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MARKET IMPERFECTIONS FOR TRACTOR SERVICE PROVISION IN NIGERIA: INTERNATIONAL PERSPECTIVES AND EMPIRICAL EVIDENCE

By

Hiroyuki Takeshima

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EXECUTIVE SUMMARY

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

In Nigeria, despite the scarcity of tractors, average horsepower and prices of tractors appear high. These patterns are different from the experiences in other parts of the world where initially tractor horsepower was often smaller, such as Asia, or farmers were better endowed with land and wealth, such as Latin America. 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 suggested that the spatial mobility of tractors is generally low and the use of tractors is highly seasonal. There do not seem to be plausible explanations for the seeming dominance of large tractor use based on available information on prices and soils. Nevertheless, these patterns seem driven by the own initiative of the private sector rather than by government policies.

Indivisibility of large tractors and limited mobility of supplies may cause imperfections in the custom tractor 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 for the research presented here we tested these hypotheses focusing on the differences among marginal adopters of tractor hiring services and non-adopters with similar characteristics. The results are three-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 non-adopters with similar characteristics. This difference seems to arise from adoption per se, rather than the intensity of adoption, which is consistent with the hypothesis of imperfection in the custom tractor 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 often has been an integral part of agricultural transformation around the world, playing an important role in keeping farm production costs low by supplying the cheap farm power required along 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 historically adoption of agricultural mechanization has been largely driven by demand for more frequent cultivation, area expansion, and to save labor (Pingali 2007; Herdt 1983). Despite its indivisibility and dependence on the availability of spare parts and repair services, in most areas of the world the 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 their liquidity constraints, individuals were able to accumulate sufficient wealth over time to manage the fixed costs necessary to acquire tractors. Adaptive design innovations to improve the performances of tractors have mostly been provided by the private sector as well. These experiences in the United States (Manuelli and Seshadri 2014), Asia, and other regions have led to the broad belief that agricultural mechanization will increase once demand grows, with few supply-side constraints.

Questions still remain, however, regarding whether the situation in SSA is the same as in other regions. Although land scarcity is an increasingly relevant phenomenon in SSA (Jayne, Chamberlin, and Heady 2014), Asian experiences show that mechanization can grow in land scarce environment as well. In Nigeria, SSA's most populous country, the current mechanization level seems low even though the share of the agricultural sector in the national economy has been low and declining. Related in complex ways to the ongoing debate about low agricultural labor productivity in SSA (McMillan, Rodrik, and Verduzco-Gallo 2014; Gollin, Lagakos, and Waugh 2014), agricultural mechanization levels in Nigeria are also lower than might be expected given that less than half of the workforce in Nigeria is now employed in the agricultural sector. Agricultural productivity growth and cost reductions in production do not appear to happening through other pathways either. Despite 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 et al. 2016). The average horsepower of tractors and thus the average price of tractors in Nigeria appears to be 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 in the country is rare due to the risk of damage, and formal loans are typically unavailable due to their high transactions costs. These conditions suggest potentially significant effects of indivisibility and liquidity constraints on tractor investments and on the supply of tractor services. Furthermore, these patterns do not seem to be led by government policies, but often by initiatives of the private sector itself.[1]

Tractors, particularly of high horsepower, exhibit economies of scale. Takeshima et al. (2014) showed that many of the tractors in Nigeria cost more than US$10,000, 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 2015). Because of such high capital costs, tractors are

[1] For example, demand generally exists for smaller-scale machines in Nigeria as well as in other parts of West Africa, such as motor pumps (Takeshima & Yamauchi 2012; Takeshima et al. 2010), or power tillers in Ghanaian rice irrigation schemes (Takeshima et al. 2013b). The dominance of large tractors in Nigeria does not seem to be explained merely by a preferences for larger types of machinery.

unique. In countries like Nigeria, tractors may be less scale-neutral technologies than has historically been the case in other countries in their early stages of agricultural mechanization.

Understanding the current patterns of agricultural mechanization in SSA is crucial to understanding whether the current level of agricultural mechanization is optimal from an economic standpoint and how agricultural transformation can be facilitated in the region. This study provides some insight into these questions using Nigeria as an example. This is done through examining data collection from two farm household surveys in Nigeria as well as from secondary data and the research literature. First, we consider agricultural mechanization in Nigeria from historical and international perspectives. We then analyze empirically the determinants of tractor use in Nigeria, as well as the presence of some market failure.

The current equilibrium for agricultural mechanization in Nigeria – the dominance of large tractors – may be the result of several factors. The majority of existing tractors may be large simply because the government has historically promoted large tractors. However, a second factor may be the characteristics of demand for tractors, which are determined by the prevailing production technologies and environments in Nigeria.

This study builds on earlier research literature on agricultural mechanization by providing evidence on the adoption patterns of tractor services from Nigeria using pseudo-panel datasets and various spatial datasets to control the heterogeneous factor endowments. The research also contributes to the broader literature on agricultural and structural transformation by offering insights into the mechanisms for the adoption of custom tractor hire service, which is a potentially important facilitator for moving labor out of the agricultural sector and into more productive sectors.

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

2. IMPERFECTIONS IN THE 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 in other countries with relevance to West Africa is that the size of agricultural machinery employed had been relatively small at the beginning of agricultural mechanization process. Historically, agricultural mechanization started with the adoption of two-wheel tractors or lower horsepower four-wheel tractors, rather than the high horsepower four-wheel tractors (Table 2.1). This pattern is seen around the world. In the United States in the early 1900s, average tractor horsepower was around 10 to 20 horsepower (hp) when the adoption of tractors began (Olmstead and Rhode 2001). In many Asian countries, both two-wheel tractors with typically less than 15 hp and four-wheel tractors generally with around 30 hp were widely adopted in the early period of agricultural mechanization.[2]

Table 2.1: Typical horsepower of tractors in selected countries over time

	~ 1960s	1970s –1980s	1990s–2000s
Brazil	no data	65-75 hp [a]	
China	no data	1978: 1 million 11 hp; 800,000 42 hp [b]	2010: 18 million <20 hp; 4 million >20 hp)
India	no data	15-50 hp [c]	2000: 23% of tractors 20-30 hp; 55% 30-40 hp; 14% 40-50 hp [d]
Indonesia	no data	1984: 8,880 10hp; 2,470 12hp 4wt; 640 20hp 4wt; 150 35hp 4wt; 860 50hp 4wt [e]	2000: 100,000 10 hp 2wt [c]
Nepal	no data	35 hp [f]	no data
Pakistan	no data	30-60 hp (imported) [c]	no data
Thailand	no data	1978: 300,000 <45 hp; 33,000 >45 hp [c]	no data
United States	1910-1950: 10-20 hp [g] 1960s: 20-30 hp [g, h]	1986 – tractors increased in numbers from 1930 by 5.1 times, while total hp increased by 12.4 times [i] 1990: 100-150 hp [j]	no data
United Kingdom	1960s: 35 hp [c]	no data	no data
Western Europe	no data	1970s: 45 hp common [d]	no data
Vietnam	no data	no data	2006: 266,000 <12 hp; 100,000 12-35 hp; 24,000 >35 hp [d]

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).

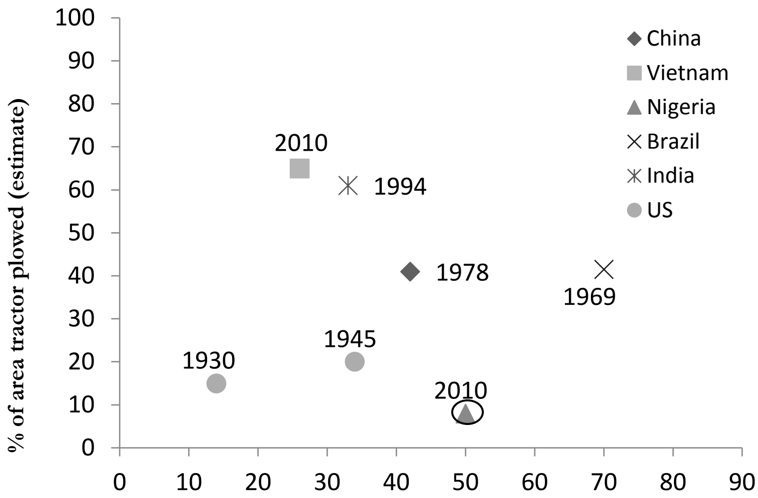
Note: hp = horsepower; 4wt = four-wheel tractor; 2wt = two-wheel tractor.

Currently in Nigeria and Ghana, the power range for most tractors is typically between 50 and 70 hp. Tractor horsepower largely determines the optimal operational scale for the machine and the size of the required fixed investment. Historically, agricultural machinery has been a relatively scale-neutral technology around the world. However, this is not the case in present day Nigeria. Tractor horsepower has been relatively high in Latin America, but as is shown below, farmers have been much wealthier than current farmers in Nigeria. In other words, liquidity constraints

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

have been less binding and market failure less severe for machinery investment elsewhere than in Nigeria. This is also illustrated in the relationship between the average horsepower of four-wheel tractors and the level of mechanization in Nigeria and other selected countries in the past (Figure 2.1). Clearly, the dominant types of tractors in Nigeria are uncharacteristically large (high horsepower) despite the fact that the country's mechanization level is still low, which stands in contrast to the past trajectory of many other countries.

Figure 2.1: Average four-wheel tractor horsepower and level of mechanization, by country (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); Nigeria: Takeshima & Salau (2010), Takeshima et al. (2015), and informal communications with local experts for Nigeria.

Note: 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 is the average of the states of Rio Grande du Sol and Santa Catarina, as reported by Stizlein (1974, Table 7).

While it is often argued that small tractors were designed and adopted in Asia or Europe to better serve their smaller farm sizes (Binswanger 1987), that does not seem to fully explain the situations in West Africa. In Nigeria, the size of the cultivated area of farmers 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 than is the case in Latin America. In the United States, the trend toward fewer but larger farms has increased demand for larger horsepower tractors to exploit the economies of scale larger tractors offer (Hlavacek and Reddy 1986; Fulton, Heady, and Ayres 1978). The pattern in Nigeria contradicts this.

Relatively lower horsepower in Asia is not simply because of the dominance of two-wheel tractors that are particularly suited for wet paddy production.[3] Four-wheeled tractors had been

[3] In Burma, soil preparation during the rainy season is not possible with four-wheel tractors due to their weight and the poor traction conditions of the clay soils. Accessibility to individual plots on each farm is much better using two-wheel power tillers rather than four-wheel tractors. "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 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). It was found at the same time that one power tiller substituted for 22 pairs of draught animals in Bangladesh (Gill 1983). In Asia, two-wheel power tillers have mostly been used for flooded paddy cultivation and provided a more complete total tillage substitute for draft animals than did four-wheel tractor. With four-

popular as well, particularly in South Asia, where rice – non-rice crop rotations are common (Pingali 2007).[4] In India, where four-wheel tractors are dominant, 8 hp two-wheel tractors are one-third of the price of 30 to 40 hp four-wheel tractors. In Pakistan, two-wheeled tractors were not popular in the 1980s because operating costs were higher than those for four-wheeled tractors (Farrington 1986). Similarly, in the United States, tractor horsepower was often as low as 10 hp in the 1920s when adoption started, even though most farming was on dry land. Tractorization was considered a more gradual process, with farmers often substituting a few horses (out of five or six horses owned) with one tractor, while maintaining a stock of horses (primary examples investigated by Clarke 1991).

