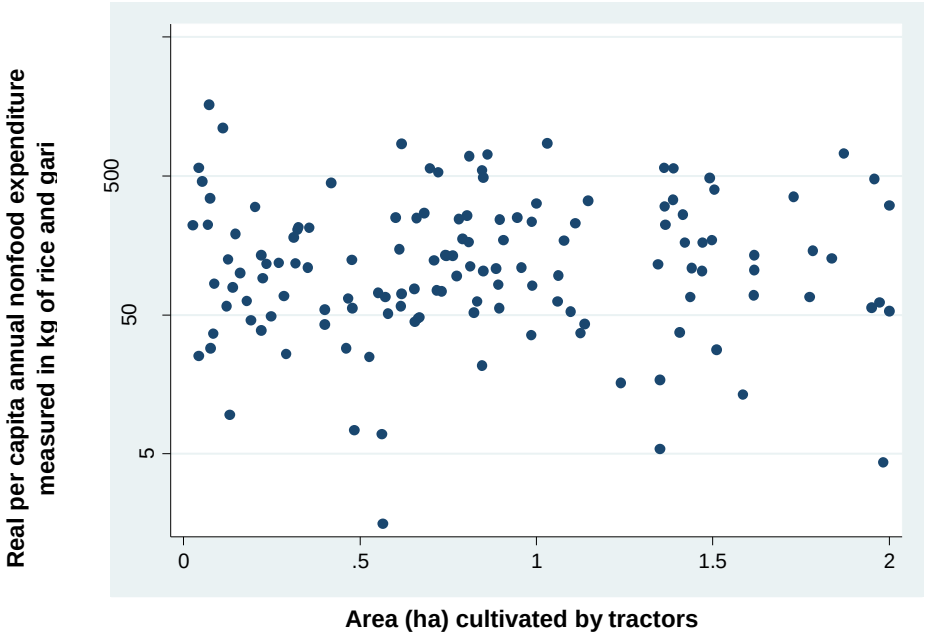
Source: Author's estimation.
Note: *** 1 percent, ** 5 percent, * 10 percent. Dependent variable = natural log of per capita household expenditure.

Insights from the Generalized Propensity Score Matching Method

Our objective is to separate, as much as possible, the effect of the marginal adoption of tractors from the effect of the tractor use intensity (area cultivated by tractors). The effects of tractor service adoption estimated in previous sections can contain the effects of tractor use intensity if marginal treatment effects are positive. This is, however, unlikely the case. First, as is shown in Figure 4.1, there is low one-to-one correlation between the real per capita expenditure level and tractor use intensity among those households using tractors on up to 2 ha of land.

The lack of marginal treatment effects of tractor use intensity can also be more formally examined through generalized propensity score matching method (GPSM) proposed by Hirano and Imbens (2004). GPSM is an extension of PSM to the case in which treatment is continuous rather than binary. We use a STATA program `doseresponse` developed by Bia and Mattei (2008). Estimation focuses on observations where area (ha) cultivated by tractors is greater than 0 and not greater than 2. Using the same set of variables used for PSM above, normality assumptions are satisfied at 5 percent statistical significance level, so that the estimated dose response functions are consistent. We use the cutoff points of 0.5, 0.75, and 1.5 to obtain GPS adjusted means of each covariate, as they seem to satisfy the balancing properties across each of these subgroups (based on Bayes Factor test, there are only moderate evidence against the balancing property).

Figure 4.1 Weak correlation between real per capita expenditure and tractor use intensity among marginal adopters



Source: Author.

Results of GPSM are shown in Table 4.5. Treatment and GPS variables together rarely explain the variations in the log of real per capita expenditure, which are indicated by the high p-value of the lack of overall fit (more than .900). These results again suggest that, among marginal adopters of tractors, the effects of tractor use intensity are minimal. The significant impacts of tractor service adoptions found in PSM above are therefore more likely to be from the adoption itself (extensive margin), and not from the accumulated marginal treatment effects of tractor use intensity (intensive margin).