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

Geopolitical zone	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.

Farm Wealth Level Relative to Tractor Prices

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

Table 2.3: Farm household characteristics in Brazil, 1950

Type of farm households	% of all farm households	Average cultivated area (ha)	Cultivated area per worker (ha / worker)	Average production value per ha (2010 US$)	Average production value per farm household (2010 US$)
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).

wheel tractors, substantial labor is generally required for tidying up field corners, repairing damaged bunds, and leveling (Farrington 1986). This raises the hypotheses that adoption of two-wheel power tillers has been facilitated by existing production practices that involved animal traction on wet paddy.

[4] In Sri Lanka, four-wheel tractor ownership has been more profitable than power tiller ownership (Ulluwishewa and Tsuchiya 1983). Four-wheel tractors were also shown to be more suitable for use in rental markets over a larger geographic area and more amenable for use as transport vehicles. Four-wheel tractors have also been more popular than two-wheel tractors for large-scale sugarcane production (IRRI 1978). Large tractors might have preceded a high degree of water control development, such as in central Luzon or in central Thailand, where their use in sugarcane farming may have stimulated adaption to rice (IRRI 1983). However, four-wheeled tractors in Central Luzon were rapidly replaced with power tillers in the 1970s (Otsuka, Gascon, and Asano 1994). Japan switched from two-wheel tractor to four-wheel tractor after the 1970s (IRRI 1978). There, the rapid shift from walking tractors to riding tractors in 1972 (IRRI 1986) had been enabled by the adoption of high-lug tires for soft soil.

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

Table 2.4: Farm sizes, cash margins, and tractors in the United States in 1920 and 1930

	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: [a] Cash margin is from Clarke (1991, Table 3), which is synonymous to profit. Tractor price based on Clarke (1991, 109). Both figures are converted by authors using $1.00 in 1930 = $13 in 2010.
[b]Assessed from Olmstead and Rhode (2001, Figure 1 and Table 3).

Similarly, during the period from 1920 to 1930 when 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]

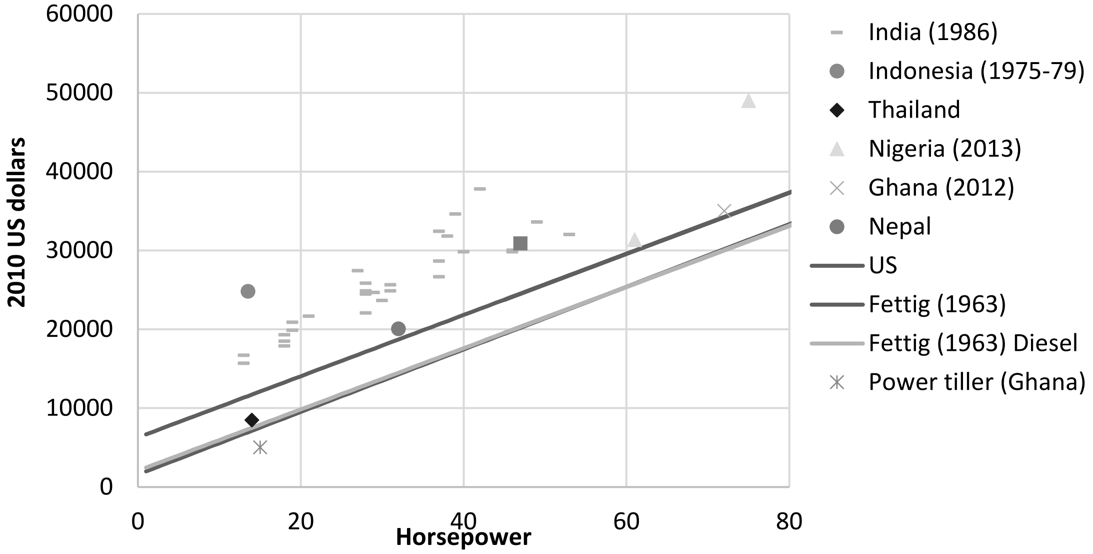
Dominance of Large Tractors in Nigeria – General Lack of Plausible Explanations

Typically, the price of tractors and horsepower has a positive, but either linear or nonlinear, association (Figure 2.2). In linear cases, the tractor price is proportional to its horsepower. In nonlinear cases, the price increase per horsepower tends to diminish at higher horsepower range. With such nonlinear associations, large tractors can provide greater horsepower per unit price.

[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.

Meanwhile, horsepower, speed, and capacity of plowing are relatively linear. Under such conditions, large tractors tend to achieve lower costs than do small tractors.

Figure 2.2: Horsepower and tractor prices



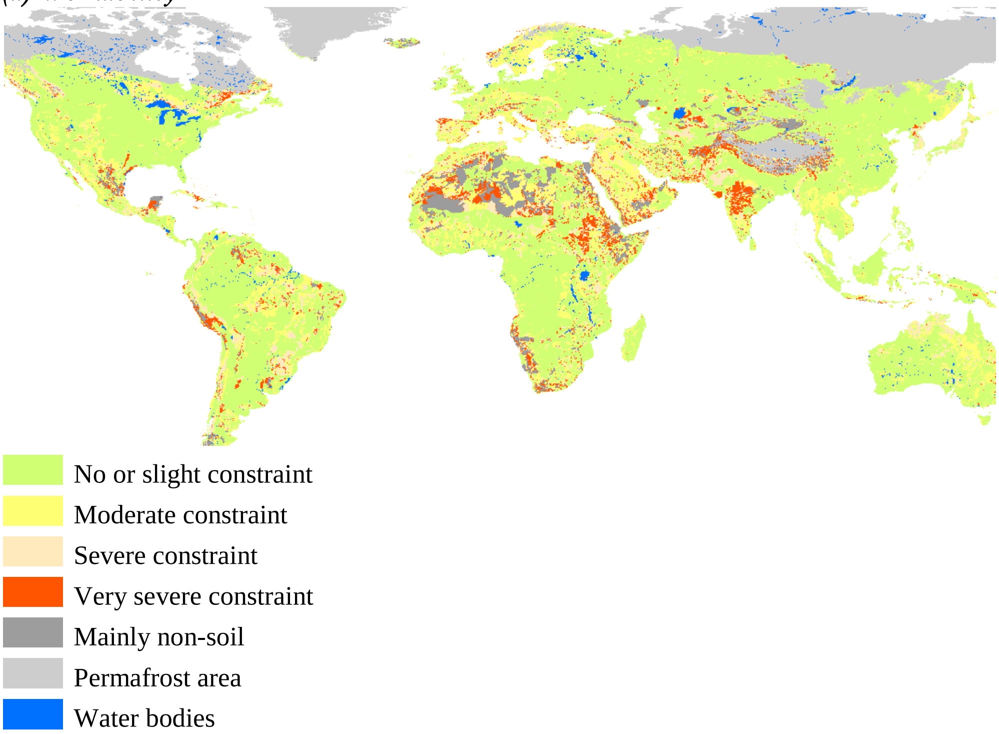
Source: World Bank (2012), WDI (2014), IRRI (1986); Takeshima et al. (2014), Roumasset and Thapa (1983), IRRI (1986), Hayami and Ruttan (1970); Fettig (1963).

Note: Ghana data 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 from Takeshima et al. (2013). India data from IRRI (1986), PPP conversion rate = 0.5, US$ 1.00 in 1986 is US$ 1.99 in 2010. Since the figures for India may include implements, we multiplied the price by two-thirds to obtain assumed tractor only prices. Nigeria data from Takeshima et al. (2014), PPP conversion rate of 0.6 in 2013, and US$1.00 in 2013 is US$ 0.94 in 2010. Nepal data from Roumasset and Thapa (1983), conversion rate assumed to be 1 rupee = $0.0683 in 1982, PPP conversion rate = 0.4, US$1.00 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 $1.00 in 1962 = $7.22 in 2010. Hayami and Ruttan (1970, 1137) provide similar figures for tractors between 1915 and 1960.

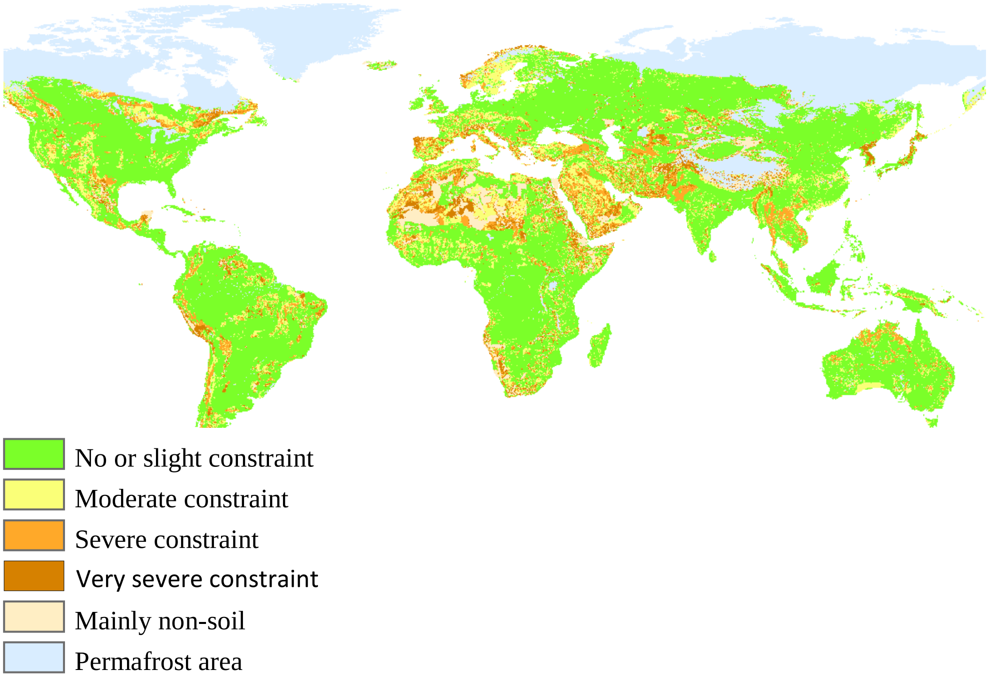
However, the reverse is also possible. From the manufacturing standpoint, there are sufficiently large numbers of smaller tractors (both two-wheel and four-wheel) produced in Asia (particularly China and India), which can be easily imported into Nigeria if there is demand. Many of the large tractors produced for Africa seem to be produced separately from the domestic tractor 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, than the manufacturing costs of small tractors. In the Kpong area in Ghana, where power tillers are used, the commercial (unsubsidized) price of Indian 15 hp power tillers is approximately $4,000 ($5,000 at PPP), which is below the plot of the linear relationship between tractor cost and power found by Fettig (1963) and shown 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 results in higher shipment costs per tractor. This is less of a concern for smaller horsepower tractors, as they are 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 their price alone.

Figure 2.3: Workability and rooting conditions of soils

(a) Workability



(b) Rooting conditions



Source: Fischer et al. (2008).

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 selection of how powerful a tractor to employ. For plowing upland fields, power tillers and small four-wheel tractors with less than 30 hp are typically not competitive with larger four-wheel tractors, 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 any heavier than those cropped in other parts of the world. Figure 2.3 maps the workability and rooting conditions of soils, both of which affect ease of tillage (Fischer et al. 2008). The soils in West Africa do not appear any heavier nor provide any greater constraints to workability or rooting conditions relative to the soil in Asian countries such as India.

Unclear Policy Effects

It could be argued that the dominance of larger tractors in Nigeria is due to government promoting them. However, in underdeveloped areas such as rural Nigeria and in SSA more generally, the public sector typically has low capacity for regulatory enforcement, particularly in areas distant from the capital cities (Michalopoulos and Papaioannou 2014). Consequently, it is unlikely that the government can successfully influence the type of tractors used in the country.

In Nigeria, promotion of large-scale irrigation equipment, such as sprinklers or drip irrigation, has been unsuccessful in the past, while private investments in small-scale irrigation pumps have been relatively more successful (Takeshima et al. 2010). Similarly, 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 an effective rice import tariff systems to be commercially successful, something that government has not been able to successfully put into place (Johnson 2014). Likewise, locally fabricated threshing machines are commonly found in the major rice-producing regions of Nigeria, although there have been no direct efforts from the government to promote them. Consequently, even if government promotes large tractors, if the private sector finds smaller 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 spread despite governments' attempts to promote larger-scale agricultural machines (Biggs and Justice 2013).

Is it also a possibility that large tractors dominate the tractor market in Nigeria because they were originally brought in by government, possibly for political patronage of certain constituents, and they came eventually to dominate the market through resale. However, if these tractors are to be valuable for political purposes, they have to have economic value as well so that recipients can use them on their farm plots profitably or re-sell them in the market. But following this logic, if smaller tractors are valued by farmers, government can patronize more potential voters by purchasing larger quantities of smaller tractors at the same cost as spent on fewer large tractor. Government may not do so, because they judge that small tractors have low value for recipients. Although subsidized small tractors can be resold profitably, if demand is low, the prices received from side-selling such tractors may be low as well. However, it likely would be easier to sell smaller tractors than large ones, as then the issue of indivisibility is less serious.

We conclude that there are no clear explanations for why large, high horsepower tractors dominate in countries such as Nigeria, despite the large numbers of smallholder farmers. This study does not attempt to examine these reasons. But if this is the equilibrium for agricultural mechanization reached through the interplay of a combination of various economic and policy factors, this pattern of tractor use is likely to persist.

3. AGRICULTURAL LABOR MARKET IN NIGERIA

Rising farm wages are considered one of the driving forces of agricultural mechanization. Increasing wages raise the relative cost of labor to land or capital, and induce farmers with high land endowments to substitute labor with machinery, while inducing farmers with low land endowments to exit agriculture. This economic 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 2010 and 2012 surveys of the Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS-ISA) survey series for Nigeria 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 specifically on labor use in agriculture, 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

Human capital levels in Nigeria, measured by level of education, have risen over the past several decades. The average number of years of formal education among the population aged 15 years and older is approximately 6 years, which is similar to some South Asian countries such as India, Pakistan, and Bangladesh.[6] The trend of increased enrollment in primary or secondary schools has remained steady, following similar neighboring countries such as Ghana (World Bank 2014).

Education levels vary by gender and location (urban versus rural) (Table 3.1). The average educational attainment 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 rural/urban

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 geopolitical zones. Table 3.2 summarizes the estimated working age of the population in each zone, disaggregated by level of education attained. The Northwest and Northeast zones host the largest number of population without any formal education, while the southern zones typically have larger populations with at least some level of secondary education.

[6] Each education level is defined as follows; 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 years of education attained to each category as follows; no education = 0; received some primary education = 3; completed primary education = 6; received some secondary education = 9; completed secondary education = 12; and 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: Educational status of working age population (15–60 years) in Nigeria, millions

Geopolitical zone	(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	*none*	0.0 ± 0.0
South-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	*none*	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	*none*	0.0 ± 0.0
South-south	1.2 ± 0.1	2.0 ± 0.2	1.5 ± 0.2	4.1 ± 0.3	2.5 ± 0.2	1.2 ± 0.2	*none*	0.0 ± 0.0
Southwest	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
Total	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 male	12.5	5.1	3.8	10.2	5.6	2.3	2.0	0.0
Rural female	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.

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.

Hired Labor Use for Planting Activities

The use of hired farm labor is common in Nigeria. In 2010 and 2012, about 64 percent of farm households hired workers at some point during the cropping season to supplement family labor for farming activities such as land preparation, planting, or weeding (Table 3.3).[7] Typically, farm households (including those not hiring workers) pay a total of $40 for hired workers. Households using tractors are more likely to hire workers (78 percent), and pay more for their labor ($112 per household).

Table 3.4 provides estimates of labor use in total person-hours by a typical farm household in each geopolitical zone. A typical farm household spent between 500 and 1,000 person-hours in the four months prior to the interview for land preparation, ridging, planting, weeding, and fertilizer application. For farm households using only manual labor, hired labor provided 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 =

[7] 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 data may not be perfect measures of hired labor use for land preparation, planting or weeding. However, they provide reasonable indicators of how common the use of hired workers is for these farming activities.

228 ÷ 740). The Northeast zone typically uses the largest amount of hand labor, approximately 1,000 person-hours, for these activities—which is considerably higher than what is used in other regions. This may reflect the heavier reliance of farming on manual labor in the Northeast zone, although the causes of this are not clear.

Table 3.3: Use of hired labor for planting season

Geopolitical zone	% hiring labor in the past four months				Median total payments for the cropping season (except harvesting) – all households (including nonhirers) (US$)		
	All	Without animal or tractors	With animal but not tractors	With tractors	Without animal or tractors	With animal but not 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
Southern zones [a]	61	61	0	88	40	0	188
Total	64	62	70	78	40	38	112

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

Table 3.4 provides estimates of labor use in total person-hours by a typical farm household in each geopolitical zone. A typical farm household spent between 500 and 1,000 person-hours in the four months prior to the interview for land preparation, ridging, planting, weeding, and fertilizer application. For farm households using only manual labor, hired labor provided 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 amount of hand labor, approximately 1,000 person-hours, for these activities—which is considerably higher than what is used in other regions. This may reflect the heavier reliance of farming on manual labor in the Northeast zone, although the causes of this are not clear.

Table 3.4: Total hours spent for the entire farm on cropping activities (land preparation, ridging, planting, weeding, fertilizing) by farm households members and hired labor in the past four months, zonal means

Geopolitical zone	Family members			Hired labor (assuming 1 day = 8 hours)			Total		
	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	0	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
Southern zones	450	0	648	68	0	320	518	0	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 hiring-out their 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 to 60 years) who worked primarily in agricultural activities for payment (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 c 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

Geopolitical zone	% of households hiring out agricultural workers			Average number of hired out agricultural workers[a]		
	Total	Total among farm households	Total among nonfarm households	Total	Total among farm households	Total among nonfarm households
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
Southern zones	32 ± 2	77 ± 2	6 ± 1	0.5	1.1	0.1
National	43 ± 1	76 ± 1	8 ± 1	0.6	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 zones, the share is close to 60 percent, which is significantly higher than the 30 percent reported in the southern zones. 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 no hired-out 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 eventual increased demand for agricultural mechanization.

Importantly, the differences across farm households and nonfarm households are not due to differences in their general hiring out activities. 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 – 83 percent of both groups reported some members hiring out their labor. The average number of hired out workers are also similar – 1.5 for farm households versus 1.4 for non-farm households. 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 agricultural and nonagricultural, in the past 12 months – based on post-planting survey

Geopolitical zone	% of households hiring out agricultural or non-agricultural workers: Total	Total among farm households	Total among nonfarm households	Average number of hired out workers[a]: Total	Total among farm households	Total among nonfarm households
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
National	83 ± 1	83 ± 1	83 ± 2	1.5	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.

4. IMPERFECTIONS OF TRACTOR HIRING MARKET: EMPIRICAL EVIDENCE

Two aspects are important in assessing the extent of market imperfections in the tractor hiring market in Nigeria: (1) whether actual tractor uses follow standard economic theory; and (2) whether marginal adoption of tractors significantly affects key outcome variables, such as household expenditure. If (1) holds, it indicates that at least some aspects of the tractor hiring market in Nigeria functions in response to economic forces. In other words, significant effects of supply-side factors, such as the presence of large farms nearby who are more likely to own tractors and provide hiring services, on tractor demand can indicate that a market structure that is more likely to lead to market imperfections exists, due to supply-side constraints arising from the sparsity of such service providers. Condition (2) indicates that even a marginal tractor adoption involves significant changes in the allocations of production resources such as family labor, land or cash, and farm / non-farm production behaviors ("regime switching") for the households, which is consistent with the hypothesis that the tractor hiring market is imperfect. We describe these aspects of tractor hiring in Nigeria and provided corresponding empirical evidence in more detail in this section.

Determinants of Tractor Uses and Its Intensities

We first assess if tractor use in Nigeria follows standard economic theory. In particular, we assess if determinants of tractor uses are consistent with those suggested in the literature on the demand for mechanization and the discussion on potential supply-side constraints in the previous sections. The analytical approach we take is a variant of the hurdle model where there is a hurdle that must be overcome before a farmer accesses the tractor hiring market. Both the process of gaining such access to the tractor hiring market and, thereafter, the intensity of tractor service use are generally affected by key determinants of mechanization adoption. Following the transactions costs literature (for example, Takeshima and Winter-Nelson 2012) this process is framed as,

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

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, household farm size, 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 a 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 the reduced form probit and the 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 a partial observability probit (Poirier 1980; Abowd and Farber 1982). The results of such analyses, however, may be susceptible to the specifications of each stage. We therefore use a reduced form probit and check its robustness through a fairly simple specification of a partial observability probit. The results of the partial observability probit are shown in the Appendix.

Data Sources

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 a 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 a pooled cross-section specification to estimate (1). However, we also apply a modified 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 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 plot sizes. Because total farm size, individual plot size, and measurement of tractor use intensity (the area cultivated by tractors) are important determinants of tractor use, we excluded these observations from our analyses. After further dropping missing observations and outliers, a total of 5,241 observations were used for the analyses.

Descriptive statistics of the 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 using tractors.

Other sets of variables are identified based on the literature on the evolution of farming systems and on 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 Geographic Information System data (Ramankutty et al. 2008). The sum of cultivable land and pasture in an LGA was divided by the population of the 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 soil texture, effective soil depth or volume, and soil phases. It is scaled as follows: 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) digital soil maps presented at a 1km by 1km resolution.