Table 4.5 No marginal treatment effects of tractor use intensity up to 2 hectare (dose response model)

Dependent variable	ln (real per capita expenditure)		
Treatment	.122 (.432)	.701 (.997)	.618 (1.001)
GPS	-.066 (.656)	-.037 (.659)	-1.654 (1.826)
Treatment*GPS	-.070 (.543)	-.197 (.579)	-.081 (.592)
Treatment squared		-.261 (.404)	-.287 (.405)
GPS squared			1.110 (1.169)
Constant	-.339 (.555)	-.502 (.610)	-.013 (.799)
R^2	.003	.006	.014
p-values of overall fit	.952	.944	.893
Number of observations	127	127	127

Source: Author.
Note: [a]Numbers in parentheses indicate the standard errors of estimated coefficients.

5. CONCLUSIONS

Agricultural mechanization has been an integral part of agricultural transformation around the world. Yet the mechanization patterns in SSA are not well known. We fill this knowledge gap using Nigeria as an example.

Patterns of tractor service adoption in Nigeria are unique. Adoption appears slow given the low and declining shares of the agricultural sector in the overall economy and labor employment. Despite the low mechanization level, high horsepower, four-wheel tractors seem to dominate the tractor market.

Although the mechanization levels are low, examinations of the determinants of tractor service adoptions indicate that current tractor use patterns in Nigeria remain consistent with the factor endowment predictions. In other words, the tractor service market may be partly functioning in a way that reflects the underlying economic conditions.

However, tractor service adoptions are also partly affected by the presence of large farm households within the districts, which tend to be the supplier of tractor services. This is consistent with the hypothesis of market imperfections due to supply-side constraints. Further examinations of the impacts of tractor service adoptions suggest that market failure continues to exist in the tractor service market. This is reflected by a substantial change in income level arising from a marginal adoption of tractor services, which would not be observed if the tractor service market is perfected.

APPENDIX: SUPPLEMENTARY TABLE

Abowd and Farber (1982) develops a partial observability probit model based on sequential decisionmaking, which is more appropriate in our case than Poirier (1980).

Table A.1 Robustness check through Abowd and Farber (1982)'s partial observability probit

	Partial observability probit	
Dependent variable	**Probability of having access to tractor hiring market**	**Probability of using tractor, upon getting access to hiring market**
Ln (cultivable land per capita)		.009***
Average area (ha) of owned or distributed land per plot		-.001
Number of owned or distributed plots		.002
Household size		.001
# of working age household members (no education, M)		-.004
Primary education, M		.002
Secondary education or above, M		-.001
Koranic education, M		-.004
Any other education, M		-.028
# of working age household members (no education, F)		-.003
Primary education, F		.001
Secondary education or above, F		.003
Koranic education, F		.002
Any other education, F		-.007
Ln (real district average farm wage)		.023
Ln (real asset value)		.003***
Own draft animals (yes = 1, no = 0)		.001
Ln (real values of draft animal)		.000
Real price of one kg of fertilizer (average of Urea and NPK)		.001
Soil with high workability (1 = workable, 0 = otherwise)		.017*
Bulk density of the soil (tons per m^3 of soil)		.053
Clay contents of the soil (clay content (<2 μm) in %)		-.001
Distance to the nearest town with population of 20,000 (hours)		.000
Euclidean distance to the nearest dam (geographical minute)		-.008
Euclidean distance to the nearest river (geographical minute)		-.236
Ln (sample maximum owned/distributed land within district, ha)	.004**	
Time dummy (year 2012 = 1)	Included	Included
Sector dummy (rural = 1, urban = 0)		Included
Correlated random effects components		Included
Zonal dummies		Included
Constant		Included
Number of observations	5241	5241

Source: Author. *** 1%, ** 5%, * 10%.

Notes: [a]Significance is based on EA cluster-adjusted standard errors. M = male, F = female.

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