Table 4.1: Descriptive statistics of farm household variables used in the analyses of the determinants of tractor use in Nigeria

Variables	Mean	Median	Standard deviation
Use tractors (1 = yes; 0 = no)	0.04	0.00	0.19
Average area (ha) of owned or distributed land per plot	0.74	0.33	4.06
Number of owned or distributed plots	1.34	1.20	0.76
Household size	6.16	6.00	3.20
Working age male household members with no education, number	0.29	0.15	0.35
Working age male household members with primary education, number	0.28	0.25	0.19
Working age male household members with secondary education or above, number	0.68	0.65	0.49
Working age male household members with Koranic education, number	0.09	0.00	0.22
Working age male household members with any other education, number	0.00	0.00	0.01
Working age female household members with no education, number	0.62	0.50	0.52
Working age female household members with primary education, number	0.30	0.25	0.24
Working age female household members with secondary education or above, number	0.49	0.43	0.44
Working age female household members with Koranic education, number	0.11	0.00	0.26
Working age female household members with any other education, number	0.00	0.00	0.01
Real district average farm wage [a]	6.04	5.00	2.04
Real asset value excluding land [a]	857.9	292.7	3080.8
Own draft animals, 0/1	0.12	0.00	0.33
Real values of draft animal [a]	355.7	0.00	2031.7
Real price of one kg of fertilizer (average of Urea and NPK) [a]	1.09	0.86	1.83
Cultivable land per capita in LGA (ha)	0.51	0.36	0.58
Soil with high workability (1 = workable, 0 = otherwise)	0.62	1.00	0.49
Bulk density of soil (tons per m^3 of soil)	1.33	1.30	0.10
Clay content of 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)	0.97	0.79	0.70
Euclidean distance to the nearest river (geographical minute)	0.02	0.02	0.01
Sample maximum owned/distributed land within district (ha)	4.83	1.95	16.49
Real per capita expenditure per year (excluding food) [a]	212.0	78.7	3745.9

Source: Author based on LSMS (2011, 2013).
Note: [a] Real values are computed using spatial deflators based on average local values of equivalent amounts (kilogram) of rice and white gari.

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

All other variables are calculated from Nigeria LSMS-ISA survey data sets (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 a spatial price index consisting of the average of the district median prices of local rice and *gari* (made from cassava), which are major staple foods in Nigeria.

Nonfood household expenditure is used as an outcome variables in the next section. The expenditure variable is a calculated figure, aggregated over all items reported in the expenditure modules of the LSMS-ISA surveys, each converted into a 12-month equivalent amount. Specifically, we combine short-term expenditures (7 days and 30 days) from the 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 the post-planting survey instead of the 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 the post-harvesting survey instead of the post-planting survey ensures that the majority of the reference period is after the planting season, so that long-term expenditure *after* the use of tractors is captured. Real expenditure values are obtained by deflating through the above spatial price index.

One of the unique variables used in the analysis is the sample maximum landholding of owned- or community-distributed farmland within the LGA. This variable on the largest landholding in the sample is expected to proxy for 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 in 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.[8]

The results of the 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 meaning. 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.[9]

[8] 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. Such information is not available in our data or from the 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 raises the likelihood that sufficient number of tractor owners exist in the district and could provide hiring services.

[9] Although programs such as STATA allow this adjustment, there is 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 4.2 therefore provide generally conservative estimates of the statistical significance of the estimated coefficients.

Table 4.2: Determinants of the area cultivated by tractors (pseudo-panel double hurdle model; marginal effects evaluated at mean of observations)

	Probability of using tractor	Area cultivated by tractors (ha)
Dependent variable	Probit	Truncated Regression
Ln (cultivable land per capita)	0.007***	-0.011
Average area (ha) of owned or distributed land per plot	-0.000	0.153***
Number of owned or distributed plots	0.002	0.012
Household size	0.001	0.024
# of working age household members (no education, M)	-0.004*	-0.078
Primary education, M	0.002	0.018
Secondary education or above, M	-0.001	0.021
Koranic education, M	-0.003	-0.162
Any other education, M	-0.019	0.398*
# of working age household members (no education, F)	-0.002	-0.041
Primary education, F	0.001	-0.088
Secondary education or above, F	0.003**	-0.099**
Koranic education, F	0.002	0.009
Any other education, F	-0.006	-0.350
Ln (real district average farm wage)	0.014	-0.129
Ln (real asset value)	0.003***	0.023
Own draft animals (yes = 1, no = 0)	0.002	-0.246
Ln (real values of draft animal)	-0.000	0.072*
Real price of one kilogram of fertilizer (average of Urea and NPK)	0.0007	-0.007**
Soil with high workability (1 = workable, 0 = otherwise)	0.014***	0.770**
Bulk density of the soil (tons per m^3 of soil)	0.041	-1.115
Clay contents of the soil (clay content (<2 μm) in %)	-0.001**	-0.022*
Distance to the nearest town with population of 20,000 (hours)	0.001	-0.094*
Euclidean distance to the nearest dam (geographical minute)	-0.006*	-0.333**
Euclidean distance to the nearest river (geographical minute)	-0.183	-3.832
Ln (sample maximum owned and distributed land within district, hectare)	0.003**	--
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: [a] Significance is based on standard errors adjusted for EA cluster effects. *** 1 percent, ** 5 percent, * 10 percent.
M = male, F = female; Ln =natural log; NPK = Nitrogen, Phosphate, and potassium.

The 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 land and a substitute for labor. 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 of labor with tractors.

Doubling real asset values raises the adoption possibility by 0.2 percentage points, possibly because of 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 that includes mechanized plowing can have high returns.

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 that are more appropriate for cultivating larger areas (as indicated in Takeshima et al. 2014). However, this point must be investigated further. The number of highly-educated, female, working-age household members has negative effects on tractor use intensity, although 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 suggests 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 facilitating subsequent production practices, such as second plowing or 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 the largest owned or distributed land holding within the 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 in tractors and to hire-out their tractor to 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 the 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 scarcity 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.

Technology Adoption under Market Failure – a Simple Conceptual Illustration

We illustrate a household's decision-making 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

$$\max_{\mathrm{I_r,L_r,M_r}} \Pi = I_0 \cdot [F_0(L_0; z) - p_L L_0] + I_1 \cdot [F_1(L_1, M_1; z) - p_L L_0 - p_M M_1 - \eta] \qquad (2)$$

subject to

$$I_0 + I_1 = 1 \text{ and } L_r, M_r \geq 0 \quad \forall\, r. \qquad (3)$$

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 agricultural machinery 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. However, there are transactions costs η associated with switching to regime 1. This cost is due to various constraints, including the limited mobility of tractors discussed in earlier sections.

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

$$\max_{\mathrm{I_r,C_r,X_r}} \Pi = F(L, M; z) - p_L L - p_M M. \qquad (4)$$

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

$$\left.\frac{\partial \Pi}{\partial M}\right|_{\frac{\partial F}{\partial M} = p_M} = \frac{\partial F}{\partial M} - p_M = 0 \qquad (5)$$

In other words, a marginal increase of *M* from *M* = 0 should have no effect on the outcome variables.[10]

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

$$-\int_{L^*}^{L_0} \left(\frac{\partial F(L, M_0)}{\partial L} - p_L\right) dL + \int_{M_0}^{M^*} \left(\frac{\partial F(L^*, M)}{\partial M} - p_M\right) dM \qquad (6)$$

[10]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.

where L^* and M^* are global optimal solutions under both regimes. Equation (6) 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 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 a constant elasticity of substitution (CES) production function,

$$\Pi = A[aM^{\rho} + (1-a)L^{\rho}]^{\beta/\rho} - p_M M - p_L L \quad (7)$$

where *M* is the mechanical power and *L* is the labor power, *a* is the share parameter, $\varrho = 1/(1-\varepsilon)$ in which ε is the elasticity of substitution between *M* and *L*, and 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 the above discussion on 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, the wedge is only 3 percent when $\beta = 0.6$, so that returns to scale are fairly diminishing, and $\varepsilon = 20$, so labor can largely substitute for tractor use. However, 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 wedges of varying size.

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

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

Source: Author.

Propensity Score Matching Among Marginal Adopters

The conceptual framework in the previous section suggests that one can detect indications of failure in the tractor service market. Specifically, if significant changes in key outcome variables are explained by the marginal adoption of a tractor, these 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 for a farmer using a tractor on 50 ha of land may be significantly different from non-adopters, such differences are likely to arise from the cost reduction in land preparation accumulated over the 50 ha of land, which cannot be separated from the changes purely due to the adoption of the tractor. However, if the changes in outcome variables are identified among farmers using a tractor for only a half hectare (thus adopting it marginally), the effects may be more likely to be due to the adoption per se.

One way in which the effect of tractor service adoption on the various outcome variables can be estimated is through propensity score matching methods (PSM) (Rosenbaum and Rubin 1983), which are widely used in other non-intervention programs (e.g., the impact of market participation studied by Takeshima & Nagarajan 2012).

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. With PSM methods, we essentially compare the differences in the outcome variable (here, household expenditures) between (1) and (2) + (3). According to the discussion in the previous section, (2) should have the same outcome as (1), while (3) should have a lower outcome than (2). Therefore, a significant difference in outcome variables between (1) and (2) + (3), which we estimate, is a sufficient condition to imply a significant difference between (1) + (2) and (3), which is the hypothesis of interest.

As note, the PSM method 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 use 0.5, 1.0 and 1.5 ha as thresholds. In Nigeria, these are fairly small cultivated areas among tractor users, most of whom cultivate 5 ha or more.[11] Thus, much of the impact of tractor adoption for such farmer, if impact is observed, is likely to be from the adoption on the extensive margin rather than on the intensive margin, which is what we need to estimate. Using lower thresholds limits the sample size of the treatment group used in the analyses to less than 30 observations, which can considerably limit the power of the test. These limitations are partly overcome in the next section where we apply similar methods for a continuous treatment variable, rather than a binary treatment variable.

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), which renders the nearest-neighbor method inappropriate for the small sample size of the treatment group used in this study. We use calipers of 0.005, 0.010, and 0.050, as the estimated propensity scores are generally in the range of 0–0.1. Using `pstest` command, all specifications are found to satisfy the balancing properties.

PSM methods are vulnerable to the violation of ignorability assumption (or "selection of observables"), which can be particularly serious in cross-section methods. However, partly controlling for LGA level unobserved fixed effects, as discussed above, can mitigate limitations on PSM methods due to the ignorability assumption. In addition, we assess the Rosenbaum

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

bounds (Rosenbaum 2002) using the command `rbounds` (DiPrete and Gangl, 2004) to see if there is any hidden bias due to violation of the ignorability assumption.

The estimated results from the PSM methods are summarized in Table 4.4. Where effects are statistically significant, critical gammas associated with the Rosenbaum bounds are shown in brackets. The effects are statistically significant under various specifications and thresholds of marginal adoptions. Using tractors on cultivated land sizes up to one ha leads to almost a 30 percent increase in per capita household expenditure compared to households with similar characteristics but not using tractors. At the median of the sample, this is equivalent to approximately USD22 per capita per year, or USD135 per year at household level. Using the threshold of 1.5 ha also leads to statistically significant effects on per capita household expenditure of around 30 percent in various specifications. Using 0.5 ha as the threshold leads to insignificant effects, although these are partly due to the small sample sizes of marginal adopters using tractors only up to 0.5 ha. These significant effects of marginal tractor adoptions are consistent with the conditions, illustrated in the conceptual framework, that can arise as a result of imperfections in the tractor hiring market.

Critical gammas in Table 4.4 are often in the range of 1.3, indicating that statistical significance holds even when unobserved covariates cause the odds ratio of treatment assignment to differ by a factor of 1.3 between treatment and control groups (DiPrete and Gangl, 2004). This variation in odds ratio may also arise from selecting marginal adopter samples based on the various thresholds. Estimated Rosenbaum bounds suggest that the statistically significant effects found in our PSM are fairly robust to the presence of these biases.

Table 4.4: Results of propensity score matching method among marginal adopters, where dependent variable is natural log of per capita household expenditure

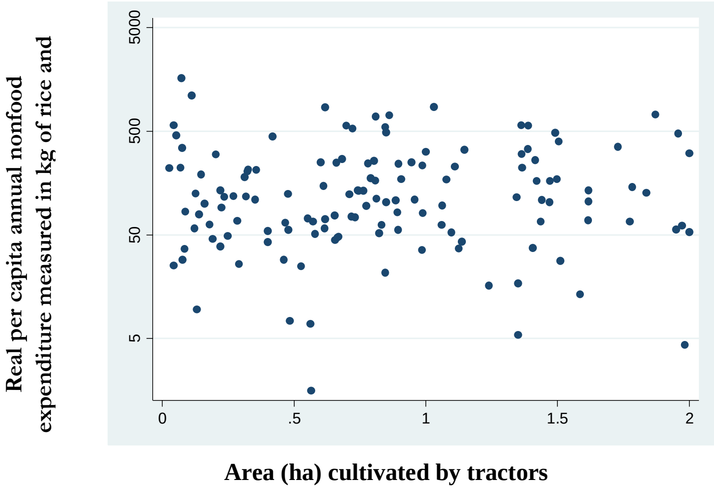
	Thresholds (area cultivated by tractors)		
Matching methods	**0.5 ha**	**1.0 ha**	**1.5 ha**
Kernel matching	0.240	0.283** [1.20]	0.314** [1.35]
Radius matching with caliper = 0.005	0.202	0.326** [1.30]	0.233* [1.10]
Radius matching with caliper = 0.010	0.213	0.390** [1.40]	0.164
Radius matching with caliper = 0.050	0.262	0.304** [1.30]	0.310** [1.35]

Source: Author's estimation. Where effects are statistically significant, critical gammas associated with Rosenbaum bounds shown in brackets.
Note: *** 1 percent, ** 5 percent, * 10 percent.

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 effects of tractor use intensity, i.e., the area cultivated by tractors. The effect 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 real per capita expenditure level and tractor use intensity among those households using tractors on up to two hectares of land.

Figure 4.1: Evidence of weak correlation between real per capita expenditure and tractor use intensity among marginal adopters



Source: Author.

The lack of marginal treatment effects of tractor use intensity can also be more formally examined through the generalized propensity score matching method (GPSM) proposed by Hirano and Imbens (2004). GPSM is an extension of PSM to the case in which the treatment variable is continuous rather than binary. We use a STATA program `doseresponse` developed by Bia and Mattei (2008). Our estimation focuses on observations where the area cultivated by tractors is greater than 0 and not greater than 1.5 ha. Bia & Mattei (2008) rely on the normality assumption of the conditional density of treatment intensity. In our case, normality assumptions are satisfied at the 5 percent statistical significance level, so that the estimated dose response functions are consistent.

Balancing tests in GPSM are conducted by comparing GPS-adjusted means of covariates across sub-groups that are defined based on treatment levels (cropped area cultivate by tractor). Following the standard approach (Hirano & Imbens 2004; Kluve et al. 2007), we conduct this test in the following way; we split the sample into three groups by the tertiles of treatment level, divide each group into five blocks, based on the quintiles of the GPS evaluated at the median treatment level within the tertile, calculate the *t*-statistics for the equality of means of covariates between blocks. We find that approximately 5 percent of the absolute values of *t*-statistics exceed 1.96, which is what we expect under the null hypothesis that means of covariates are jointly equal across groups, suggesting that the balancing properties given GPS are satisfied.

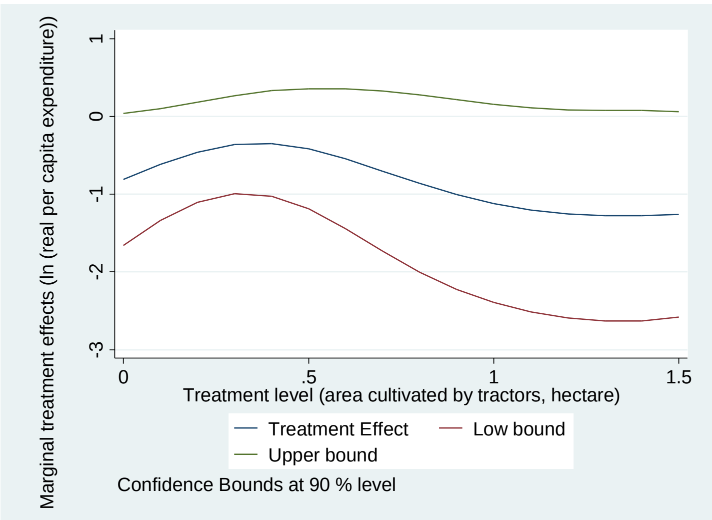
GPSM produce two results: (1) conditional expectation of outcomes given the estimated GPS (Table 4.5); and (2) marginal treatment effects (MTE), which is the derivative of the dose-response function and its confidence intervals (Figure 4.2). GPS is often statistically significant in Table 4.5, suggesting that the covariates introduce biases in estimated treatment effects in the absence of GPS, and, consequently, using GPS reduces such biases (Hirano & Imbens 2004). MTE in Figure 4.2 illustrates how the effects of tractor use on the natural log of per capita household expenditure change as tractor use intensity increases. MTEs are always insignificantly different from zero – there are no significant effects of tractor use intensity up to 1.5 ha. This further proves that the significant effect in Table 4.4 is capturing the effect of marginal tractor adoption, rather than cumulative effects of intensive tractor adoption. Figure 4.2 is based on regression results of the first column in Table 4.5, as it provides the narrowest confidence intervals and a conservative inference of MTE's insignificance.

Table 4.5: Evidence of no marginal treatment effects of tractor use intensity up to 2 hectare (Generalized Propensity Score Matching dose response model)

Dependent variable: ln (real per capita expenditure)			
Treatment	-1.136* (0.653)	-1.370(1.075)	-1.356 (1.087)
Generalized propensity score (GPS)	-1.341*** (0.494)	-1.321*** (0.501)	-1.183 (1.367)
Treatment*GPS	1.335** (0.578)	1.320** (0.583)	1.317** (0.587)
Treatment squared		0.167 (0.607)	.162 (0.611)
GPS squared			-.073 (0.675)
Constant	0.908 (0.557)	0.949 (0.579)	-.896 (0.763)
R^2	0.072	0.072	0.073
p-values of overall fit	0.045	0.088	0.152
Number of observations	111	111	111

Source: Author.
Note: Standard errors of estimated coefficients in parentheses.

Figure 4.2: Evidence of insignificant marginal treatment effects of tractor use intensity based on estimated generalized propensity score



Source: Author.

5. TRACTOR SIZES AND TIMELINESS OF OPERATIONS – A HYPOTHETICAL ILLUSTRATION

As was discussed, conditions in Nigeria seem to deviate considerably from the historical mechanization growth patterns observed elsewhere, including the size of dominant types of tractors in the country. Many factors affect the optimal size of tractors in given production environments. One of the factors that affect investments into tractors of different sizes, given a fixed amount of resources, is the balance between the speed of on-farm operation and the transactions costs associated with moving across farms and plots. The latter is important in an environment like Nigeria where mechanized land preparation service is done mostly by custom hiring of tractors, farmlands are fragmented, and farm households are scattered across locations.

Identifying the optimal size of tractor for Nigeria is challenging, as it requires detailed data on the performance of different types of tractors and careful analyses to identify their optimal use within production environments. In this section, we provide some insights into how overall tractor performance can be affected by the relative importance of on-farm operational speed and the transactions costs associated with operating in each plot, using a simple illustrative exercise. Specifically, we compare the performance of tractors of different horsepower in terms of the time required to plow 200 0.5 ha plots, each owned by different farm households, taking into consideration the balance between the speed of on-farm operation, and the speed of inter-farm movement.

The time required to plow a fixed amount of land is an important aspect of tractor performance. This is because the window of opportunity for plowing at the onset of the rainy season in Nigeria is often quite short. Missing the optimal timing of plowing can lead to significant yield losses.[12]

We first describe general background conditions in Nigeria regarding the speed of on-farm operations for different sizes of tractors, plot sizes, and distances between plots that can affect the transactions costs for tractor operations per plot. We then illustrate a hypothetical example comparing the performance of two types of tractors.

Speed of On-farm Operation

One of the major advantages of larger tractors is the speed of operation on the plot, e.g., the time required to complete one hectare of plowing. The speed of on-farm operation varies due to many factors, including the horsepower of the tractor. The time required often has is inversely proportional to the horsepower of the tractor – using a tractor with twice the horsepower can halve the time required to complete the plowing on a plot.

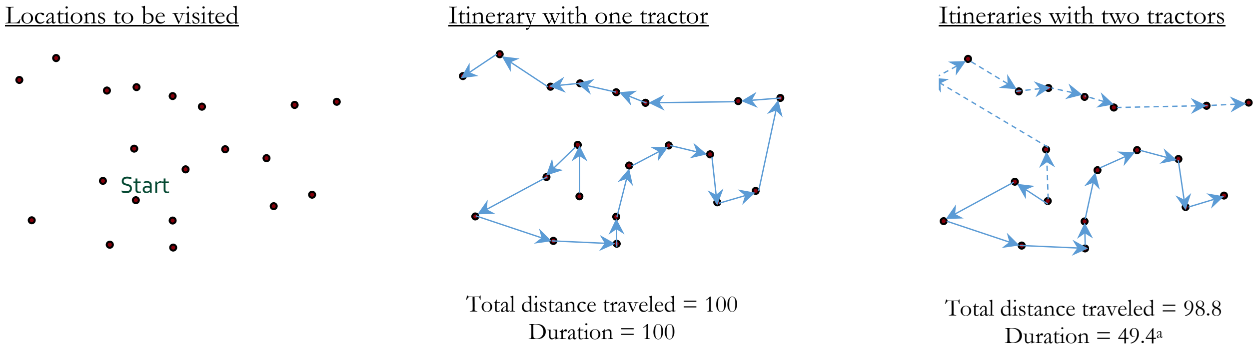
However, in some cases this may not hold. Anecdotal evidence suggests that in Nigeria soils in some areas are too hard to be plowed by smaller tractors. In such case, the time required to finish plowing may be more than proportionately larger than the horsepower indicates – that is, halving the horsepower may increase the time required for plowing by three times, instead of two times.

[12]Delaying in land preparation and planting after the onset of rainy season often leads to significant yield loss, typically 1-2 percent per day of delay for maize in Nigeria (Fakorede1985) and Zambia (Haggblade 2005). The demand for mechanization service is thus highly seasonal in Nigeria (Takeshima et al. 2014, 2015; Takeshima 2015).

Transaction Costs per Plot – Insights from Farm Plot Sizes and Plot Distances in Nigeria

Various transactions take place when a tractor moves from one plot to the next plot or from one farmer to the next. Time may be spent on activities like assessing the soil quality, receiving payment from farmers, or negotiating prices. If plots and their owners are scattered geographically, providing land preparation services can involve significant transaction costs per plot. Figure 5.1 provides a simple illustration of these points, based on the so-called "traveling salesmen's problem" (Bektas 2006), which can be solved by Mixed Integer Programming. It illustrates how two units can travel to the intended number of locations at lower travel costs (proxied by the combined distance travelled), and with shorter travel time than can one unit.[13]

Figure 5.1: Illustrative example of relationship between number of tractors and duration of time required to provide plowing services to all clients



Source: Author's modifications based on the multiple-travlling salesmen's problem by Bektas (2006).
[a]Time span reflects the simultaneity of two travels, and thus shorter.

Based on the LSMS-ISA data for Nigeria, the median size of plots on which tractors were used is 0.6 ha, while the median size of all cultivated plots in Nigeria is around 0.3 ha. Expanding tractor use on these smaller plots may pose a challenge in using large tractors, since the ratio of travel time to plowing time may increase. The LSMS-ISA data also reports the distance from the residence of the farm household to the plots the household farms (Table 5.1). Farm plots are typically located between 700 and 1,000 meters away from the households' residence. Although larger plots are located slightly closer to the household residence, except in South-South and Southwest zones, they are still 400 to 600 meters away from the household residence in the northern zones. The plots where tractors are used tend to be located further away, typically 2,000 to 2,200 meters from the residence of the farm household, albeit with variations across regions. It is beyond the scope of this study to investigate why plots where tractors are used tend to be located further away from the households' residence.

Whether these distances are substantial constraints for tractor use efficiency in terms of transactions costs is an empirical question. Several factors may affect such costs. For example, if the farmer who is hiring-in the tractor service prefers to monitor tractor use on his or her plots, operators will have to wait until the farmer arrives. Other transactions like payment may also have to take place. The distance to plots from the residence may also be positively correlated with the distance from the nearby road, which can increase the tractor travel time to the plots.

[13] Note that Figure 5.1 assumes that the travelers do not have to return to the origins. This is appropriate to the case of tractor hiring, in which the goal is to cover as many plots as possible within the short duration of the season suitable for plowing, and tractors can be brought back to the original locations later on at the cheapest means possible or can even remain at the destination hiring station and start off from there in the next plowing season. While more sophisticated operations research is needed to incorporate the logistical complexity in real life, the example here provides insights into the potential efficiency gains from more optimal tractor size.

Of course, if the returns from tractor use are substantially high, both agents, the tractor operators and the farmers will develop mechanisms to minimize such costs. But the transactions costs will remain and can be significant given the importance of timeliness in mechanized land preparation.

Table 5.1: Typical distances from farm households' residence to farm plots (km) in Nigeria, by geopolitical zones and tractor use status

Geopolitical zone	All farm plots		Plots where tractors were used	
	Simple median (90% CI)	Weighted by plot size	Simple median (90% CI)	Weighted by plot size
North-central	1.10 ± 0.10	0.6	3.5 ± 0.5	5.0
Northeast	0.98 ± 0.04	0.4	1.5 ± 0.2	1.1
Northwest	0.60 ± 0.03	0.4	1.7 ± 0.9	2.2
Southeast	0.24 ± 0.03	0.2	0.5 ± 0.6	0.5
South-south	0.80 ± 0.10	2.5	--	--
Southwest	1.20 ± 0.10	2.2	2.0 ± 0.5	2.0
National	0.7 ± 0.0	1.0	2.0 ± 0.4	2.2

Source: Author's calculation based on the LSMS data.
Note: All figures are adjusted for sampling weights. Plots with no area measures in hectare, which account for approximately 10 percent of all plots, are excluded.
90% confidence interval (CI) for simple medians are assessed on the samples not weighted by sample weights.
Plots reported being more than 100km away excluded, as questionable whether farm household has substantial control over them.

Hypothetical Illustration

Using a simple hypothetical exercise, here we illustrate the implications of the above issues on the trade-off between on-farm operations and inter-plot movement in the overall speed of completing mechanized land preparations.

1. **Speed of on-farm operation**: A tractor of 70 horsepower in Nigeria can typically complete the plowing of one hectare in 3 to 4 hours, although there can be substantial variations depending on soil type, topography, and other factors.[14] In other words, 70 hp tractors can plow typical plots in Nigeria (0.5 ha, as mentioned above) in between 1.5 and 2 hours. Information is relatively scarce regarding the performance of smaller tractors in Nigeria. In theory, tractors with half the horsepower should need twice as much time as the larger tractors to plow the same area.[15] However, anecdotally it is still sometimes believed that many of the soils in Nigeria are generally too hard for small tractors to plow effectively. We also consider the case where a 35 hp tractor takes 3 times longer to plow a plot than does a 70 hp tractor.
2. **Transaction time per plot**: There are no empirical estimates for these transactions times in Nigeria, but they can be substantial. Due to the scarcity of information, here we use three transaction cost levels (i) no transactions time (0 hour); (2) transaction time of 1 hour per plot; and (3) 2 hours per plot. While these are arbitrary and further studies are needed to investigate these more closely, they provide us with some insights into how

[14] Based on informal communications with local Nigerian experts.

[15] This line of calculation is roughly consistent with studies evaluating the performance of other types of tractors. For example, a 13 hp power tiller in Niger state is found to require on the order of 20 hours per hectare for land preparation (Ademiluyi & Oladele 2008).

transaction times per plot play an important role in the performance of large and small tractors.

Figures based on a small survey among tractor owner-operators in Kaduna and Nasarawa states (Takeshima et al. 2014; 2015) suggest that annually a typical owner of a 60 to 70 hp tractor cultivates approximately 150 ha over 750 hours of use per year, after deducting between 200 and 300 hours annually spent on off-farm use of the tractor. On average, these tractor owners spent 5 hours per ha, which includes between one and two hours of inter-plot movement of the tractor and other transactions.

Table 5.2 summarizes the results of this hypothetical exercise in terms of the duration of plowing season (number of hours) required to complete the plowing of 100 ha (200 plots) either by one large tractor or by two small tractors. As was described above, one of the important focus is the timing of plowing operation within the short window of the onset of rainy season. Table 5.2 therefore counts each hour only once if two tractors operate simultaneously; this is one of the advantages of having two smaller tractors for covering large areas within a short amount of time, depending on the circumstances. For example, if one large tractor can plow a 0.5 ha plot in 1.5 hour or each of two small tractors can plow a 0.5 ha plot in 3 hours, and there is no transactions time incurred per plot, then both combinations of tractors can plow 100 ha (200 0.5 ha plots) in 300 hours. If, there is 1 hour of transaction time associated per plot, using one large tractor requires 500 hours to complete the plowing of 100 ha, while it will take only 400 hours using two small tractors to do so. However, if small tractors need 4.5 hours (instead of 3 hours) to complete each 0.5 ha plot, then using two small tractors will require 550 hours to complete the plowing of 100 ha. In this case, using one-large tractor can complete the plowing of 100 ha within a shorter window of time in the plowing season (500 hours vs 550 hours).

Table 5.2: Duration of plowing season in hours required to complete by tractor 100 ha (200 plots), by on-farm operational speed and transaction time per plot, hypothetical examples

		Operational speed of tractors (hours per 0.5 ha plot; L = large tractor; S = small tractor)			
		L - 1.5; S - 3.0	**L - 2.0; S - 4.0**	**L - 1.5; S - 4.5**	**L - 2.0; S - 6.0**
Transaction time per plot	**Tractor size and number**	**Hours required to plow 200 plots totaling 100 ha in area**			
0 hour	One large	300	400	300	400
	Two small	300	400	450	600
1 hour	One large	500	600	500	600
	Two small	400	500	550	700
2 hours	One large	700	800	700	800
	Two small	500	600	650	800

Source: Author's calculations.
Note: Transaction time per plot include time spent on activities such as assessing soil quality, receiving payment from farmers, negotiating prices, etc. and on moving the tractor from plot to plot.

A key pattern observed in Table 5.2 is that the time required to plow 100 ha of plots (0.5 ha each) is sensitive to transaction time per plot. Smaller tractors have an advantage. Even if the plowing by a small tractor takes three times longer than the large tractor per plot of land, this plowing advantage can dissipate as the transaction time per plot increases. If transaction time per

0.5 ha plot is 2 hours and each tractor can complete 0.5 ha plot in 4.5 hours, using two small tractors requires 650 hours of plowing season, which is shorter than 700 hours by using one large tractor.

Key Messages

Promoting the appropriate capacity of tractors has important implications on the affordability of tractors and on the accessibility of custom hiring services to farmers who do not own tractors. This is particularly relevant to agricultural machinery given the indivisibility of inputs, a factor which is less important for some other agricultural inputs, such as improved seed and fertilizer.

We have assessed which demand and supply factors are causing the dominant type of tractor in Nigeria to be higher horsepower (50 hp or above) four-wheel tractors, rather than lower-power tractors. Additional research is needed. In this section, we provided an illustrative example on how tractor size matters for providing timely land preparation services, if the goal is to serve smallholders who tend to be scattered geographically with each endowed with small plots of land. The example shows that a greater number of smaller tractors may more efficiently serve these plots if their on-farm operational speed is not too disadvantaged relative to large tractors and there are substantial transactions costs associated with providing tractor plowing service to each plot. However, if the opposite is true, a fewer number of large tractors may be more efficient. In certain cases, private tractor owners' motives may be to expand their farm area, rather than serving neighboring farmers. This was quite commonly found in Ghana (Houssou et al. 2015), and anecdotally reported in Nigeria as well (Takeshima et al. 2014; 2015). These types of farmers may be in areas with large pieces of land that are less fragmented. In such cases, the benefits from the speed of operation on the farm from large tractors may be more attractive economically than the inter-plot mobility of smaller tractors. Which of these conditions are more important for the overall growth of the agricultural sector in Nigeria is an empirical question which must be investigated in the future studies.

Providing financial support for increased uptake of agricultural machinery will remain a challenge for government. Commercial banks are often reluctant to provide loans to farmers, including to medium-to-large scale farmers among whom tractor owners and, thus, suppliers of custom hiring of tractors are often found. This is because of the high transactions costs associated with information asymmetry in assessing the likelihood of default and repayment monitoring. While government guaranteed loans may partly mitigate the effects of risks associated with lending, it may sometimes aggravate other problems, e.g., moral hazard by the banks. Without addressing these problems, providing financial support for smaller tractors through the banks may remain difficult. In addition, financing a larger number of smaller tractors may raise the aforementioned transactions costs relative to the loan amount, further discouraging bank lending.

The potential of smaller tractors may hinge on the fact that a substantial share of tractors in the private sector in Nigeria have been purchased by farmers' personal saving without bank loans (Takeshima et al. 2015). This is likely to be the case for smaller tractors as well. Since smaller tractors are cheaper than larger tractors, their increased availability in the market Nigeria may boost tractor investments by medium-size, middle-income farm households. This may raise tractor density in Nigeria, compared to the current situation in which only the few large, high-income farm households own tractors.

6. POLICY IMPLICATIONS

The pattern of tractor service adoption in Nigeria 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 dominate the tractor market. Examination of the determinants of tractor service adoption 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 underlying economic conditions.

However, tractor service adoption is also partly affected by the presence of large farm households within 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 examination of the impact of tractor service adoption suggests that market failure continues to exist in the tractor service market. This is reflected in the observed substantial change in income level arising from marginal adoption of tractor services, which would not be observed if the tractor service market were perfected.

Overall, the analysis leads to the following policy messages:

1. The public sector and Nigeria's donor community should recognize that, while the private sector tractor hiring service market that has developed over time in Nigeria seems capable of meeting some of the demands for mechanization, access to this service is still constrained. These constraints arise possibly due to the indivisible nature of tractors and the persistent difficulty in developing rural finance schemes that can facilitate tractor purchases by agents who are efficient in providing services but face barriers in owning tractors. As a result, tractor services supply is too rigid to respond to demand that is only marginally high. This condition may be different from past experiences around the world where constraints on access to tractors had been less serious thanks to growth in the number of smaller tractors available at an early stage of mechanization. This pattern is not seen in Nigeria today.

2. Data are needed regarding the locations of functional tractors in the country, most of which are in private hands and unregistered. Often the Federal and State Ministries of Agriculture either only have a list of those who received subsidized tractors under government schemes. These lists account for only a minority of the tractors being used. Information on the locations of functional tractors owned by private operators can help the government identify areas where tractor service supply is particularly constrained.

3. The Nigerian government has long attempted to address the issues of poor tractor accessibility by farmers and, over time, gradually improved their approaches based on lessons learned. It is now widely acknowledged that government-run tractor hiring units are rarely effective, and government agencies have shifted into distributing tractors at subsidized prices to certain recipients who they hope will provide hiring services to other farmers. While this has been an improvement, a recent IFPRI study found evidence that such an approach is broadly ineffective because recipients selected by government are often less efficient in supplying mechanization services than pure private tractor owner operators who obtained tractors outside government channels (Takeshima et al. 2015). The Federal government acknowledges this and has withdrawn from programs involving the subsidized distribution of tractors under the recent Agricultural Transformation Agenda. However, government continues to subsidize tractor users (mostly smallholder

farmers) instead of the suppliers of mechanization services. The findings of this study suggest that subsidizing users remains ineffective because it does not resolve fundamental supply side constraints. Overall, if subsidies are needed as one instrument for implementing Nigeria's agricultural mechanization policy, it may be best to use vouchers to subsidized tractor purchases in the private market, without government selecting the voucher recipients. However, the issues of voucher-based systems must be addressed in parallel, particularly inefficiency in voucher redemptions mechanisms.

4. Additional policy research is needed to better understand a range of issues related to fostering increased use of tractors in farming in Nigeria. These issues include identifying the best way to improve farmers' access to tractors, where are the best geographical areas for government to work to improve the access of farmers to tractor services, and undertaking an assessment of soil characteristics to predict demand for tractors.

5. More research is also needed on why there is less demand for smaller, lower horsepower tractors in the country. An increase in the demand for those tractors could address to some degree the problem of the indivisibility of mechanization technologies relying on larger tractors.

6. Our analysis indicates that intensive tractor uses may substitute for fertilizer use. Combining support for fertilizer subsidies with support for tractors may offset the effects of each effort and be counter-productive. This suggests a need to reexamine the design of the recent Growth Enhancement Support programs which both subsidize payments for those obtaining tractor hiring services and provide subsidies for purchasing fertilizer.

7. It is important to note that the growth of tractor uses in Nigeria in the medium to longer term will depend on a broader set of issues. Insufficient investment into agricultural Research and Development or infrastructures (such as irrigation facilities) can suppress domestic agricultural production even in the face of growing food imports and rising food prices (Gyimah-Brempong et al. 2016). The insufficient advancement in agricultural production technologies may limit returns from and intensive uses of farm power, which tractors are supposed to substitute. Tractor use growths in such conditions can continue to remain low, just as the overall domestic agricultural sector stagnates. Continued broad agricultural support for technology and infrastructure development remains a key for sustaining the growth of the demand for tractors.

8. While supply side innovations can lower the costs of tractors and tractor services, it is unclear whether significant reductions in tractor prices given the horsepower as they took place in 20th-century world, will take place again in the medium term. Combined with general trends of weakening exchange rates, it is unclear if Nigerian market can expect to see substantial reductions in the price of tractors in the medium term. Technology indivisibility associated with large tractors will remain and likely to pose challenges to potential investors. The growth of supply of tractor hiring services may in part depend on whether the growth of non-farm economies can induce private investment into tractor service provision.

APPENDIX: SUPPLEMENTARY TABLE

Farmers' adoption of tractor hiring service requires clearing two hurdles – one for having access to tractor hiring market, and the other for actually adopting tractor hiring service. Because we only observe the actual adoption of tractor hiring service, and do not observe the clearing of the first hurdle, our empirical specification made restrictive assumptions about how household characteristics affect the clearing of each hurdle. While entirely relaxing these assumptions are challenging, we can at least investigate if results are robust if we separate out some variables which are more likely to be associated with the clearing of the first hurdle rather than the second hurdle, Partial observability probit model provides such framework, and while its estimation is often challenging, models are generally estimable if the number of parameters is small in one of the equations and they do not overlap across both equations. Abowd and Farber (1982) develops a partial observability probit model based on sequential decision-making, which is more appropriate in our case than Poirier (1980). Here, we show the results of a very simple specification in which the clearing of the first hurdle (having access to tractor hiring market) is assumed to depend only on the presence of large farms nearby, which is measured by the maximum farm size of samples within the same LGAs. The signs of coefficients and statistical significance are qualitatively similar to those in Table 4.2, partly validating our assumptions of combining two hurdles into a single probit model.

Table A.1: Robustness check through partial observability probit

Dependent variable	Partial observability probit	
	Probability of having access to tractor hiring market	Probability of using tractor, upon getting access to hiring market
Ln (cultivable land per capita)		0.009***
Average area (ha) of owned or distributed land per plot		-0.001
Number of owned or distributed plots		0.002
Household size		0.001
Working age male household members with no education, number		-0.004
Working age male household members with primary education, number		0.002
Working age male household members with secondary education or above, number		-0.001
Working age male household members with Koranic education, number		-0.004
Working age male household members with any other education, number		-0.028
Working age female household members with no education, number		-0.003
Working age female household members with primary education, number		0.001
Working age female household members with secondary education or above, number		0.003
Working age female household members with Koranic education, number		0.002
Working age female household members with any other education, number		-0.007
Ln (real district average farm wage)		0.023
Ln (real asset value)		0.003***
Own draft animals (yes = 1, no = 0)		0.001
Ln (real values of draft animal)		0.000
Real price of one kg of fertilizer (average of Urea and NPK)		0.001
Soil with high workability (1 = workable, 0 = otherwise)		0.017*
Bulk density of the soil (tons per m3 of soil)		0.053
Clay contents of the soil (clay content (<2 μm) in %)		-0.001
Distance to the nearest town with population of 20,000 (hours)		0.000
Euclidean distance to the nearest dam (geographical minute)		-0.008
Euclidean distance to the nearest river (geographical minute)		-0.236
Ln (sample maximum owned/distributed land within district, ha)	0.004**	
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	5,241	5,241

Source: Author, based on method of Abowd and Farber (1982).
Notes: Significance based on EA cluster-adjusted standard errors. *** 1%, ** 5%, * 10%.

REFERENCES

Abowd, J., and H. Farber. 1982. "Job Queues and the Union Status of Workers." *Industrial and Labor Relations Review 35:* 354–367.

Barraclough, S.L., and A.L. Domike. 1966. "Agrarian Structure in Seven Latin American Countries." *Land Economics 42* (4): 391–424.

Barro, R., and J.W. Lee. 2013. "A New Data Set of Educational Attainment in the World, 1950—2010." *Journal of Development Economics 104:* 184–198.

Bektas, T. 2006. "The Multiple Traveling Salesman Problem: An Overview of Formulations and Solution Procedures." *Omega 34* (3), 209–219.

Bia, M. and A. Mattei. 2008. "A Stata Package for the Estimation of the Dose-response Function through Adjustment for the Generalized Propensity Score." *Stata Journal 8* (3): 354–373.

Biggs, S., and S. Justice. 2013. "*Rural Mechanization: A History of the Spread of Smaller-scale Technology in Selected Asian countries."* Paper prepared for a regional workshop on "Rural Mechanization: Technology and Policy Lessons for Bangladesh and other Asian Countries. Dhaka, Bangladesh, March 7–8.

Binswanger, H. 1978. *The Economics of Tractors in South Asia: An Analytical Review.* New York: Agricultural Development Council; and Hyderabad: International Crops Research Institute for the Semi-Arid Tropics.

Binswanger, H. 1987. *Agricultural Mechanization: Issues and Options.* Washington DC: World Bank.

Caliendo, M., and S. Kopeinig 2008. "Some Practical Guidance for the Implementation of Propensity Score Matching." *Journal of Economic Surveys 22* (1): 31–72.

CSAM (Center for Sustainable Agricultural Mechanization). 2014. "Country Pages." Accessed July 2, 2014. http://un-csam.org/cp_index.htm.

Chamberlain, G. 1984. "Panel Data.*"* In *Handbook of Econometrics,* vol. 2, edited by. Z Grilliches and M. D. Intriligator. Amsterdam: North-Holland. 1247–1318.

Clarke, S. 1991. "New Deal Regulation and the Revolution in American Farm Productivity: A Case Study of the Diffusion of the Tractor in the Corn Belt, 1920–1940." *Journal of Economic History 51* (1): 101–123.

Cragg, J. G. 1971. "Some Statistical Models for Limited Dependent Variables with Application to the Demand for Durable Goods." *Econometrica 39* (5): 829–844.

Dehejia, R., and S. Wahba. 2002. "Propensity Score Matching Methods for Non-experimental Causal Studies." *Review of Economics and Statistics 84* (1): 1053–1062.

DiPrete, T., and M. Gangl (2004), "Assessing Bias in the Estimation of Causal Effects: Rosenbaum Bounds on Matching Estimators and Instrumental Variables Estimation with Imperfect Instruments." *Sociological Methodology 34* (1): 271–310.

Fakorede, M.A.B. 1985. "Response of Maize to Planting Dates in a Tropical Rainforest Location." *Experimental Agriculture* 21 (1): 19–30.

FAO (Food and Agriculture Organization of the United Nations). 2000. *Rivers of Africa.* Rome: FAO.

———. 2012. *AQUASTAT: Geo-referenced Database on Dams.* Computer Disk. Rome: FAO.

Farrington, J. 1986. "Mechanization Policy and the Impact of Tractors in South Asia — A Review." In *Small Farm Equipment for Developing Countries, 85–124.* Los Banos, Philippines: International Rice Research Institute.

Fettig, L P. 1963. "Adjusting Farm Tractor Prices for Quality Changes, 1950–1962." *Journal of Farm Economics 45* (3): 599–611.

Fischer, G., F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg 2008. *Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008).* Laxenburg, Austria: International Institute for Applied Systems Analysis; Rome: Food and Agriculture Organization of the United Nations.

Fulton, C.V., E.O. Heady, and G.E. Ayres. 1978. *Farm Machinery Costs in Relation to Machinery and Farm Size.* CARD Reports. Book 82. Ames: Iowa State University.

Gill, G.J. 1983. "Mechanised Land Preparation, Productivity and Employment in Bangladesh." *Journal of Development Studies* 19 (3): 329–348.

Gollin, D., D. Lagakos, and M.E. Waugh. 2014. "The Agricultural Productivity Gap." *Quarterly Journal of Economics 129* (2): 939–993.

Gyimah-Brempong K, M Johnson & H Takeshima. 2016. *The Nigerian Rice Economy: Policy Options for Transforming Production, Marketing, and Trade.* Philadelphia. University of Pennsylvania Press.

Haggblade, S. 2005. "From Roller Coasters to Rocket Ships: The Role of Technology in African Agricultural Successes". In *The African Food Crisis*, ed. G. Djurfeldt, H. Holmen, M. Jirström, and R. Larsson. Wallingford, UK: CABI Publishing.

Harvest Choice. 2012. "*Average Travel Time to Nearest Town over 20K (hours) (2000).* " Accessed October 10, 2014. http://harvestchoice.org/data/tt_20k.

Hayami, Y. 1969. "Industrialization and Agricultural Productivity: An International Comparative Study." *The Developing Economies 7* (1): 3–21.

Hayami, Y., and V. Ruttan. 1970. "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960." *Journal of Political Economy 78* (5): 1115–1141.

Herdt, R. 1983. "Mechanization of Rice Production in Developing Asian Countries: Perspective, Evidence and Issues." In *Consequences of Small Farm Mechanization*, 1–14. Los Baños, Philippines: International Rice Research Institute.

Hirano, K., and G. W. Imbens. 2004. "The Propensity Score with Continuous Treatments. In *Applied Bayesian Modeling and Causal Inference from Incomplete-Data Perspectives,* edited by A Gelman and X.L. Meng, 73–84. Hoboken, NJ: John Wiley and Sons.

Hlavacek, J.D., and N.M. Reddy. 1986. "Identifying and Qualifying Industrial Market Segments." *European Journal of Marketing* 20 (2): 8–21.

Houssou N., C. Asante-Addo, X. Diao, & S. Kolavalli. (2015). *Big Tractors, but Small Farms: Tractor Hiring Services as a Farmer-Owner's Response to an Under-Developed Agricultural Machinery Market.* IFPRI GSSP Working Paper 39. Accra: International Food Policy Research Institute.

IRRI (International Rice Research Institute). 1978. *Economic Consequences of the New Rice Technology.* Los Baños, Philippines: International Rice Research Institute.

———. 1983. *Consequences of Small-Farm Mechanization.* . Los Baños, Philippines: International Rice Research Institute.

———. 1986. *Small Farm Equipment for Developing Countries.* Los Baños, Philippines: International Rice Research Institute..

ISRIC (International Soil Reference and Information Centre). 2013. "*Soil Property Maps of Africa at 1 km."* Accessed January 24, 2015. http://www.isric.org/data/soil-property-maps-africa-1-km.

Jayne, T.S., J. Chamberlin, and D. Headey. 2014. "Land Pressures, the Evolution of Farming Systems, and Development Strategies in Africa: A Synthesis." *Food Policy 48*: 1–17.

Johnson, M. 2016. "Policy Options for Modernizing the Milling Sector." In *Transforming the Nigerian Rice Economy: Opportunities and Policy Challenges*, edited by K. Gyimah-Brempong, M. Johnson and H. Takeshima. Philadelphia: University of Pennsylvania Press.

Kienzle, J., J.E. Ashburner and B. G. Sims. 2013. *Mechanization for Rural Development: A Review of Patterns and Progress from around the World. Rome:* Food and Agriculture Organization of the United Nations.

Manuelli, R.E., and A. Seshadri. 2014. "Frictionless Technology Diffusion: The Case of Tractors." *American Economic Review* 104 (4): 1368–91.

McMillan, M., D. Rodrik, and I. Verduzco-Gallo. 2014. "Globalization, Structural Change and Productivity Growth, with an Update on Africa." *World Development 64*: 11–32.

Michalopoulos, S., and E. Papaioannou. (2014). "National Institutions and Subnational Development in Africa." *Quarterly Journal of Economics* 129 (1): 151–213.

NBS (Nigeria Bureau of Statistics) and World Bank. 2010. Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) 2010. Nigeria Post-planting Survey Data. www.worldbank.org/lsms-isa. Abuja and Washington, DC: NBS and the World Bank.

———. 2012. Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) 2012. Nigeria Post-planting Survey Data. www.worldbank.org/lsms-isa. Abuja and Washington, DC: NBS and the World Bank.

Olmstead, A.L, and P.W. Rhode. 2001." Reshaping the Landscape: the Impact and Diffusion of the Tractor in American Agriculture, 1910–1960." *Journal of Economic History* 61 (3): 663–698.

Otsuka, K., F. Gascon, and S. Asano. 1994. "Green Revolution and Labour Demand in Rice Farming: The Case of Central Luzon." 1966–90. *Journal of. Development. Studies* 31 (1): 82–109.

Perry, G.M., A. Bayaner, and C.J. Nixon. 1990. "The Effect of Usage and Size on Tractor Depreciation." *American Journal of Agricultural Economics* 72 (2): 317–325.

Pingali, P. 2007. "Agricultural Mechanization: Adoption Patterns and Economic Impact." In *Handbook of Agricultural Economics*, edited by R. Evenson and P. Pingali. Amsterdam, Netherland: Elsevier. 2779–2805.

Poirier, D. J. 1980. Partial Observability in Bivariate Probit Models." *Journal of Econometrics 12* (2): 209–217.

Ramankutty, N., A.T. Evan, C. Monfreda, and J.A. Foley. 2008. "Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000." *Global Biogeochemical Cycles, 22* (1): 1–19.

Rosenbaum, P.R. and D.B. Rubin. 1983. "The Central Role of the Propensity Score in Observational Studies for Causal Effects." *Biometrica 70*: 41–55.

Rosenbaum, P.R. 2002. *Observational Studies.* New York: Springer.

Roumasset, J., and G. Thapa. 1983. "Explaining Tractorization in Nepal: An Alternative to the 'Consequences Approach'." *Journal of Development Economics 12* (3): 377–395.

Shrestha, B.K. 1978. "Status of Agricultural Mechanization in Nepal." In *Proceedings of the International Agricultural Machinery Workshop*, 61–68. Los Baños, Philippines: International Rice Research Institute.

Stitzlein, J.N. 1974. "The Economics of Agricultural Mechanization in Southern Brazil." PhD Dissertation. Unpublished. Columbus: The Ohio State University.

Takeshima H. 2015. "Onset Risks And Draft Animal Investment in Nigeria." *Journal of International Agricultural Trade and Development* 9 (2): 1–27.

Takeshima, H., A. Adeoti, S. Okoli, S. Salau, and V. Rhoe. 2010. *Demand Characteristics for Small-scale Private Irrigation Technologies: Knowledge Gaps in Nigeria*. IFPRI NSSP Working Paper 18. Abuja, Nigeria: International Food Policy Research Institute.

Takeshima, H., H. Edeh, A. Lawal, and M. Isiaka. 2014. *Tractor Owner Operators in Nigeria: Insights from a Small Survey in Kaduna and Nasarawa states.* IFPRI Discussion Paper 01355. Washington, DC: International Food Policy Research Institute.

Takeshima H, E Edeh, A Lawal & M Isiaka. 2015. Characteristics of Private-Sector Tractor Service Provisions: Insights from Nigeria. *The Developing Economies* 53 (3): 188–217.

Takeshima H & L Nagarajan. 2012. Minor Millets in Tamil Nadu, India: Local Market Participation, On-farm Diversity and Farmer Welfare. *Environment and Development Economics* 17 (5): 603–632.

Takeshima, H., A. Nin Pratt, and X. Diao. 2013. *Agricultural Mechanization Patterns in Nigeria: Insights from Farm Household Typology and Agricultural Household Model Simulation.* IFPRI Discussion Paper 01291. Washington, DC: International Food Policy Research Institute.

Takeshima H, K Jimah, S Kolavalli, X Diao & R Funk. 2013b. *Dynamics of Transformation: Insights from an Exploratory Review of Rice Farming in the Kpong Irrigation Project.* IFPRI Discussion Paper 01272. Washington, DC: International Food Policy Research Institute.

Takeshima, H., and E. Nkonya. 2014. "Government Fertilizer Subsidy and Commercial Sector Fertilizer Demand: Evidence from the Federal Market Stabilization Program (FMSP) in Nigeria." *Food Policy* 47: 1–12.

Takeshima, H. and S. Salau. 2010. *Agricultural Mechanization and the Smallholder Farmers in Nigeria.* IFPRI Nigeria Strategy Support Program (NSSP) Policy Note 22. Abuja: International Food Policy Research Institute.

Takeshima, H., and A. Winter-Nelson. 2012. "Sales Location among Semi-subsistence Cassava Farmers in Benin: A Heteroskedastic Double Selection Model." *Agricultural Economics* 43 (6): 655–670.

Takeshima H and F Yamauchi. 2012. "Risks and Farmers' Investment in Productive Assets in Nigeria." *Agricultural Economics* 43 (2): 143–153.

Thorbecke, E., and T. van der Pluijm. 1993. *Rural Indonesia: Socio-Economic Development in a Changing Environment* (No. 3). New York: NYU Press.

Ugwuishiwu, B.O., and A.P. Onwualu. 2009. "Sustainability and Cost of Agricultural Mechanization in Nigeria as Affected by Macro-Economic Policies." *Journal of Agricultural Engineering and Technology* 17 (2):44–56.

Ulluwishewa, R., and K. Tsuchiya. 1983. "A Study of the Causal Factors for Farm Mechanization in Sri Lanka." *Journal of the Faculty of Agriculture, Kyushu University* 28 (2-3): 91–110.

World Bank. 2012. *Agribusiness Indicators: Ghana.* Washington DC: World Bank.

———. 2014. *World Development Indicators*. Washington DC: World Bank.

Yang J., Z. Huang, X. Zhang, and T. Reardon. 2013. "The Rapid Rise of Cross-Regional Agricultural Mechanization Services in China." *American Journal of Agricultural Economics* 95 (5): 1245–1251.